PROLOGUE BY NOBEL LAUREATE **DR. NORMAN BORLAUG**

The Fertilizer Encyclopedia

Vasant Gowariker

V.N. Krishnamurthy
Sudha Gowariker
Manik Dhanorkar
Kalyani Paranjape

WILEY

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Dedication

To all farmers, who keep the world alive

EDITORIAL TEAM

1. Chief Editor and Author:

Dr. Vasant Gowariker: Senior Chemical Technologist and ISRO Distinguished Professor. Chairman, Rajiv Gandhi Science & Technology Commission (Cabinet Rank), Government of Maharashtra. Formerly, Advisor on Science & Technology to India's (four successive) Prime Ministers.

2. Editors and Authors:

(a) **Dr. V. N. Krishnamurthy**: Senior Chemist & Industrial Consultant. Formerly, Head of Physico-chemical-analytical labs, R & D and Processing Complexes dealing with chlorates, phosphates, nitrates, oxidizers, polymers, speciality chemicals and materials.

(b) **Mrs. Sudha Gowariker**: Active experimenter in plant and soil sciences and science writer. Author of several books, essays and articles since 1980 – some of which are included in high school textbooks in two major Indian States.

(c) **Dr. Manik Dhanorkar**: Agriculturist with post-graduate degree in agriculture, and a doctorate in biological sciences. Involved in development of integrated nutrient and plant disease management programs as well as studies pertaining to deficiencies in crop plants.

(d) **Ms. Kalyani Paranjape**: Management and enterprise consultant with deep interest in agricultural methodology. Post-graduate degree in business management, with work experience in multi-disciplinary fields. Occasional writer for English periodicals.

There were several hundreds of people with whom we interacted while creating this Encyclopedia. Following are only a few of them: 1. Dr. Karl Harmsen, Former senior scientist, International Fertilizer Development Centre, Alabama, USA. 2. Dr. Jacqui Daukes, University of London, London. 3. Dr. Suresh Karkhanis, Former Senior Geo-Chemist, PetroCanada, Calgary (Canada). 4. Dr. Raj Venkatesan, Manager, Processor Engineering, Andritz Ruthner Inc. Arlington, Texas, USA. 5. Dr S. M. Virmani, Former Senior Scientist, International Crop-Research Institute for Semi-Arid and Tropics, Hyderabad. 6. Dr I. V. Subba Rao, Former Vice Chancellor, Acharya N. G. Ranga Agricultural University, Hyderabad. 7. Dr. Rajendra Prasad, Former IGAR National Professor, Indian Agricultural Research Institute, New Delhi. 8. Professor Sohan Modak, Former Head, Departments of Botany and Zoology, University of Pune, Pune.

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The authors are grateful to (i) Technology Information Forecasting & Assessment Council (TIFAC) of the Government of India, under the chairmanship of Dr. R. Chidambaram, for financing the project during 1998–2005, (ii) the Project Monitoring Committee, comprising Professor V. S. Ramamurthy (Chairman), Professor Y. S. Rajan, Dr. Laxman Prasad, Dr. B. C. Biswas and Dr. Girish Bapat, (iii) Dr. S. S. Ranade of the Institute of Micronutrients, Dr. Badrinarayan Barwale of Maharashtra Hybrid Seeds Company Ltd. (Mahyco) and Mr. Shailesh Mehta of Deepak Fertilizers and Petro-Chemicals Corporation Ltd., for their guidance and financial support in getting the work peer-reviewed, (iv) a large number of distinguished scientists in agronomy, horticulture, plant pathology, crop science, agricultural chemistry, fertilizer chemistry, environment, and soil and breeding technology – who lent their expertise in completing the peer-review process, (v) the technical and administrative personnel of the project, as well as the Director of Jnana Prabodhini, for handling the administrative and financial matters of the Project, (vi) Dr. Norman E. Borlaug, for going through the manuscript and writing the prologue, and (vii) Dr. M. S. Swaminathan, for his invaluable guidance and writing the foreword.

Last, but not least, there are three individuals who have inspired, sustained and resurrected the project, respectively – perhaps even without being aware of it. The first is the President of India, Dr. A.P.J. Abdul Kalam, during whose chairmanship of TIFAC, the project was initiated in 1998; the second is Dr. Laxman Prasad, Adviser DST, and the third is Dr. T. Ramasamy, the present Secretary, DST and Chairman, TIFAC Executive Committee. Our hands will never be tired of saluting them if and when the world's farmers and millions concerned with the production of soil nutrients come to reckon *The Fertilizer Encyclopedia* as indispensable to the growth of their knowledge and prosperity.

Prologue by Dr. Norman Borlaug, Nobel Laureate 1970 and Father of the Green Revolution

Advanced industry is invariably built upon a productive agricultural sector. Indeed, in virtually every industrialized country, an agricultural revolution preceded its industrial revolution. This co-existence is not a coincidence. There is a logic.

The industrialized countries, with 20 percent of world's population, account for 36 percent of fertilizer consumption, while the developing countries, with 80 percent of the world's population, account for 64 percent of fertilizer consumption. Thus, the people of the industrialized world use more than twice the amount of fertilizers, per capita, as do the people of the developing world.

Fertilizer, combined with other high-yielding factors of production, including improved crop varieties (many of them transgenic varieties in the case of maize and soybean), crop protection chemicals, sophisticated farm machinery, and superior crop management information, has resulted in average cereal yields in the USA of 6.8 t/ha in 2003 compared to 2.6 t/ha in India.

When I look back over the last four decades, I am pleased to have played a role in helping to restore soil fertility in Asia and other parts of the developing world. Today, fertilizer consumption per hectare of arable land in many Asian countries equals or exceeds that of the industrialized countries. Forty years ago, hardly any chemical fertilizer was used.

As a result of science-based high-yield cereal crop technology, the world's farmers have been able to triple the global cereal harvest -from 650 to 2,000 million tons over the past 50 years - on only 10 percent more land. Had the agricultural technology of 1950 persisted today, farmers would have needed an additional 1,100 million ha of additional land -of the same quality - to equal the 2003 world cereal harvest, instead of the 660 million ha than was actually used. Obviously, Asia didn't have such additional land available.

Despite the outstanding agricultural achievements in Asia over these past decades, there are still 500 million hungry people, another 200 million in sub-Saharan Africa, and another 100 million in other regions of the developing world. Thus, there is no time for complacency, either in expanding food production or in finding ways to more equitably distribute our food supply so that all have access to an adequate diet. In particular, fertilizer consumption in sub-Saharan Africa, which only stood at 1.3 million nutrient tons in 2002 -about 9 kg/ha of arable land -must be dramatically increased, if soil nutrients are to be restored and food security assured.

Asian farmers, in particular, must now judiciously increase their per hectare use of fertilizers, looking for greater efficiencies in use and also in dealing with deficiencies of secondary and minor elements. In achieving this goal, *The Fertilizer Encyclopedia* compiled by Dr. Vasant Gowariker, Dr. V. N. Krishnamurthy, Ms. Sudha Gowariker and Dr. M. N. Dhanorkar, will be of great help. This unique and scholarly contribution will be an invaluable resource to students, academicians, professionals, consultants, and industry people all over the world concerned with inorganic, organic and bio-fertilizers and their surroundings. I would like to congratulate the entire team that has assembled this splendid reference book, including the Chief Editor, the three Editors, the Consulting Editors, and many other people whose painstaking work has made this book possible.

21/03/05

Norman E. Borlaug
Distinguished Professor of
International Agriculture
Texas A & M University

Foreword by Dr. M. S. Swaminathan, First World Food Prize Laureate

The 19th century witnessed the finding of mineral nutrients by Liebig in Germany, a discovery that opened up prospects for rendering the law of diminishing returns from the soil irrelevant. From the dawn of agriculture or settled cultivation about 12,000 years ago, a great challenge faced by farmers has been the maintenance of fertility and health of the soil. This was addressed by different methods like shifting cultivation (practice known as Jhum cultivation is still prevalent in northeast India) and cereal-legume crop rotations. However, with the development of mineral fertilizers, it became possible to address issues relating to the "hunger of the soil" in a more effective manner. The chemical fertilizer industry grew rapidly. It also became evident soon that what the soils need is a balanced supply of nutrients, with adequate quantities of micro- and macronutrients. This led to the growth of soil testing laboratories as well as complex fertilizers containing a mixture of nutrients.

The publication of the book '*Silent Spring*' by Rachael Carson forty years ago led to rethinking on the methods used to replenish soil fertility and maintain soil and plant health. This resulted in the development of integrated nutrient supply systems involving an appropriate blend of mineral fertilizers, organic manures, bio-fertilizers, green manures and cereal-legume crop rotations, as well as integrated pest management systems.

The Fertilizer Encyclopedia, which is the outcome of painstaking research by Dr. Vasant Gowariker and his colleagues over several years, is a timely contribution to our understanding of problems of maintenance of soil fertility and crop productivity.

This is a unique volume on micro and macro plant nutrients, soil fertility and plant-soil nutrient-environment related issues. It can serve as a *vade-mecum* for a large number of academicians, extension workers, professionals and researchers who are working in this area. *The Fertilizer Encyclopedia* serves the purpose of providing all concerned with a comprehensive reference book, covering up-to-date information on plant nutrients, their behavior in soil, their chemical and physical characteristics, their physiological role in plant growth and soil fertility. Production methods for a wide range of fertilizers are also described. The organic, inorganic and bio-fertilizer industry with an annual turn-over of over 70 billion dollars, today gives employment to millions of people all over the world. And yet, it is extraordinary that nothing even remotely similar to this exhaustive *Encyclopedia* by Dr. Gowariker and his colleagues has existed so far.

With several hundred diagrams, photographs, tables, graphs, flowsheets, chemical equations and illustrations, the present *The Fertilizer Encyclopedia* comprises about nine hundred pages, written in a user-friendly manner, and peer-reviewed by a large number of experts. All entries have at every stage been thoroughly reviewed by well-known experts in related areas to ensure authenticity of the technical content and clarity of the presentation. The *Encyclopedia* will be of invaluable help to all interested in organic, inorganic and bio-fertilizers, and the fertilizers, and the related environmental issues, as well as to those looking at fertilizers in the context of such soil properties as texture, structure, reaction, organic matter, cation exchange capacity, percentage base saturation and problems like salinity and acidity.

I am confident that *The Fertilizer Encyclopedia* will have a vast clientele across the world from the categories of: (a) students, teachers, researchers, departmental libraries and central libraries of agricultural colleges and universities as well as departments and centers dealing with botany and environmental sciences; (b) research and teaching institutions dealing with agronomy, horticulture, plant pathology, crop science, agricultural chemistry and soil science; (c) advisers, consultants, professionals and extension specialists concerned with crops, soil, soil nutrients and agricultural related issues; (d) fertilizer manufacturers and dealers, distributors and consultants associated with fertilizer industry; (e) multi-disciplinary groups dealing with environmental activities; (f) public libraries; (g) policy makers.

The Chief Editor, Dr. Vasant Gowariker, holds a doctorate degree in chemical engineering from a British University, and has written several books and over 200 research publications. He has many years of international work experience in high positions, including concurrently two part-time assignments, the one on the Outside Editorial Staff of Pergamon Press (Oxford) and the other, on the External Panel of Examiners of the Oxford and Cambridge Examination Board. In his professional career of over 45 years, he has actively dealt, among other things, with issues relating to fertilizers, soil fertility, analytical techniques, climate impact on crops and weather forecasting. His inter-disciplinary team consists of eminent chemists, plant pathologists, agriculturists, science writers and management experts who, after many years of dedicated effort, have produced *The Fertilizer Encyclopedia*. Apart from Dr. Gowariker, the other formal editors are: Dr. V. N. Krishnamurthy, Ms. Sudha Gowariker, Dr. M. N. Dhanorkar, Ms. Kalyani Paranjape and a large number of eminent Consulting Editors. An interesting aspect of the present work is that the entire texts are written by those very five persons, in consultation with a large number of experts, and they have also edited *The Fertilizer Encyclopedia.*

In the coming decades, population-rich but land-hungry countries like India and China will have to produce more food and other farm commodities under conditions of diminishing per capita availability of arable land and irrigation water. Maintenance of soil health and fertility will hold the key to achieving productivity advances in perpetuity without associated ecological harm, a phenomenon I have termed "ever-green revolution". The present *Fertilizer Encyclopedia* is an important and timely contribution in the context of the human quest for an evergreen revolution in our farms based on precision farming techniques. We owe Dr. Gowariker and his eminent associates a deep sense of gratitude for this labor of love. They have provided us with a powerful tool to launch and sustain an evergreen revolution in agriculture.

M. S. Swaminathan

M. S. Swaminathan
First World Food Prize Laureate

Preface by Authors and Editors

In 1993, the Government of India appointed one of us (VG) to form a one-man committee. The mission was to recommend measures to bring a fresh and holistic perspective to fertilizers. That's when we started dreaming of creating *The Fertilizer Encyclopedia*. The next few years, we spent equipping ourselves technically to realize that dream. We also spoke to other people about our idea among them agriculturists, industrialists, researchers, chemists and environmentalists, and got valuable inputs from them.

The work assumed a project form in 1998 – that is, five years after our preparatory studies. In the subsequent nine years that it has taken us to actually complete *The Fertilizer Encyclopedia*, a lot has happened in the universe of fertilizers. New advances and issues have gained importance especially those concerning the environment. We have revisited and updated entries repeatedly to reflect these happenings. To take cognizance of the merging boundaries between various disciplines, our team of writers and reviewers has grown more multi-disciplinary. We have gone to the extent of printing the manuscript as a first draft, complete with pictures, graphs, tables, etc. for peer reviews, and then incorporating the suggested improvements.

Today, all that is behind us. We feel happy that we have created something that Professor Norman E. Borlaug, N. L (1970) considers "unique and scholarly and an invaluable resource to students, academicians, professionals, consultants and industry people all over the world concerned with inorganic, organic and bio-fertilizers."

How to Use *The Fertilizer Encyclopedia*

This encyclopedia covers about 4500 terms of interest to a spectrum of users ranging from academicians to industrial consultants, to fertilizer industry people to those with a casual interest in gardening.

In encyclopedias, many a time the user goes to an entry, only to get redirected to another page for the information needed. We have tried to minimize the reader's effort at least in some frequently required entries, although it has meant repeating text.

The following are some of the significant practices followed in this volume:
(i) The words in bold indicate that these are explained elsewhere as entries; however, the names of the frequently occurring chemical compounds (such as urea, ammonia, NPK) or terminologies (such as pH) are not made bold although these do appear as entries in the Index.
(ii) Scientific names of organisms (such as Mycobacterium or Herbaspirillum spp.), words of non-English origin (such as Kharif or Rabi) and titles of tables and figures are italicized.
(iii) All measurement units are in SI system; for those familiar with other units, conversion tables are given in the appendices.
(iv) General terms (such as profitability or economic returns) are explained only to the extent of the main objective of this encyclopedia.
(v) Appendices and bibliography are at the end of the Encyclopedia.

Vasant Gowariker
(Chief Editor and Author)

V. N. Krishnamurthy
(Editor & Author)

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(Editor & Author)

Manik Dhanorkar
(Editor & Author)

Kalyani Paranjape
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by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

A

AAS

AAS is short for **atomic absorption spectrometer**.

Abherent

Any substance that prevents adhesion of a material to itself or to another material is known as abherent. It may be in the form of a dry powder (like talc, mica or diatomaceous earth), a suspension (of say, bentonite) or a soft solid (stearic acid, teflon, waxes, etc.)

Abherents are used as dusting agents and mould washes in the adhesives, rubber and plastic industries. Fats and oils are used as abherents in the baking industry. Fluorocarbon resin coatings on metals are widely used on cooking utensils.

In the fertilizer industry, abherents are used to impart free flowing characteristics to powders like urea, ammonium sulphate, phosphates, etc.

AB horizon

Horizons are soil layers which are roughly parallel to the soil's surface. They are unique in their feel, color, profiles, etc.

An AB horizon is also called **EB horizon**. It is a transition horizon between the leached E (eluvial) horizon and the accumulation horizon (B.) The AB or EB horizon is more like the A or E above it than like the B below it. (See also Soil horizons.)

Abiotic factors

Abiotic factors are physical and chemical components of nature, such as rainfall, minerals, heat or wind.

Abnormal seedlings

Seedlings that do not grow into normal healthy plants even when planted in good quality soils under fovorable conditions of light, temperature and water supply are called abnormal seedlings. For example, seedlings with weak or malformed parts, such as stubby roots or split hypocotyls and those without primary leaves or terminal buds, can be termed abnormal seedlings (Fig.A.1.)

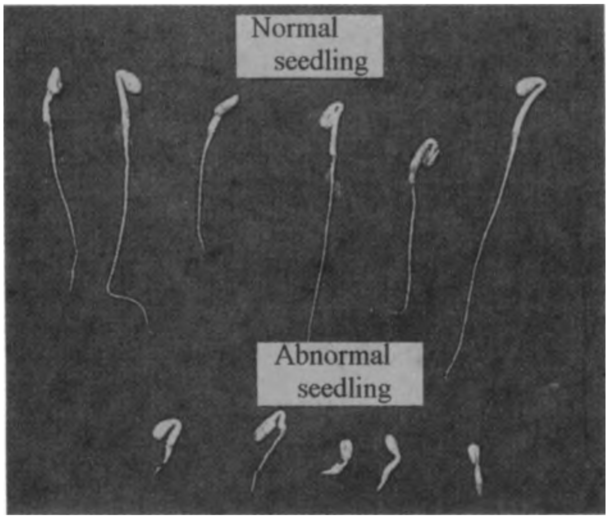


Fig.A.1: Normal seedlings show healthy growth, whereas abnormal seedlings show stunted, abnormal growth. (Courtesy: Mahyco Seeds Ltd., Mumbai, India.)

Abrasion

Gradual erosion of a material, either by physical forces (simultaneous cutting, shearing and tearing) or by chemical degradation (chiefly oxidation) is called abrasion. Abrasion causes the deterioration of materials like fertilizers, textiles, leather, plastics, paints and coatings on solid objects. Temperature is a significant factor in abrasion. Friction raises the temperature of the surface, which in turn, increases the abrasion.

An **abrasive** is a material used for grinding, rubbing, polishing or cleaning a hard surface. Abrasive action can be brought about by the grains on grinding wheels, or by a coating on paper or cloth. Abrasive products, by virtue of their refractory properties and superior hardness, have advantages in speed of operation, smoothness and depth of cut. The products can be used for grinding and polishing (e.g., glass) cutting (e.g., metals), cleaning and machining of metals, and in the manufacture of many products.

Important natural abrasives include diamond, corundum, emery, garnet, feldspar, calcined clay and silica. Silica in its various forms such as sand, sandstone, flint and diatomite is used as an abrasive. Some examples of synthetic abrasives are aluminum oxide, boron carbide, silicon carbide and titanium carbide.

Abrasion resistance of granule

Abrasion resistance of a granule is its resistance to forming dust, fines and/or being fractured. (See also Granular strength of fertilizers.)

Abrasive: See Abrasion

Abrupto argillic: See Argillic horizon

Abrupt textural change

Abrupt textural change refers to a boundary between an ochric epipedon (or albic horizon) and the underlying argillic horizon. A significant increase in clay is seen over a very short vertical distance in the zone of contact between the A or E horizon and the underlying horizon. This increase in clay should be twofold over 7.5 cm, if the clay content of the A or E horizon is less than 20%, and at least 20% if the clay content of the A or E horizon is greater than 20%.

Abscisic acid

The name abscisic acid (ABA), a weak organic acid, is derived from the ability of a substance to promote abscission. **Abscission** is the natural detachment of leaves, branches, flowers, etc. from plants. Abscisic acid is a naturally occurring plant growth inhibitor, and is one of five major plant hormones. It carries out a number of important functions in the growth and development of plants. It is a key factor controlling stomatal movements, leaf senescence and bud and seed dormancy.

Abscisic acid (ABA) is present in leaves, fruits and seeds, and is distributed throughout the plant body. The synthesis of ABA takes place mainly in **chloroplasts**. The rate of synthesis of ABA increases when the plant is under stress.

Chemically, abscisic acid is a member of the terpenoid family. The chemical structure of ABA is shown in Fig.A.2.

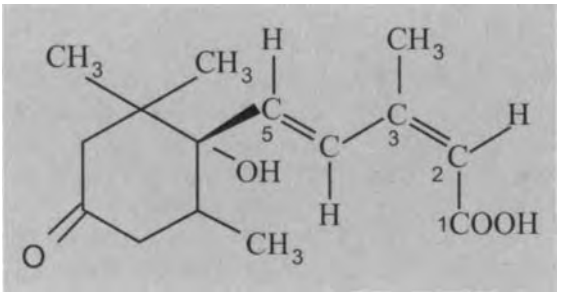


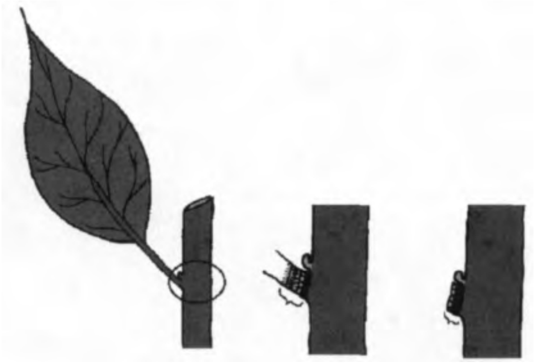
Fig.A.2: Structural formula of abscisic acid

Abscission

Abscission is the natural detachment of leaves, branches, flowers, etc. Separation of an organ takes place due to the disintegration of the wall of the separation layer. Almost any part of the plant, from a small bud to branches of several inches in diameter can be abscised in some plant species. However, annuals tend to show little abscission, especially of leaves.

Abscission is useful in plants in many ways. It involves self-pruning, dispersal of seeds or other reproductive structures, and removing dead, injured or diseased parts.

Abscission facilitates recycling of mineral nutrients to the soil, thus maintaining a balance in leaves, roots, and in vegetative and reproductive parts. Generally, the process of abscission is restricted to the abscission zone of an organ (Fig.A.3). The portion of the abscission zone that remains attached to the plant, develops into a corky protective layer.



Abscission zone Separation layer Protective layer

Fig.A.3: Abscission

When auxins are applied (as is done in experimental trials) to the distal side (organ) of the abscission zone, it retards abscission, whereas, when it is applied to the proximal side (stem), it accelerates abscission. Gibberellin, a growth hormone, delays abscission. On application to young fruits or leaves, gibberellin promotes growth, delays maturation and ultimately prevents or delays abscission. Abscisic acid promotes abscission and senescence and can also retard plant growth. As a matter of interest, ethylene in small amounts can also distort and reduce plant growth and promote senescence and abscission.

Absolute temperature

Absolute temperature denotes a temperature measured on an absolute scale. It is a temperature scale used in theoretical physics and chemistry and in engineering calculation.

Absolute temperatures are expressed in Kelvin or degrees Rankine corresponding to the centigrade and Fahrenheit scales respectively. Kelvin is obtained by adding 273.15 to the degree centigrade temperature (if above 0°C) and subtracting the degree centigrade temperature from 273.15 (if below 0°C). Degrees Rankine are obtained by subtracting 460 from the Fahrenheit temperature. The closest approach to absolute zero is -272°C.

Absorbent

Any substance exhibiting the property of absorption is called an absorbent. Absorbent cotton, so made by the removal of natural waxes is one such example.

Absorption

The process by which a solid or liquid takes up gas, or a solid takes up a liquid, is known as absorption.

The movement of a fluid or a dissolved substance across a cell membrane is also called absorption. In plants, water and nutrients are absorbed from the soil by the roots (Fig.A.4). This phenomenon is due to a combined effect of osmotic pressure within the plant cells, electrical charge of the absorbed ions, surface tension, permeability of the cell membranes, etc. The fixation of potassium ion between the layers of clay minerals, such as **illite**, is also due to absorption.

Absorption is different from **adsorption**. While the absorbed substance permeates the bulk of the absorbing substance, adsorption is a surface phenomenon.

The movement of ions and water into plant roots against the activity gradient is called **active absorption**, whereas the movement of water into the roots resulting from the pulling forces on the water column in the plants (to compensate for the water lost by transpiration) is called **passive absorption**.

Absorption ratio of potassium: See Potassium absorption ratio

Abstraction license

Abstraction license is an authorization issued by a water authority to allow water to be drawn from a water source for irrigation and/or for commercial or domestic uses.

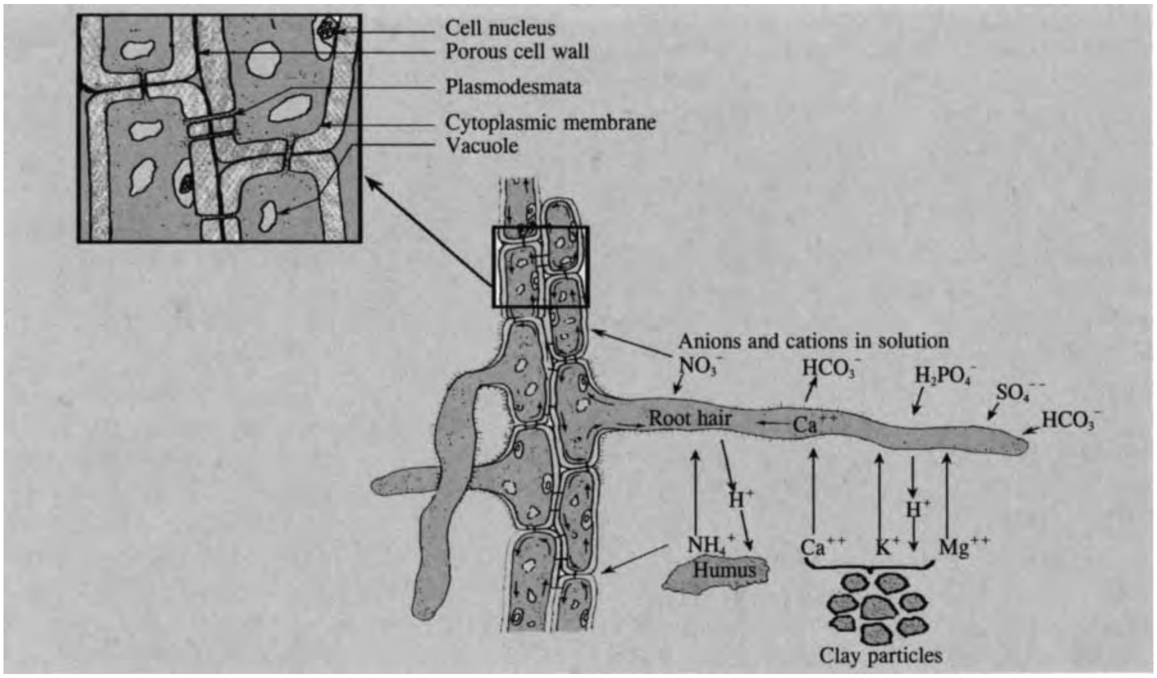


Fig.A.4: Diagrammatic representation of absorption of plant nutrients from the soil by plant roots. Inset: An enlarged portion of the root tissue.

Accelerated caking test

The accelerated caking test is one of several tests to evaluate the caking tendency of fertilizers. (See Caking tendency, evaluation of.)

Accelerated erosion

Accelerated erosion occurs when geological erosion (caused mainly by wind, water and heat) is accompanied by human activities, leading to the top soil being removed rapidly.

Accelerated erosion is rapid and often destructive. (See also Soil erosion.)

Accelerator

The substance that accelerates the speed and output of a process is called an accelerator. (See also Activator.)

Acceptable risk

Acceptable risk is a concept that has developed in recent times when environmental issues like air and water pollution, and the hazards of toxic substances (like insecticides and pesticides) have received greater focus. Acceptable risk is defined as the risk level at which a seriously adverse result is highly unlikely, but about which an assurance of 100% safety cannot be given. It means living with a reasonable assurance of safety and acceptable uncertainty. Diagnostic x-rays, fluoridation of water and ingestion of saccharin in small amounts are some examples of acceptable risks.

Acceptance inspection

The inspection of a sample of raw material or of a finished product, based on some set criteria and procedures, which leads to inference of whether the material or the product is acceptable or not, is called the acceptance inspection. The standards of acceptance inspection are set according to the product requirement at the user's end rather than by the inherent capabilities of the process.

Accessory nutrients

Among the various nutrients essential for plants, there are some growth enhancing nutrients like vitamins, purines, pyrimidines and amino acids. These are called accessory nutrients. (See also Plant nutrients.)

Accessory structural elements

Accessory structural elements are **nutrient elements** that form part of more active and vital living plant proteins (Fig.A.5). Some examples of this are the following: (i) Proteins contain nitrogen which constitutes

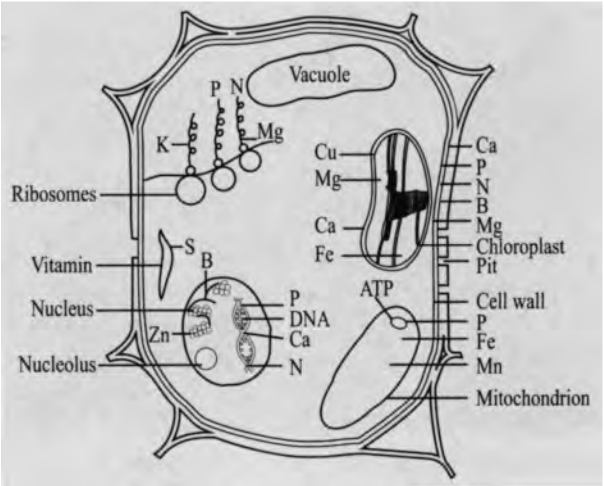


Fig.A.5: Diagrammatic representation of various nutrient elements in a plant cell.

1 to 3% of plant tissue. (ii) Phosphorus constitutes 0.05 to 1.0% of plant tissue and is found in nucleoproteins, phytin and lecithin. (iii) Sulphur is a constituent of many proteins. Its content varies from 0.05 to 1.50% in plant tissue.

Acclimated micro-organism

An acclimated micro-organism has the ability to adapt to environmental changes, such as a change in temperature, pH, oxygen concentration, etc. Acid tolerant rhizobia are examples of acclimated micro-organisms.

Accretion of soil: See Soil accretion

Accumulation layer

Materials leached from the upper soil layer are accumulated in the layer below. The layer that receives the leached material becomes the accumulation layer. The accumulation layer (or **accumulation zone**) or **illuvial layer** has a fairly high clay content. (See also Soil horizons.)

Accumulation zone: See Accumulation layer

Accumulators

Plants which concentrate large quantities of elements such as selenium and aluminum in their tissues are known as accumulators. Such plants can be used for toxicity control as in bioremediation.

Among non-living materials, an accumulator is a voltaic cell or battery that can be recharged by passing current through it from an external D.C. supply. The charging current, passed in a direction opposite to that of the cell supplying the current, reverses the chemical reactions in the cell. Those using acid, nickel-iron and nickel-cadmium are among the common types of accumulators.

Acetobacter diazotrophicus

Acetobacter (or *Gluconacetobacter*) *diazotrophicus* is a nitrogen fixing endophyte, very specific to sugar-rich crops. It tolerates acidic and nitric conditions and can be isolated from the soils, roots, stems and leaves of sugar cane and sweet sorghum.

Acetoclastic bacteria

Bacteria that form methane exclusively from acetic acid in anaerobic digestion are called acetoclastic bacteria. These bacteria grow slowly and take several days to double.

Acetogenic bacteria

Bacteria that ferment fatty acids (mainly propionic and butyric acids) to acetic acids are called acetogenic bacteria.

Acetylene reduction assay

The biological reduction of dinitrogen ($N\equiv N$) to ammonia (NH_3) is carried out by prokaryotes in soil and plants with the help of the enzyme nitrogenase. Nitrogenase also reduces a variety of substrates like acetylene, nitrite, cyanide, etc. It also catalyzes the reduction of acetylene to ethylene. The end product ethylene is easily detected by gas chromatography.

$$\underset{\text{(Acetylene)}}{C_2H_2 + 2H^+ + 2e^-} \longrightarrow \underset{\text{(Ethylene)}}{C_2H_4}$$

The reduction of acetylene is only indicative of nitrogen fixation which has to be, however, confirmed by isotopic methodology or other methods. The theoretical ratio of 1 mole of nitrogen fixed per three moles of acetylene reduction cannot be used for quantifying the fixation as the ratios can vary widely. This is because a part of the electrons are diverted for concomitant hydrogen evolution. Acetylene reduction assay is therefore to be interpreted with caution and can be used in a limited sense to screen for putative diazotrophs.

The word assay refers to testing or determination of the quality, content or concentration of a substance. In an acetylene reduction assay, excited nodules, detached roots with nodules, whole plants or microbial suspensions are enclosed in a closed container in which 10% of the volume is replaced by acetylene. After incubation for a suitable period, the ethylene evolved is sampled and estimated by gas chromatography using a flame ionization detector. The rate of ethylene evolved is indicative of the nitrogen fixing potential of the system. Because of its simplicity, high specificity and sensitivity, low cost and short assay period, the method has been widely applied to detect nitrogen fixation in a whole range of systems ranging from purified nitrogenase components to legume-*Rhizobium* associations.

Acid

Acids are one of the largest classes of chemicals whose aqueous solutions have one or more of the following properties: (a) sour taste, (b) ability to turn litmus paper red and cause other indicator dyes to change to characteristic colours, (c) ability to react with and dissolve some metals to form salts, and (d) ability to react with bases or alkali forming salts. All acids contain hydrogen. In water, acids ionize and form hydronium ions (H_3O^+), usually written simply as hydrogen ions.

Acids are classified as strong acids or weak acids according to the concentration of hydrogen ions that results from ionization. Hydrochloric acid, sulphuric acid, nitric acid and perchloric acid are strong acids since they ionize almost completely in dilute aqueous solutions. Acetic acid and carbonic acid are weak acids. The pH range of acids is from 6.9 to 1 and is a measure of the acid character in an aqueous solution.

In solvents other than water, acid is defined as a substance that ionizes to release the positive ion of the solvent. The Lowry-Bronsted definition of an acid as a substance that can give up a proton is useful in the understanding of a base. The most significant contribution to the theory of acids was the electron-pair concept enunciated by G. N. Lewis. According to Lewis, any molecule or ion that can combine with another molecule by forming a covalent bond with two electrons from the second molecule or ion is an acid. Thus, acid is an electron acceptor like BF_3 or $AlCl_3$. The hydrogen ion is the simplest substance that will do this.

The terms 'hard' and 'soft' acids and bases refer to the ease with which their electron orbitals can be distorted. Hard acids have positive oxidation state, and their valence electrons are not readily excited. Soft acids have little or no positive charge and possess easily excited valence electrons. Hard acids combine with hard bases and soft acids with soft bases. Soft acids tend to accept electrons and form covalent bonds more readily than hard acids. For example, halogen acids show a progression from hard (HF) to soft (HI).

Major groups of acids are as follows:

(i) Inorganic mineral acids like hydrochloric acid and phosphoric acid.

(ii) Organic acids, whose four major groups are (a) mono carboxylic acids which contain one COOH group (examples include acetic acid), (b) dicarboxylic acid, which contain two COOH groups (examples include pthalic, sebacic and adipic acids), (c) fatty acids which contain long chain COOH groups (examples include oleic, palmitic and stearic acids), and (d) amino acids which contain NH_2 and COOH groups (examples include glycine.) Organic acids can also be classified into (a) aliphatic acids, such as acetic acid and formic acid, and (b) aromatic acids, such as benzoic acid and salicylic acid.

Acid former

Acid formers constitute a group of facultative and obligate microbial anaerobes, capable of hydrolyzing and fermenting organic compounds (in sewage) to organic acids, like acetic acid and propionic acid. These microbes should, for better anaerobic sludge digestion, be in equilibrium with methanogenic bacteria.

The main acid formers (in view of their numbers in sludge compared to the facultative anaerobes) are **obligate anaerobes**.

Acid forming fertilizers

Chemical fertilizers are known for their acidity and basicity forming tendency. A fertilizer that leaves behind an acidic effect in the soil is an acid forming fertilizer. For example, bacteria oxidize ammonium-containing fertilizers like ammonium chloride, ammonium sulphate and urea to form nitrate and hydrogen ions, as shown below:

$$NH_4^+ + 2O_2 \xrightarrow{\text{Bacteria}} NO_3^- + H_2O + 2H^+$$

All fertilizers containing nitrogen, sulphur and phosphorus, and fertilizers lacking metallic cations belong to the category of acid forming fertilizers.

Sulphur, an ingredient of some fertilizers and fungicides, is oxidized to sulphate and hydrogen ions as:

$$2S + 3O_2 + 2H_2O \xrightarrow{\text{Thiobacilli}} 2SO_4^{2-} + 4H^+$$

The sulphate ion by itself is not acidic. The acidifying capacity of nitrogenous fertilizers varies widely. Some countries make it a mandatory requirement that the acid forming capability of fertilizers be specified in terms of calcium carbonate or lime required to neutralize the acidic effect (kg of lime/kg of nitrogen fertilizer.) This quantity of lime depends on the anions (Cl^-, NO_3^-, SO_4^{2-}, etc.) present in the fertilizer as well as the amount of nitrate formed from oxidation of ammonium ions.

The quantity of calcium carbonate required to neutralize the acid residue of a fertilizer is its **equivalent acidity**. The theoretical equivalent acidity values of some fertilizers are given in Table-A.1.

Table-A.1: Theoretical equivalent acidity values of some nitrogenous fertilizers

Fertilizer	Equivalent acidity (kg of $CaCO_3$ per 100 kg of fertilizer)
Ammonium chloride	128
Ammonium phosphate (16% N + 20% P_2O_5)	86
Ammonium sulphate	110
Ammonium sulphate-nitrate	93
Urea	84

Acidic low moor peat

The acidic low moor peat is a highly decomposed raw material with pH less than 7 for **peat** fertilizers.

Acidic soils

Soils with pH less than 7.0 are called acidic soils. Decomposing organic matter and root respiration produce carbon dioxide. This carbon dioxide dissolves in water and forms carbonic acid, which acidifies the water, and causes soil acidity. Soil acidity is determined by hydrogen ions (H^+) or by the content of hydroxyl aluminum $Al(OH)^{2+}$ or aluminum (Al^{3+}) ions. Ammonium nitrate, ammonium phosphate and ammonium sulphate-nitrate are among the **acid forming fertilizers**.

Bacteria oxidize ammonium-containing fertilizers to form nitrate and hydrogen ions. Some fertilizers and fungicides contain sulphur which is oxidized to sulphate and hydrogen ions. Some of these are excreted by plant roots, lowering the soil pH within the root zone.

Leaching increases soil acidity, albeit slowly, in soils with a high carbonate content. In highly industrialized areas, acid rain caused by the discharge of the oxides of sulphur and nitrogen to the atmosphere makes the soil acidic. Removal of the crop also makes the soil more acidic and depletes the reserves of calcium, magnesium and potassium.

Soil acidity can be corrected by several methods. Flooding the soil, for instance, raises the soil pH, although this is effective only for crops like lowland paddy that grows in waterlogged conditions. Another method is **liming**, which is to add alkaline material to acidic soils. Alkaline substances provide a conjugate base which reacts with hydrogen ions. (See also Soil acidity, correcting of; Liming materials.)

Acidic stain

In the staining technique, if the color comes from a negative ion (organic anion), the stain is described as an acidic stain. For example, eosin. (See also Staining.)

Acidimetry

The determination of the concentration of an acid in a solution or a mixture is called acidimetry. The acid character of soil is usually tested by titration with a solution of base of a known strength (standard solution.) An indicator is generally used to establish the end point.

Acidity index

Acidity index is a term applied to commercial fertilizers which are left behind as a residue in the soil. The amount of calcium carbonate required to neutralize the acid residue in soil is known as its acidity index. It is the amount of calcium carbonate in kg required by 100 kg of a fertilizer.

Acidity index is an important chemical property of acid soils, which affects plant growth and nutrient uptake. (See also Base saturation.)

Acidity quotient

Acidity quotient (**AQ**) is defined as the exchange in acidity ratio of litter, given by the ratio of exchange acidity of humus to that of the top horizon. It characterizes the influence of humus on soils. AQ of less than 1 indicates healthy soil.

Acid neutralizing capacity

The acid neutralizing capacity (**ANC**) of a substance is given as the moles of protons per unit volume or the mass required for changing the pH of an aqueous system to a desired value at which the net charge from the ions not reacting with the hydroxyl ion (OH^-) and hydrogen ion (H^+) is zero.

ANC is expressed as:

$$\mathrm{ANC} = [\mathrm{HCO_3^-}] + 2[\mathrm{CO_3^{2-}}] + [\mathrm{OH^-}] - [\mathrm{H^+}]$$

ANC increases as pH increases. The rate of change of ANC with pH (dANC/dpH) is called the **buffer intensity**, ßH. The buffer intensity of acid soils, found in the temperate zone which are rich in organic content, falls in the range of 0.1 to 1.5 mol/kg of organic matter per pH unit.

Proton budgets are estimated in terms of Kmol/hectare/year in field soil. Protons are produced by release reactions (involving C, N and S) and by the bio-uptake of organic matter and carbon dioxide (aq). The protons are consumed in mineral weathering reactions such as hydrolysis, complexation and ion exchange, or may be lost due to inflow processes or deep percolation. If the production of protons is more than their consumption or loss, as is often the case in the tropics and in podzols in temperate regions, the soil becomes progressively acidic.

Liming is the time-honored method of mitigating soil acidity.

Acidophilic cell components

In the staining technique, the cell components that are stained with acidic dyes are classified as acidophilic cell components. (See also Staining.)

Acid peat

Peat is vegetable matter partly decomposed in wet acid conditions to form a brown deposit. The degree of decomposition and conversion of organic matter and the surrounding environment create different types of peat. Peat is used as fuel in gardening, etc.

Acid peat (oligotrophic) is of atmospheric origin. Over the ages, as bogs developed their own peculiar vegetation (like hazel, pine trees, reeds, moss, etc.), the decomposition of dead plant material led to the accumulation of peat in lake beds. This accumulation led to the stagnation of the lake, and made the peat and the water acidic in nature.

Acid peat is commonly added to soil that is not acidic. Acidic peat, sulphur or ferrous sulphate can help lower soil pH to 4.4.

Acid phosphate of lime

Acid phosphate of lime is another name for **concentrated superphosphate**.

Acid rain

Acid rain is rain that contains excessive concentration of acidic radicals like nitrate and sulphate. It is a major pollutant in Canada, Norway, Sweden, the United States and many highly industrialized countries. Millions of tons of sulphur dioxide and nitrogen oxide are discharged into the atmosphere as gaseous particles which are oxidized to sulphuric and nitric acids. When these oxides of sulphur and nitrogen get dissolved in atmospheric moisture, they cause acid rain. Similarly, sulphur dioxide and nitrogen oxides emitted in the atmosphere by forest fires and the burning of fossil fuels are converted into the respective acids and precipitated as acid rains.

Usually, the pH of rain water is 5.6 to 5.7, but that of acid rain can be as low as 2.0. The amount of dissolved sulphur during annual rainfall ranges from 10 kg/ha (in less industrial areas) to as much as 100 kg/ha (in highly industrialized areas).

Acid rain affects plant growth. It also damages foliage, impairs photosynthesis, destroys fish in lakes and rivers, and affects marble, limestone and buildings (especially stone masonry constructions). Lichens are particularly sensitive to changes in pH and are used as indicators of acid pollution. In many developing countries, acid rain is caused by excessive burning of wood, coal and petroleum products.

Though oxides of sulphur and nitrogen are principal culprits in causing acid rain, emission of ammonia from livestock waste, fertilizer applications and industrial processes also contribute considerably to the formation of acid rain. Certain volatile organic compounds can also cause acid rain through photochemical reactions.

Acid rain is also known to lead to the dissolution of toxic metals like cadmium, copper and aluminum which otherwise remain adsorbed onto sesquioxides and humus.

Acid sulphate soil

When sulphur-bearing iron pyrites present in acid soils ($pH < 4$) oxidize to form sulphuric acid, the soil gets converted into an acid sulphate soil. Such a continuous process of acid formation renders the soil impossible to reclaim.

In anaerobic conditions, acid sulphate soil contains relatively high amounts of sulphides, whereas in aerobic conditions, it contains high amounts of sulphates.

Acid sulphate soils, also called **cat clays**, are found especially in coastal belts and in estuarine and delta areas of the humid tropics. These are known as ***Katteklei*** (cat's coat) in The Netherlands. In India, acid sulphate soils occur in the states of Orissa, Kerala and West Bengal.

Acidulated bone

A ground bone or a bone meal treated with sulphuric acid is called acidulated bone.

Acidulated phosphate rock

A raw phosphate rock, treated with sulphuric acid is called acidulated phosphate rock. (See also Single super phosphate.)

Acidulated superphosphate

Acidulated superphosphate is a superphosphate formed from acidulation of phosphate rock with sulphuric acid.

Acidulating the soil

Any substance treated with acid is said to be **acidulated**. To make superphosphate fertilizer, phosphate rocks are acidulated with sulphuric acid. A ground bone or bone meal treated with sulphuric acid is called **acidulated bone**.

Generally, moderately acidic soil is better suited to plants than neutral or basic soils. When soil is inherently high in carbonates, as in arid and semi-arid regions, some amount of acidification improves plant growth.

The acidulation of paddy soil increases rice yields by increasing the availability of micronutrients. Similarly, acidification increases the production of potatoes, blueberries, cranberries, azaleas, rhododendrons, camellias and conifer seedlings.

For acidulation, several acidic or acid forming materials (like elemental sulphur, iron pyrites, sulphuric acid and aluminum compounds) are used. Sulphur in elemental or suspension form is the most effective soil acidulant, if applied several weeks before planting a crop. The microbial oxidation reaction may be slower in alkaline soils, especially in cold seasons. Less sulphur is required when applied in band mode than when broadcast.

Sulphuric acid is used for (a) reclaiming the soils affected by sodium or boron, (b) increasing the availability of phosphorus and micronutrients, (c) reducing ammonia volatilization, (d) increasing water penetration, (e) controlling certain weeds and soil-borne pathogens, and (f) enhancing range grasses. It can be dribbled on the surface of the soil, applied in ditch irrigation water or applied with a knife applicator.

Aluminum sulphate is also used for acidulating soils. Liquid ammonium sulphide, when applied in bands or through irrigation water, decreases soil pH and increases the water penetration in saline-alkali irrigated soils. Ammonium polyphosphate and ammonium thiosulphate solution acidify the soil in and near the band and increase micronutrient availability.

Acidulation

The treatment of any substance with an acid is called acidulation. For example, phosphate rock is acidulated with sulphuric acid to make superphosphate fertilizer.

Acid value

Acid value is known as the number of milligrams of potassium hydroxide required to neutralize the free acids present in one gram of substances like soil, fat, oil, etc. Acid value is determined by the titration of a known quantity of the sample in aqueous solution or KCl solution for soils, and hot 95% alcohol for oils and fats using phenolphthalein as an indicator.

Acquifers

Geological formations like sand, gravel or any porous rock that transmit water underground are called acquifers. (See also Ground water.)

Acre-inch-day

Acre-inch-day is a measure of the quantity of water flow covering one acre of land to a depth of one inch in 24 hours or 0.042 cu ft/sec. This unit is used mainly in the USA.

Acrisols

In the FAO/UNESCO system of soil taxonomy, intensely acidic soils with a low base saturation are called acrisols.

Acropetal translocation of fungicides

Acropetal is a botanical term which means "developing from below upwards". **Translocation** here means transport of a dissolved substance within an organism, especially in the phloem of a plant or actively across a cell membrane. For instance, when a fungicide enters plant tissues and is transported upwards, the phenomenon is called acropetal translocation of the fungicide.

Actin

Actin and myosin are the principal fibrous proteins of muscle; their interaction brings about muscle contraction. (See also Protein.)

Actinomycetales

Actinomycetales is a bacterial order. Filamentous bacteria, called **actinomycetes**, come under this order.

Actinomycetes

Actinomycetes are filamentous micro-organisms that are intermediate between bacteria and fungi. They have a mass of fine elongated threads called **mycelium**, which resembles the typical growth structure of fungi. They reproduce asexually by fission, or through spores. Actinomycetes means ray fungi because of the mycelia, but they are distinct from fungi in many ways. Actinomycetes come under the bacterial order of **actinomycetales** and belong to the phyla Actinobacteria. Like bacteria, actinomycetes secrete some polysaccharides and help retention of water in soils. Their cell wall is typical of bacteria. They are **prokaryotic**, which means that their genetic material is not enclosed in the cell nucleus. Most actinomycetes are aerobic and help decompose organic matter, like cellulose and other resistant organic molecules. The characteristic odor of a freshly plowed moist field is due to soil actinomycetes. A very few of the actinomycetes establish symbiotic nitrogen fixing association with plants like soapberry, alders, bitterbrush, coffee berry, Australian pine, mountain mahoganies, etc.

Actinomycetes are helpful to at least seven botanical families. Actinomycetes help in the synthesis of a great variety of antibiotics like streptomycin, aureomycin, terramycin and neomycin.

While actinomycetes can survive in soils with low moisture, they develop best in moist and well-aerated soils.

Activated sewage products

Activated sewage products are obtained from aerated, flocculated organic matter, inoculated with micro-organisms. The dried organic matter when ground, screened and bagged is used as a fertilizer.

Activated sludge

Sludge, when subjected to microbial action, becomes a **biologically active substance** and is called activated sludge. It is a solid-liquid viscous mixture which is soft, thick, wet or muddy. Domestic sewage containing more than 20% solid is also called sludge. Similarly, industrial organic wastes from processes such as alcohol distillation, paper making, meat packing, flour making and petroleum refining are also called sludge. Some of these residues contain excessively high sodium while others contain toxic substances.

A mixture of organic materials resulting from the purification of municipal waste contains both macronutrients and micronutrients. There are two types of this sludge: (i) **Imhoff sludge** - which is a low-grade sludge containing 2 to 3% ammonia and about 1% phosphoric acid. (ii) Activated sludge - which is a high-grade sludge containing 5.0 to 7.5% ammonia and 2.5 to 4.0% phosphoric acid. These are derived from running sewage through settling tanks, without access to air, and then leaving it to decompose anaerobically. After the activated sludge treatment, lagooning may be used effectively. Activated sludge is also derived by pumping air or oxygen through porous plates at the bottom of the settling tanks. Twenty percent of the sludge is added as a nutrient for aerobic bacteria. The resulting solids are filtered and dried. The dried sludge is used as a fertilizer. Repeated exposure to atmospheric oxygen by mechanical infusion of air into the sewage increases bacterial activity in the sludge. This product is good for land use as its plant nutrient content ranges from 3 to 6% N, 2 to 4% P_2O_5 and 0.5 to 1.5% K_2O.

The sewage and septage residues, along with industrial waste, can replace chemical fertilizers equivalent to about 1% of nitrogen, 4% of phosphorus and 0.5% of potassium. This amounts, on a dry weight basis, to roughly 4% nitrogen, 2% phosphorus and 0.4% potassium, irrespective of the chemical composition of the sludge.

Sludge often contains toxic heavy metals such as boron, cadmium, copper, mercury, nickel, lead, selenium and zinc as well as phytotoxins, pesticides or other toxic compounds. **Sewage sludge** may carry pathogens and infectious agents responsible for cholera, diarrhoea, hepatitis, helminth parasites, poliomyelitis and tapeworms. To reduce the pathogenic hazards from sludge, many techniques are used which are as follows: (a) composting outside the soil for at least 21 days, (b) storage as a semi-liquid, anaerobically digested for at least 60 days at 20°C, or 120 days at 40°C, or a combination thereof, (c) treatment, when moist, with lime for at least 3 hours, and (d) pasteurization for 30 minutes at 70°C.

The quantity of sludge to be applied annually depends on the lowest tonnage needed to meet the nitrogen requirement of the crop or the quantity that can be used by the crop without making it toxic for the plant.

Sludge is used for crops like forages, oilseeds, small grains, commercial sod (turf grass) and trees. It is, however, not used for root crops, vegetables, fruits, tobacco and dairy pastures. Crops respond to sewage sludge as they do to a commercial fertilizer in the first year of application; the response may get better in subsequent years because of the residual effect of the added plant nutrients. Many physical properties of the soil (such as the water and nutrient holding capacity, infiltration, aggregation) are seen to improve with the application of sludge. Repeated application of large quantities of sludge (>10 t/ha) may cause '**soil sickness**'.

Activator

Generally, an activator or **accelerator** is a substance that activates, accelerates or increases the total output of a process. Microbial cultures added to organic materials or residues to hasten their decomposition act as **biological accelerators**. These microbial cultures include fungi like *Aspergillus* sp., *Paecilomyces fusisporus, Trichurus spiralis, Trichoderma viride* and other phosphate solubilizers (Fig.A.6).

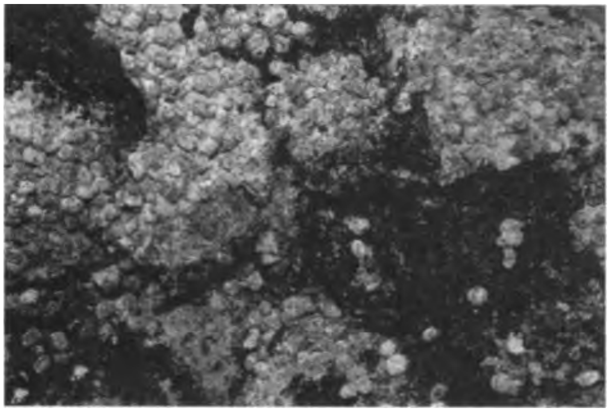


Fig.A.6: Growth of various compost accelerators is evident as differently colored colonies on the medium.

Metallic oxides (like zinc oxide), which promote cross-linking of sulphur in rubber vulcanization are other examples of accelerators. Similarly, oxides of magnesium, calcium or lead are also effective accelerators when mixed with rubber. Organic accelerators should ideally not be added to this mixture.

Stearic acid, along with thiazoles, increases the effectiveness of acidic organic accelerators. Any trace amount of a substance, required to induce luminescence in certain crystals, is also an accelerator. Silver and copper activate zinc sulphide and cadmium sulphide.

Active absorption

The movement of ions and water into plant roots against the activity gradient is called active absorption.

Active acidity

Active acidity is one of the two types of acidity. (See also Reserve acidity.)

Active biomass : See Biomass

Active calcium carbonate

Active calcium carbonate is a fine form of lime which is readily soluble in carbonated water. It enriches soil solutions with bicarbonate that progressively saturates the adsorption complex of clay-type soils. In contrast, active calcium carbonate renders iron insoluble in carbonated water.

Active ion uptake

When ions move against a concentration gradient, it is called an active ion uptake. (See also Ion uptake, active and passive.)

Active lime

Active lime is a fine form of lime. It is readily soluble in water containing carbon dioxide. It enriches soil solutions with soluble bicarbonate, which progressively saturates the adsorption complex of the soil with a high content of clay.

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2$$

$$Ca(HCO_3)_2 + H_2\text{- clay} \longrightarrow Ca\text{-clay} + 2CO_2 + 2H_2O$$

Active lime is insoluble in lime-rich soils, leading to lime chlorosis. Chlorosis, caused by iron deficiency, makes plant leaves lose their color abnormally. Chlorosis is common in those soils of Northern Africa, which are rich in active lime. Peach, chestnut and oak do not tolerate active lime.

Lime activity is determined by the **Drouinean method** in which lime is treated with excess ammonium oxalate. Calcium oxalate precipitates from the active lime and the excess oxalate of ammonium is determined by titration with potassium permanganate. This method is applicable usually to soils containing more than 8% total lime.

Activity index

Activity index (**AI**) is a measure of the suitability of slow nitrogen releasing substances, as a nitrogen fertilizer. An example of such a substance is urea-formaldehyde-ureaform. The activity index is defined as :

$$AI = \frac{\%CWIN - \%HWIN}{\%CWIN} \times 100$$

where CWIN is the cold water insoluble nitrogen (25°C) and HWIN is the hot water insoluble nitrogen (98 to 100°C.)

Ureaform contains about 38% nitrogen, a fraction of which is cold water insoluble and another fraction is hot water insoluble. For ureaform to be effective as a nitrogen fertilizer, the AI should be at least 40, according to American Association of Plant Food Control Officials (AAPFCO).

Activity ratio

Activity ratio is the ratio of the activity of two types or species of cations in an equilibrium solution. Plants take up potassium ions from the aqueous liquid phase of soil and its solutes. The concentration of potassium ions in the soil solution depends mainly on the crop, its type and growth. The optimum potassium level varies between 10 and 60 ppm depending on the crop, the soil texture, overall fertility level and moisture content.

The effectiveness of soil potassium for a crop uptake is influenced by the presence of other cations like calcium and magnesium. Aluminum cations (in acidic soils) and sodium ions (in salt affected soils) may also influence the uptake of soil potassium by the crop.

The activity ratio of potassium (AR^k) in solution in equilibrium with soil is given by:

$$AR^k = \frac{a_k}{\sqrt{a_{(Ca+Mg)}}}$$

where a_k is the activity of potassium ion and $a_{(Ca + Mg)}$ is the activity of calcium and magnesium cations. AR^k provides a satisfactory estimate of the availability of potassium. The activity ratio is also a measure of labile potassium in soil and gives the amount available to the crop roots.

To describe the soil status, it is necessary to specify not only the current potential of potassium in the labile pool but also the way the intensity depends on the quantity of labile potassium present through multiple measurements. The relation between exchangeable potassium ions (Quantity, Q) and the activity of solution potassium cation (Intensity, I) is a good measure of the status of potassium in the soil and the availability of more labile potassium in that soil. The ability of a soil to maintain the activity ratio against depletion by leaching is governed partly by three factors: the labile potassium pool, the rate of release of the fixed potassium, and the diffusion and transport of potassium ions in the soil solution. Usually, a neutral (normal) ammonium acetate solution is a good extractant for exchangeable soil potassium.

Activity ratio of potassium

The activity ratio of potassium is the ratio of the activity of potassium in soil extract to irrigation water, which shows the relative activity of potassium ions in the exchange reactions with soil.

Actomag

Actomag is a trade name for a selectively calcined dolomite produced by a patented US process. When dolomite is calcined at an appropriate temperature, magnesium carbonate ($MgCO_3$) is decomposed, leaving behind magnesium oxide (MgO, 27%) and nearly intact calcium carbonate ($CaCO_3$, 67%).

Actual acidity

Actual acidity is a type of acidity, determined by the hydrogen ion concentration in a solution as measured by the hydrogen-ion electrode. (See also pH.)

Acute toxicity

Acute toxicity refers to the ability of a substance to cause damage to a living tissue or impairment to the central nervous system or severe illness (leading in extreme cases to death) when ingested, inhaled or absorbed by the skin. The amount required to produce these results varies widely from substance to substance and the duration of its exposure to the living creature.

Acute toxicity is evidenced during short exposure that is a single, brief exposure; **chronic toxicity** refers to long-term exposure.

Additive

An additive is a substance which is added to another material to improve the properties of the latter. Additives are often added in small amounts. For example, a small quantity of kaolin or talc is added to ammonium nitrate granules or prills to make them free flowing. Similarly, 0.3 to 0.4% formaldehyde is added to urea to make urea abrasion resistant.

Adenosine diphosphate

Adenosine diphosphate (**ADP**) is a phosphorus compound formed during the breakdown of **adenosine triphosphate** (**ATP**) by dephosphorylation. It is made of adenine, ribose, five carbon sugars and two phosphate groups (Fig.A.7). ADP acts as a source of energy in biochemical reactions.

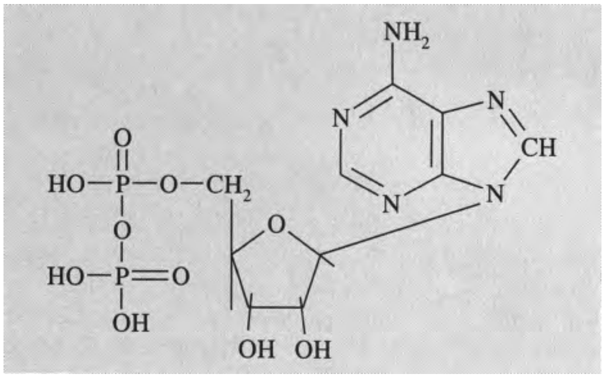


Fig.A.7: Structure of ADP.

Adenosine monophosphate

Adenosine monophosphate (**AMP**) is a phosphate compound (Fig.A.8) formed by the hydrolysis of covalent bonds of **adenosine triphosphate** (**ATP**) molecules (linking to adenosine and 3-phosphate groups by N-glycosidic linkage and phosphodiester bonds respectively), by the process of dephosphorylation.

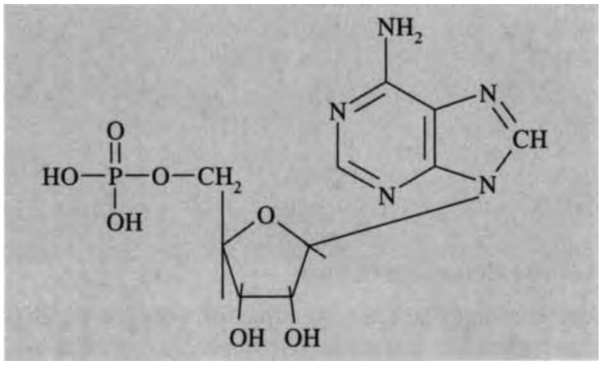


Fig.A.8: Structure of AMP.

Adenosine triphosphate

Adenosine triphosphate (**ATP**) is a nucleotide of fundamental importance as a carrier of chemical energy in all living organisms. The most important function of phosphorus in a plant system is to store and transfer energy. During biochemical processes, ATP (Fig.A.9) gets synthesized to store releasable energy with the breakdown of ATP to **adenosine diphosphate (ADP)** and to phosphate ion by dephosphorylation. Here, ADP and ATP act as energy currency within the plant.

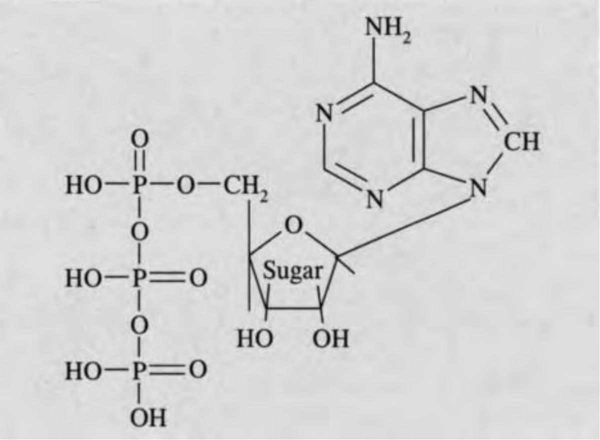


Fig.A.9: Structure of ATP.

In the ATP molecule, deoxyribose is linked covalently to adenosine (through an N-glycosidic linkage) and to three phosphate groups. These phosphodiester bonds are sequentially hydrolyzed to yield an ADP molecule and an inorganic phosphate, or a molecule each of **adenosine monophosphate (AMP)** and pyrophosphate, by dephosphorylation. Both reactions yield a large quantity of energy (about 30.6 kJ/mole) that is used to bring about muscle contraction as well as active transport of ions and molecules across the cell membrane, and synthesis of the biomolecules. The reactions bringing about these phenomena often involve an enzyme-catalyzed transfer of the phosphate group to intermediate substrates. Most ATP mediated reactions require magnesium ions as cofactors.

ATP is generated by the phosphorylation of AMP and ADP in the presence of sufficient phosphorus, which uses chemical energy obtained from oxidation of food. This takes place during glycolysis and the **Krebs cycle** but most significantly it is also a result of oxidation-reduction (**Redox reactions**) of the electron transfer chain that finally reduces molecular oxygen to water. Almost every metabolic reaction of any significance proceeds via phosphate derivatives.

Adhesion

Adhesion, the act of sticking together, involves mutual bonding caused by an attraction between surface molecules of two different substances placed in contact. There can be adhesion between two liquids, two solids, or a liquid and a solid. The inter-facial forces acting here may consist of valence forces or interlocking action or both.

The separation of two different phases (A and B) requires energy. Adhesion is measured as a force or work necessary to separate the two phases with unit interface area. The work necessary to tear off the adhesion (W_a) when the two phases share an interface area of 1 m^2 is:

$$W_a = \sigma_A - \sigma_B - \sigma_{AB}$$

where σ_A and σ_B are the surface energies of the two surfaces, σ_{AB} is the surface energy of the interface between A and B.

When a liquid is in contact with an insoluble solid, three kinds of surface energy exist: (a) between the liquid and the gaseous phase, (b) between the solid and the gaseous phase, and (c) between the solid and the liquid phase. The work of adhesion is calculated from:

$$W_a = \sigma_L(1 + \cos\theta)$$

where σ_L is the surface energy at the liquid-air interface and θ is the angle of wetting.

The mutual attraction between molecules of the same substance is called **cohesion**. Synthetic soil conditioners facilitate the cohesion of micro-aggregates into macro-aggregates.

In the case of a fertilizer, its particles can cake or agglomerate on storage due to adhesion, leading to poor flow. Such caking or lumping makes fertilizer application difficult.

Adhesive contacts in fertilizer caking

As a result of molecular attraction, adhesive contacts (**capillary adhesion**) are formed between the surfaces in contact; the forces of attraction are known as **van der Waals forces**. Such a contact is influenced mostly by the plasticity of particles and the pressure exerted on the material (fertilizer) when stored in bulk.

Adjusted SAR

Adjusted SAR is short for **adjusted sodium adsorption ratio**.

Adjusted sodium adsorption ratio

Sodium adsorption ratio (**SAR**) represents the tendency of sodium to increase its proportion on the cation exchange sites at the expense of the other types of cations. SAR is given by the ratio of sodium content to the content of calcium plus magnesium in water. When water contains bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions, they precipitate calcium and magnesium ions which increase the SAR value. Acidic waters can dissolve solid carbonates and bicarbonates, which in turn form carbonates of calcium and magnesium. The new formula, taking into account these changes, is known as the adjusted SAR. It is given by the following equations:

$$\text{Adj SAR} = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \times [1 + 8.4 - pH_c]$$

$$pH_c = (pk_2' - pK_c') + p(HCO_3^- + CO_3^{2-}) + p(Ca^{2+} + Mg^{2+})$$

where $(pk_2' - pK_c')$ is essentially the Ca, Mg and Na ion concentration, $p(HCO_3^- + CO_3^{2-})$ is the carbonate and bicarbonate concentration, $p(Ca^{2+} + Mg^{2+})$ is the concentration of calcium and magnesium ions.

Adjuvant

Adjuvant in general means something helpful or auxiliary. It is a substance that enhances the body's immune response to an antigen. When added to the main composition, the adjuvant improves the functioning of the main ingredient; the characteristics of the latter can change - in terms of improved wetting, reduced evaporation, increased penetration, better translocation, better weathering characteristics, retarded nutrient release, better pH adjustment, enhanced deposition and compatibility and reduced odor.

There are four types of adjuvants, namely (a) **surfactants**, (b) **oils**, (c) **drift retardant**, and (d) others.

Surfactant adjuvant molecules have a lipophilic and a hydrophilic phase. The former usually consists of a long-chain hydrocarbon or a benzene ring structure that has very low solubility in water but high solubility in oil, the latter having a high affinity for water. From the structure of the hydrophilic phase, three classes of surfactants are recognized, namely, anionic surfactants, cationic surfactants and non-ionic surfactants. In agriculture, the most commonly used surfactants are non-ionic which are non-toxic, easy to use and not affected by hard water.

The following are examples of the three surfactant classes: (i) **Anionic surfactants** - Sodium stearate $C_{17}H_{35}COO^-Na^+$. (ii) **Cationic surfactants** - Cetyltrimethyl ammonium bromide $C_{16}H_{33}(CH_3)_3N^+Br^-$. (iii) **Non-ionic surfactants** (Fig.A.10) - Poly (ethylene oxide) laurylalcohol $C_{12}H_{25}O(CH_2CH_2O)_{23}H$.

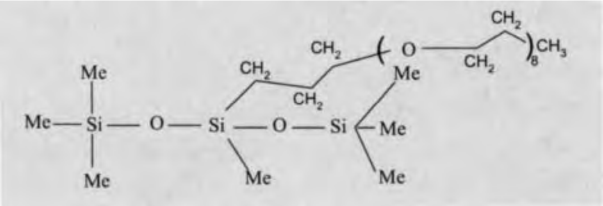


Fig.A.10: A new form of silicone type, non-ionic surfactant.

Surfactants have different uses as wetting and/or dispersing agents, emulsifiers, foaming agents, detergents, etc. A wetting agent (<0.1%) is added to herbicide sprays to make the droplets spread evenly over leaves, thus increasing the coverage and eventual uptake of the herbicide.

Exhaustive research on surfactants has revealed that a specific surfactant is ideal for a specific herbicide on a particular species. In recent times, formulations containing phytobland oils and highly concentrated (4 to 10%) surfactants are gaining increased popularity. These products are more effective in improving herbicide retention and uptake than the surfactant alone. For some herbicides, the amount to be applied (usually around 2 liters/ha) is displayed on the label.

Oil adjuvants have been used in herbicide sprays for many years and are divided into 3 types. (i) **Phytotoxic, non selective adjuvants in herbicides**: These are highly unsaturated (for example, diesel and oil) and readily sulphonated, giving them a low unsulphonatable residue character. Oils of this category are added to the knock-down type herbicides to facilitate uptake through the bark for spraying canals and ditch-banks or to brush killers. (ii) **Phytotoxic, selective adjuvants in herbicides**: These are not actually adjuvants and may be sprayed directly without mixing with water or in combination with herbicides.(iii) **Phytobland oil-water emulsions**: These are nearly saturated light oils. They are not phytotoxic and are added to herbicides for better penetration in foliage. These are called by different names, such as **corn oils, superior spray oils, supreme spray oils**, etc.

When a liquid is forced through a spray orifice under pressure, a large number of extremely fine spray droplets accompany the normal sized droplets. These 'fines' can be easily diverted from the target area even by a slight breeze. If the herbicide is sufficiently phytotoxic and the breeze is sufficiently strong or if the fines produced are substantial, the fines can seriously damage non-target plants and crops. A long chain polymer, such as anionic polyacrylamide, can be added to the spray tank to reduce the number of fines and to serve as a **drift retardant**.

Miscellaneous adjuvants include (a) foaming agents which are often used to generate a glob of foam at either end of the spray boom to serve as a marker, (b) emetics which cause immediate vomiting to reduce the hazard of accidental ingestion, and (c) stench creating agents added to a toxic pesticide to prevent it from being mistaken for a soft drink.

Adoption

Adoption, in the present context refers to the acceptance and implementation of an improved or a new technique related to farming, such as, a specific method of use of fertilizer or irrigation, by a farmer.

ADP

ADP is short for **adenosine diphosphate**.

Adsali sugar cane

Adsali sugar cane refers to the cropping pattern of sugar cane in which the crop (with a span of 18 months) is planted between June and August and harvested the next year from December to February. This pattern of sugar cane planting is common in the Indian states of Andhra Pradesh, Karnataka and Maharashtra.

Adsorbate

A substance that accumulates in a two-dimensional molecular arrangement at the interface is known as an adsorbate.

Adsorbent

The solid surface on which a substance (adsorbate) accumulates is called an adsorbent. Activated carbon, activated alumina and silica gel are examples of adsorbents.

Adsorption

The formation of a layer of gas, liquid or solid molecules on the surface of a solid or liquid is known as adsorption. The process is always accompanied by the evolution of heat, which is called the **heat of adsorption**. The opposite of adsorption is a process called **desorption**. A substance accumulating in two-dimensional molecular arrangements at the interface is called an **adsorbate**, whereas the solid surface on which it accumulates is called the **adsorbent**. A molecule or an ion in the soil solution that can potentially be adsorbed is known as an **adsorptive**. Organic and inorganic colloidal materials in soil adsorb other substances (such as added fertilizers), and form an **adsorption complex**. In comparison, non-colloidal substances like sand and silt have no adsorption capacity.

Depending on the nature of forces involved, adsorption is divided into two types - chemisorption and physisorption. In **chemisorption**, a single layer of molecules, atoms or ions is held to the adsorbent surface by chemical bonds. In **physisorption**, adsorbed molecules are held by the weaker **van der Waals forces**. In addition, adsorption caused by electrical attraction of the ions to a charged surface is known as **electrostatic adsorption**.

The quantity adsorbed depends on the (a) pressure (concentration) at a constant temperature illustrated by the **adsorption isotherm**, (b) temperature at a constant pressure which is expressed by the **adsorption isobar**, and (c) effect of pressure on temperature at a constant amount adsorbed which is called the **adsorption isostere**. The cause (energy or power) of adsorption is called **adsorptive force**.

Compared to a pure solvent, surface-active substances accumulate on the surface and reduce the surface energy of the solution. Bonding of ions or compounds to the surface of a solid or liquid, which is usually temporary, is similar to the bonding of a calcium ion held on the surface of a clay crystal.

Adsorption is an important feature of surface reactions, such as those involving corrosion and heterogeneous catalysis. The property is also utilized in adsorption chromatography. The incorporation of oxyanions like borate, phosphate or molybdate into secondary metal oxides like that of Fe, Al and Mn, and of transition metals like Fe or Ni into the soil organic matter are examples of adsorption.

Adsorption coefficient

Irving Langmuir developed the concept of monolayer adsorption of gases on surfaces from the kinetic theory of gases. The concept, known as **Langmuir isotherm**, relates the amount of gas adsorbed at a plain solid surface to the pressure of gas in equilibrium with the surface.

The derivation of Langmuir isotherm assumes that (a) the adsorption is restricted to a surface monolayer which is energetically uniform, and (b) there is no interaction between the adsorbed species. The following equation shows that the fraction (q) of the surface covered by the adsorbate at a gas pressure (p) is given by:

$$q = \frac{bp}{1 + bp}$$

where 'b' is a constant called the adsorption coefficient, which is the equilibrium constant for the adsorption process.

Adsorption complex

Substances like fertilizers adsorb on organic and inorganic colloidal materials in the soil to form an adsorption complex.

Adsorption, electrostatic

Adsorption caused by electrical attraction of ions to a charged surface is known as **electrostatic adsorption**.

Adsorption isobar

The quantity of substances adsorbed by a solid depends on its temperature at a constant pressure, and is expressed as its adsorption isobar.

Adsorption isostere

The effect of pressure on the temperature of adsorption at a fixed surface coverage is expressed as the adsorption isostere.

Adsorption isotherm

The quantity of substances adsorbed depends on the pressure or the concentration at a constant temperature, and is expressed as adsorption isotherm.

Adsorption mechanisms

Adsorption involves holding molecules of a gas or liquid solute as a thin film on the outer or inner surface of the material. This can occur by three mechanisms, namely, diffusion, ion outer-sphere complex and inner-sphere complex.

A solvated ion neutralizes the surface charge in a delocalized way and is adsorbed in the diffused ion swarm so that fully dissociated ions from the functional group are free to move about in the soil solution. In the second mechanism, the outer-sphere surface complex has a cation solvation shell and the bonding is exclusively electrostatic. Finally, the inner-sphere complex mechanism involves a siloxane cavity and is likely to involve both ionic and covalent bonds. Covalent bonding varies with electron configurations of both the surface groups and the complexed ion; the inner-sphere surface complex is hence considered as the molecular basis of the term **specific adsorption**.

Specific adsorption, which is usually chemical, is selective for a particular ion or substance. Similarly, diffuse ion association and outer-sphere surface complexation have the molecular basis of the term **non-specific adsorption**, wherein the prefix 'non-specific' implies near non-dependence on the electron configuration of the surface group and the adsorbed ion.

Soil solution composition determines the relative affinity of a given metal cation to a soil adsorbent. The interactive strength among the three adsorption mechanisms decreases in the order of inner-sphere complex, outer-sphere complex and diffuse ion swarm.

Adsorption, specific

Specific adsorption of an ion on a particular surface or substance is called specific adsorption. (See also Adsorption mechanisms.)

Adsorptive

A molecule or an ion in soil solution that can potentially be adsorbed is known as an adsorptive.

Adsorptive force

The energy or power of adsorption is called adsorptive force.

Adulteration of fertilizers

Adulteration of fertilizers involves the practice of adding extraneous material to a standard fertilizer to lower its quality. A fertilizer is said to be adulterated when (a) it contains harmful or deleterious ingredients or unwanted crop or weed seeds in quantities sufficient to harm the plant when applied according to the directions on the label, (b) its composition differs from that given on the label, and/or (c) useless materials like salt or sand are added to it.

Adventitious roots

Adventitious roots are those that appear on plant parts like stems, branches or even leaves. These are also called **central permanent** in crops like cereals, since they arise from crown internodes just below the surface of the soil. The same crown internodes are also the place of origin of shoots or parts above the ground. The banyan tree has adventitious roots.

AEC

AEC is short for **anion exchange capacity**.

Aeolian soil

The word aeolian means 'arising from the action of the wind'. Wind-transported soil material forms aeolian soil. **Loess** and **dunes** are examples of aeolian soils.

Loess is a material finer than sand. It can be transported and deposited by wind to great distances. Loess soils have neutral pH, well-balanced content of clay and organic matter, and are rich in plant nutrients. They possess a high nutrient storage capacity and are, therefore, productive.

Loess soils, which are mostly silt, have unique properties. For instance, they (a) are open and porous, (b) have vertical cuts more stable than the slopes, and (c) can have problems (like the formation of sinkholes, cavities and subsurface channel cutting) when used for earthen dams. There are large areas of loess in countries like Argentina, China, Germany and the United States.

Aeration factor

Aerobic micro-organisms need oxygen for respiration. The ratio of oxygen consumed by microbes in soil under optimum respiratory conditions (artificially created) to that consumed by them in the soil under natural conditions is the aeration factor expressed as a percentage. However, natural soil conditions cannot be readily simulated in a laboratory.

Aeration pores

Aeration is the process where a substance gets permeated with air or another gas. The macropores in a well-drained, moist soil, usually filled with air are called aeration pores. (See also Soil porosity.)

Aeration soil

Aeration is an exchangeable process between air from the soil and the atmosphere. In a well-aerated soil, the exchanges occur rapidly and continually.

Most crop roots, except rice, need oxygen for respiration and growth. Microbes also need oxygen for decomposition of organic matter and for oxidation of chemical compounds like ammonia, sulphur, hydrogen sulphide, iron sulphide, etc. Both roots and microbes thus consume oxygen and release carbon dioxide in the soil-air, and significantly alter its composition. Surface soils and subsoils differ in their content of oxygen, carbon dioxide and humidity.

The rate of oxygen exchange or the **oxygen diffusion rate (ODR)** depends upon the size and continuity of soil pores. Large soil pores increase the ODR, whereas small pores (like in fine clayey soils) or water filled pores restrict it. ODR depends on the soil depth, with the top few centimeters having rapid gaseous exchange as compared to the deeper layers. The wetting and drying of the soil and the soil cover also affect aeration.

A reduced aeration halts (or slows down) plant growth or the decomposition of soil organic matter. A deep ripping, drainage of excess water or addition of organic residues loosens the compacted soil and helps soil aeration.

Aerial spraying

In aerial spraying, pesticides, fertilizers or seeds are sprayed from an aeroplane or helicopter (Fig.A.11). Aerial spraying is particularly advantageous when the ground is inaccessible, excessively wet or too large, or

Fig.A.11: Aerial spraying is advantageous particularly over large areas, in tree plantations or if the land is too wet. Courtesy: "The US Environmental Protection Agency" and "International Network for Environmental Compliance and Enforcement". With permission from the office of the INECE Secretariat, Washington, DC.

when the crop height or infestation is very large. Tram lining or similar techniques can reduce the need for aerial application. (See also Sprayer.)

Aerobes

Micro-organisms requiring oxygen for respiration are called aerobes. *Rhizobium, Azotobacter* and *Azospirillum* are examples. In aerobic respiration, foodstuffs (usually carbohydrates) are fully oxidized to carbon dioxide and water, releasing chemical energy, as shown in the following reaction:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

A fermenter or a bioreactor with an aeration system for the culture of aerobic organisms is known as **aerobic reactor**. Aerobic reactor is a piece of equipment, such as fermenter or a bio-reactor with an aeration system for the culture of aerobic organisms.

Aerobic reactor : See Aerobes

Aerobic respiration

Respiration in the presence of oxygen is called aerobic respiration. Oxidation of food requires oxygen in the living cells and is accompanied by the release of water, energy and carbon dioxide.

Aerodynamic method for evapotranspiration

Aerodynamic method, which is improved by the energy balance approach, is used for estimating evapotranspiration. The method employs meteorological formulae, which consider factors influencing the removal of water vapor from the evaporating surface, the vertical gradient of humidity and the turbulence of airflow. Turbulence can be assessed by the vertical gradient in wind speed.

Aeroponics

Aeroponics is a technique of growing plants, in which plants are suspended in the air and the roots are coated with nutrient solutions. The method is used to assess the effects of certain mineral elements on plant growth.

Aerosol

Aerosol is a type of colloid. It is the dispersion of liquid or solid particles in gas such as mist, smoke or foam.

Affinity

The tendency of an atom (or compound) to react with atoms (or compounds) of a different chemical constitution is known as its affinity.

Hydrocarbons are called paraffins (meaning, no affinity) because they exhibit no reactivity with other molecules.

The hemoglobin molecule has a much greater affinity for carbon monoxide than oxygen. The free energy decrease is a quantitative measure of chemical affinity.

Afforestation

Afforestation is the planting of forest plant species either on a piece of land for the first time, or in denuded or degraded forests. Planting trees on a large scale (Fig.A.12 and A.13) prevents land degradation, as their roots tend to grow down to the underground water, pump

Fig.A.12: Afforestation with Glyricidia plantation on hills.

Fig.A.13: Afforestation with Casuarina trees.

the water out of the ground and transpire it into the atmosphere, thereby keeping the water cycle in balance.

Planting trees reduces (a) soil erosion because tree roots bind the soil and reduce its transportation, (b) soil salinity because trees keep the water table well below the soil surface due to transpiration of water, thus preventing salts from rising, and (c) run-off which reduces the quantity of soil particles and fertilizers being added to rivers.

Trees absorb carbon dioxide from the atmosphere during photosynthesis. Large-scale afforestation can help reduce the large amounts of carbon dioxide generated by the burning of fossil-fuel, coal and oil.

Appropriate mechanisms have been set-up all over the world for promoting afforestation, tree plantation, ecological restoration and eco-development activities. Special attention has been given to degraded forest areas and lands adjoining forest areas, national parks, sanctuaries and other ecologically fragile areas such as the Western Himalayas and the Silent Valley in India.

Aflatoxins

Aflatoxin refers to a group of highly toxic polynuclear moulds (mycotoxins.) They are designated as B_1, B_2, G_1, G_2, M_1 and M_2 and are produced chiefly by fungus *Aspergillus flavus*, which is a natural contaminant of fruits, vegetables and cereal grains. Aflatoxins are toxic to many animals including fish and birds. The B_2 and G_1 strains are carcinogens.

Aflatoxins fluoresce strongly under UV light. They are soluble in methanol, acetone and chloroform, but only slightly soluble in water and hydrocarbon solvents. Prevention of mould growth is the most effective protection against aflatoxins. Removal or inactivation is possible by physical and chemical means (solvent refining or hand picking). FDA (Food and Drug

Administration) does not allow any aflatoxin content in foods or feeds, although its presence up to 20 ppb does not attract penalty.

AFNOR

AFNOR is a French standard system like the German **DIN** system or **Bureau of Indian Standards (BIS)**. AFNOR sieves are one of the many principal sieves used in the determination of particle size of powders. In AFNOR, the length of the sides is stepped in geometrical progression with a common ratio of 1.259. (See also Sieving.)

After crop

After crop is another crop cultivated after the harvest of a crop, on the same piece of land and in the same year.

After cultivation

As the term indicates, after cultivation involves operations such as harrowing, rolling and other cultural activities carried out in a field after the crop is sown or planted.

Agar

A phycocolloid derived from red algae such as *Gelidium* and *Gracilaria* is called agar. It is a polysaccharide mixture of agarose and agaropectin. (See also Agar-agar.)

Agar-agar

Also known as **agar**, the word agar-agar is of Malaysian origin. It refers to the red seaweeds belonging to genus *Eucheuma,* used widely in Malaysia for making a gelatinous material.

Agar is a mucilage synthesized by red algae and stored along with cellulose in the cell wall. It is a dry, amorphous and gelatine-like extract, devoid of any non-nitrogenous material from *Gelidium* and other agarophytes. The extract is the sulphuric acid ester of a linear galactan, soluble in hot water but insoluble in cold water. A 1.5% agar solution can form a firm gel at around 35°C (with a melting point above 85°C), the gel being a mixture of a partially methylated neutral polysaccharide (**agarose**) and sulphuric acid ester (**agaropectin**) of a linear galactan. The gel is made under steam pressure or by boiling, and its agar content depends on the algal species, season and extraction method.

Agar is manufactured from various algae or seaweeds called **agarophytes**, whereas the term **agaroidophyte** denotes the red seaweeds that yield a substance chemically akin to an agar-like substance, but with different viscosity and gelling properties. The important agarophytes used for extraction of agar are *Acanthopeltis japonica, Ahnfeltia plicata* and species under the genera *Gelidium, Gracilaria* and *Pterocladia.* Other red algae are *Comphylaephora, Eucheuma, Hypnea, Gigartina* and *Furcellaria.*

Different countries use different red algae for making agar. For example, *Suhria* (Fig.A.14), *Gelidium, Pterocladia,* and *Ahnfeltia* are used in South Africa, the US, New Zealand and Russia respectively. Often, the alga carries the name of that country where it is used. For example, **Ceylon agar** (or **Ceylon moss**) refers to the dried red seaweed *Gracilaria lichenoides* found mainly in Sri Lanka, whereas the same alga found along the Indian coast bordering the Indian Ocean is called **Bengal isinglass**. *Gracilaria verrucosa* (Fig.A.15) in China is known as **Chinese moss**, whereas in Japan, agar-agar made from *Gelidium* sp. is called ***Kanten,*** which means cold sky, because it was made in cold winter days or high up in the mountains.

Fig.A.14: Suhria vittata, a red alga used in making agar.

Fig.A.15: Gracilaria verrucosa (confervoides), an agarophyte.

Agar is used for many purposes - as a solidifying agent in the culture medium used for multiplication of beneficial bacteria like *Azotobacter* and *Azospirillum* during biofertilizer production (Fig.A.16), for algal growth, for canning tuna fish (in Japan), in the sizing of fabrics, etc. Various grades of agar are used as coating material for waterproofing paper and cloth, as a glue, as a cleaning medium for liquids, as a lubricant, in hot drawing of tungsten wire for electrical lamps (for which a suspension of powdered graphite in agar gel is used), for making photographic plates and films, for imparting gloss and stiffness to leather, and as an adhesive in the manufacture of plywood. Agar is even used in food products, for thickening soups, sauces, ice creams, malted milks, jellies, candies and pastries. Due to its high temperature tolerance, agar is fovored in food products. It substitutes pectin for making jellies, jams, marmalades, etc. and serves as a clarifying agent in the manufacture of wine, beer and coffee.

Fig.A.16: Agar-agar is used in various nutrient media as a solidifying agent. Useful micro-organisms are grown on suitable agar based media.

Agar based inoculant

An inoculant that uses agar in its medium as a solidifying agent is called an agar based inoculant.

Agaroidophyte

The term agaroidophyte denotes red seaweeds that yield a substance chemically akin to an agar-like substance, but with different viscosity and gelling properties.

Agaropectin

Agaropectin is the sulphuric acid ester of a linear galactan, used for making gel.

Agarophyte

Agarophyte is an alga or seaweed used for the manufacture of agar.

Agarose

Agarose is a partially methylated neutral polysaccharide used for making gel.

Aged forest: See Forest

Age of tree: See Annual ring

Agglomeration

Agglomeration or caking (synonymous with **flocculation** or **coagulation**) refers to the process of formation of large granules or a coherent mass of material from individual particles, caused by the formation of contact points among the particles. Such conversions often occur in humid atmosphere with fine powders and particulate matter. A combination or aggregation of colloidal particles suspended in a liquid into clusters or flocks of approximately spherical shapes is also known as agglomeration. It is achieved by neutralizing electric charges which maintain the stability of colloidal suspension.

Agglomeration thus prevents the smooth and easy flow of fertilizers, thereby affecting manual application as well as application with mechanical devices. Anti-caking agents such as talc and kaoline are added to prevent agglomeration and improve flowability of fertilizers.

Agglomeration process

The clustering or grouping together of particles is known as **agglomeration** and the process by which this takes place is known as the agglomeration process. The agglomeration process is used for the production of granular NPK products. In this process, the final mechanical strengths of the agglomerated granules are obtained by mechanical interlocking or by fitting together individual particles.

Aggregate

An aggregate is a group of primary particles, sand, silt or clay that adhere to each other more strongly than to the surrounding particles. It is a unit of soil structure.

Aggregate stability can be defined as the resistance of the bonds within the aggregates to external forces of impact, shearing, abrasion or disruption arising from the escape of entrapped compressed air (slaking). It is a measure of susceptibility of the soil to water erosion, crust formation, hard setting and compaction. Stability measurements can be made on the scale of the whole soil or large aggregates (>250 µm) or on the scale of clay and silt-sized particles.

On a large scale, aggregates of whole soils are exposed to disruptive forces, usually by wet sieving and the portion of the material remaining on one or several sieves represents stable aggregates. At the scale of clay or silt-sized particles, methods generally consist of characterizing by **turbidimetry** or densitometry of the suspension, obtained by exposing the aggregate to disruptive forces.

Aggregate stability is determined by measuring the proportion of aggregates of a given size (usually 1 to 2 mm), which, under the influence of disruptive forces, do not break into units smaller than a pre-selected size (usually 250 µm).

Aggregate stability: See Aggregate

Aggregation

Aggregation is a general term describing the tendency of large molecules (or colloidal particles) to combine in clusters or clumps, especially in solution. When aggregation occurs by the removal of electric charges, by the application of heat or mechanical agitation or the addition of an appropriate electrolyte, the aggregates precipitate from the dissolved state.

Aggregation, soil

When several soil particles are bound together they make a unit called **aggregate**, and the process of this formation is called **aggregation** (Fig.A.17). A soil consisting of strong aggregates is an aggregated soil with a stable soil structure, which is suitable for plant growth.

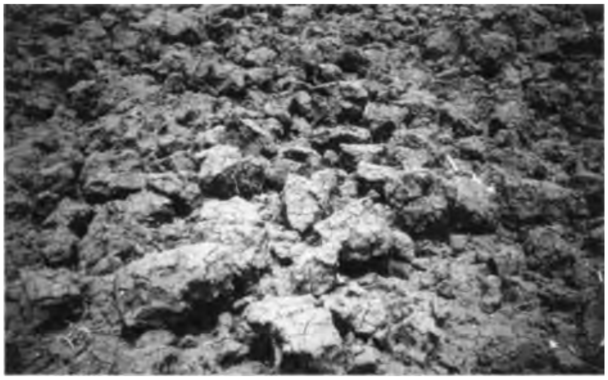


Fig.A.17: Aggregation of soil particles leads to the formation of clods.

Agon

Agon is a kind of plow which opens a furrow deeper than the raise, to improve swampy terrains.

Agricultural aircraft

For large agricultural lands, an agricultural aircraft is used to perform various operations like seeding, crop drying, fertilization, defoliation, pest control, etc. Its use is common in developed countries for large food production programs. These crafts can be helicopters or rotary wing flying machines which, due to their manoeuvrability, low-forward speed capability and operational precision offer advantages in forestry, agriculture and vector control work. However, due to the high initial price of helicopters, high adaptation and maintenance costs, and pilot skill, their use on a large scale is discouraged. An agricultural aircraft in action is shown in Fig.A.18.

Agricultural aircrafts are sought after because of their ability to operate regardless of farm conditions, irrigational facilities and the state of crop growth. The aircraft enables agricultural operations to be carried out with great speed, but not necessarily with an energy gain or saving over other methods. The field size, proximity to human habitat and sensitive non-target cultivation, and crop plant coverage are among the factors that limit the use of these aircrafts. Some of these considerations are particularly pertinent when wet and dry type pesticides are to be dispersed.

Fig.A.18: Agricultural aircraft being used for aerial spraying.

Agricultural biotechnology

Agricultural biotechnology is a branch of agricultural science that deals with research and application of **biotechnology** tools to agriculture. It involves techniques like genetic engineering, plant and animal tissue culture, development of bio-fertilizers and bio-pesticides, artificial synthesis of natural substances, etc. **Bt cotton** is a well known example of agricultural biotechnology.

Agricultural chemistry

Agricultural chemistry is not a distinct discipline. It is the science of chemical compositions and alterations which occur in the production, protection and use of crops and livestock. This branch embraces life processes that are common in the creation of food and fiber for humans and animals. To assist this creation and production, many chemical substances are developed, which come under the category of herbicides, insecticides, fungicides, plant growth regulators, fertilizers, animal feed supplements, nutritional supplements and medicinal compounds for disease prevention.

Agricultural chemistry selectively embodies the elements of many disciplines that impinge on agriculture, such as genetics, physiology, microbiology, entomology, etc.

Agricultural chemistry is used to study, explore and investigate the cause and effect relationships of biochemical reactions pertinent to plant and animal growth, to develop methods to control these reactions whenever required, and to produce the desired chemical products.

Agricultural dolomitic limestone

Agricultural dolomitic limestone is a fine, grey to white powder of a double carbonate of calcium and magnesium with 12.8% magnesium and 17% calcium. The double carbonate is much less soluble in water than the individual carbonate. (See also Calcium carbonate.)

Agricultural engineering

Agricultural engineering is concerned with the means of continually enhancing the production of food and fiber to meet the needs of the world's rising population, and elevating the standards of living.

Agricultural engineers deal with problems involving biological materials, systems and processes. They apply physical and engineering sciences and achieve new peaks in agricultural productivity by increased mechanization.

As enhanced production is demanded from an ever-decreasing land area, agricultural engineers are constantly concerned with modifying the natural environment, to create conditions closer to the ideal for plant growth and animal production. Agricultural engineers strive to make today's livestock farm operate like a factory with a high degree of automation and mechanization, with inputs for poultry, dairy and meat animals.

Agricultural engineering involves the efficient management of soil and water resources, development of newer techniques and systems for control of soil erosion, retention of soil moisture for prevention of floods and water pollution, and supply of pure water for human use.

Agricultural engineering also relates to the development of machinery for efficient agricultural operations and post-harvest operations, such as drying of grains and forages, washing, grinding and storing of fruit and vegetables, etc.

Agricultural fungicides

Agricultural fungicides are chemicals used in agriculture to minimize crop losses caused by phytopathogenic fungi. (See also Fungicides.)

Agricultural lime

The **liming materials** used for correcting the acidity of soils are also called agricultural lime.

Agricultural machinery

From initial tillage of the soil to final food and fiber production, there are many operational and precautionary steps involved. These pertain to the planting of crops, defense from pests, harvesting, conditioning, livestock feeding, and release of the farm product for processing.

To carry out agricultural operations, large special purpose machines are often used. For tillage, the generally accepted practice is to use large four, six, or eight wheel tractors or crawler tractors and high-capacity plows or disks, while for loosening compacted soils, deep rippers are conveniently employed (Fig.A.19). For all this, a push-button control activates fluid power to pump through the flexible hoses to impart linear or rotating motion, as well as to perform intricate operations by highly specialized machinery. The latter can increase the precision needed in modern agriculture using, for instance, lasers for laying out irrigation systems and microprocessors for sensing or controlling such operations as regulating feed mixtures for dairy cows or grading fruits and vegetables. A variety of electronic devices are employed in the automation of many harvesters. Plows, discs, cultivators and fertilizer spreaders are mounted on tractors, but if these are too large, they are controlled and operated hydraulically.

Fig.A.19: Special purpose machines and equipments are devised for various agricultural operations. Clockwise from top left: tractor driven plow, thresher, moldboard plow and wheat and rice harvester.

An agricultural aircraft can perform many farming operations, such as sowing rice in flooded fields, applying fertilizers and pesticides, and spraying herbicides and insecticides on grains, vegetables and fruits.

Agricultural meteorologists: See Agricultural meteorology

Agricultural meteorology

Meteorology deals with the atmospheric character of a region, and is concerned with the processes and phenomena of the atmosphere, especially as a means of weather forecasting.

Agricultural meteorologists, also called **agrometeorologists**, deal with weather prediction and its effect on crop yields, water use efficiency, weather related diseases (like pests), the length of seasons, the timing and severity of snow or frost, wind direction and intensity, problems associated with extreme weather conditions, atmospheric turbulence, remote sensing, etc.

The earth's surface exchanges radiation and mass with the atmosphere and absorbs the wind momentum; **micrometeorology** deals with the mechanisms of these exchanges.

Agricultural meteorology is concerned with the study and application of meteorology to specific problems of agriculture that arise while dealing with farming, ranching and forestry. It is also concerned with finding, in advance, the right weather conditions for the transportation of materials such as water, chemicals, fertilizers, etc.

Agricultural meteorologists use multispectral scanners placed on a number of satellites made and launched by NASA (USA), ESA (Europe), Japan, China and India for remotely sensing conditions on land and in oceans.

Agricultural sulphur

Coarse or ground sulphur used for correcting sulphur deficiency or for increasing soil acidity is called agricultural sulphur or **agri-sulphur.** It has a sulphur content of about 90%. It is oxidized to sulphate ion by soil micro-organisms when applied to the soil. The effectiveness of agricultural sulphur depends on its particle size, the rate, method and time of application, soil characteristics and the environment. Under some soil conditions, sulphur oxidizes slowly, and hence sulphur incorporation should be done 4 to 5 months prior to planting. Biological oxidation of sulphur in well-aerated wet soils is generally rapid.

Blending sulphur with solid N, P and K materials produces a variety of sulphur-based fertilizers. The sulphur component in sulphur-based fertilizers is also called **flowers of sulphur** or **brimstone**.

Agricultural waste

Agricultural waste includes weeds, straw, chaff leaves, sugar cane waste, groundnut husks, etc. It is used as raw material for making compost. (See also Compost.)

Agricultural yield

Agricultural yield is the same as agricultural production. The yield is understood as the number of ears per unit area, the number of grains per ear and the grain size. The yield is expressed in kilograms or tons per unit area (hectare).

Agriculture

Agriculture is essentially about the production of crops and livestock. It covers a whole range of technologies concerned with the production of useful substances from plants, animals, soils, livestock, etc., as well as related processing and marketing activities (Fig.A.20). The term agri-business includes all the technologies that are involved in the total inputs and outputs of farming.

Agriculture thus comprises the entire range of economic activities connected with the manufacture and distribution of all industrial inputs required for farming, farm products like crops and animals, conversion of these into finished products, and finally, marketing them.

Fig.A.20: Agriculture involves activities like crop as well as livestock production, marketing, technology development, etc.

In many countries, agriculture is the largest private sector enterprise. The final product of the food and fiber industries in the USA, for instance, amounts to about one-fourth of the gross national product and is about five times the value of farm-level production.

Agricultural practices are influenced by many factors that are characteristic of the area, the climate, soil, topography, proximity to markets, transportation, land costs and general economic standing. These vary widely across the world and bring about a wide range of agricultural products, commodity specialization, diversification as well as entrepreneurship.

As the world's population keeps increasing, there is a continuing need to develop and adopt new technologies to

Fig.A.21: Sugar cane is an example of a monoculture crop. It provides an ideal opportunity for the survival and breeding of crop pests.

increase food production. The last 50 years have seen many developments in agricultural science, technology and practices, which have led to an increase in the world's food production. However, advances in agricultural practices have, in several cases, adversely affected the environment. The indiscriminate use of fertilizers and pesticides has been a significant factor. The widespread practice of **crop monoculture**, in which one crop is grown over the same area year after year (Fig.A.21), has caused an increased use of pesticides, because monoculture provides an ideal opportunity for the survival and breeding of crop pests. The practice of monoculture has often led to the depletion of fertility of land and the destruction of natural habitats for useful soil flora and fauna.

Advances in agricultural technology have also stimulated the development of plowing machines with hydraulic devices that can dig deeper into the soil, and of seed drills that automatically plant seeds in the plowed soil (Fig.A.22).

Fig.A.22: Advances in agriculture have led to the development of improved machines like multicrop planter (left) and two furrows whole stick sugar cane cutter planter.

In many developing countries, the food supply relies solely on **subsistence farming**, in which crops and livestock are also used to feed the farmer's family. In these countries, a system known as **slash and burn** cultivation is common. In this system, vegetation in the area is cut down and burned, thus returning the minerals to the soil to reuse it for crop cultivation. The practice is followed till soil fertility drops. The area is then abandoned for a number of years and another site is cultivated similarly.

Selective breeding of crop plants and farm animals has a great impact on agricultural productivity. Advanced variants of crop plants have increased the nutritional value of the produce and also increased their resistance to diseases. While animals have been selectively bred to improve their yield of milk, meat and other products, recent developments in genetic engineering have opened up new vistas to explore the use of genetically modified crops in agriculture.

Agri-sulphur: See Agricultural sulphur

Agro-climatic zones

Crop yield is dependent on various factors such as weather, soil type, soil nutrient status, management practices and other available inputs. Weather plays an important role, more so in countries where drought, flood, cold, etc. occur in a very unpredictable way. In such countries, efficient and effective crop planning can be done only after proper understanding of agro-climatic conditions. The interpretation of long-term weather parameters of each region becomes important to identify and recognize the possible cropping period.

Agro-climatic zones are the land units developed in terms of major climates that are suitable to the range of crops grown in that particular region.

India, for instance, with about 329 million hectares of geographical area, presents a large number of complex agro-climatic situations.

Agroecosystem: See Agroecosystem research

Agroecosystem research

Ecosystem refers to a biological community of interacting organisms and their physical environment. It represents the totality of relationships among organisms and their ambient surrounding environment. All ecosystems are driven by solar energy fixed as organic carbon by green plants.

Agroecosystem refers to a model for working within an agricultural system with all its inputs and outputs.

Agroecosystem research encompasses a detailed examination of all elements of basic agricultural biology, in which economic production as one component of the biological response to the physical surroundings and to the inputs of materials and energy is made intelligible.

In short, agroecosystem research is concerned with the totality of the biology of an agricultural system. When production methods, brought to maturity through experiments, begin to move toward the limits of biological processes, agricultural systems become very important. During the transition, it becomes imperative to know which biological processes determine the yield and how they determine their limits. Whether or not the cycles involved in this phenomenon can sustain the high yield of intensive agricultural production (caused by chemicals) is determined by the chemistry of nutrient cycling.

Agroecosystem research uses methods of ecosystem analysis. They measure the entry of energy and material into the population of plants and animals, and explain how these inputs affect the physiological processes determining the growth and maintenance of these organisms.

The patterns of energy and material flow among plants, livestock and humans are simple, consistent and similar in most agricultural systems. Agroecosystems have relatively simple cycles.

Agroforestry

Agroforestry or **farm forestry** is the cultivation of forest trees on a farm, along with conventional crops, (such as herbaceous plants) which lead to economic gains. Agro-silviculture, agro-horticulture, agro-horti-silviculture and homestead agroforestry are examples of agroforestry systems.

Agroforestry methods have yet to be widely applied in tropical regions where scientific management techniques co-exist with traditional land use practices. At one level, shifting cultivation can be described as a form of agroforestry.

Increasingly, agroforestry involves the deliberate cultivation of woody plants (Fig.A.23) with particular qualities such as fast growth, economic value, fuel wood yield or nitrogen fixation.

Fig.A.23: Teak plantation on farm holdings, done for economic gain, is an example of agroforestry.

Agrometeorologists: See Agricultural meteorology

Agronomic efficiency

Agronomic efficiency refers to the amount of biological production from relevant parts of plants under field conditions or greenhouse conditions, per unit of nutrient absorbed. Agronomic efficiency is the best way to express **nutrient use efficiency**. (See also Nutrient efficiency.)

Agronomic nutrient efficiency

Agronomic or economic nutrient efficiency is the economic production per unit of the nutrient applied :

$$\begin{array}{l}\text{Agronomic}\\ \text{efficiency} = \\ \text{(kg/kg)}\end{array} \frac{\left[\begin{array}{c}\text{Grain yield of}\\ \text{fertilized crop in kg}\end{array}\right] - \left[\begin{array}{c}\text{Grain yield of}\\ \text{unfertilized crop in kg}\end{array}\right]}{\text{Quantity of fertilizer applied in kg}}$$

Agronomic response, effects of particle size on

The particle size of fertilizers influences its dissolution in soil solution and its utilization by the plant. Generally, fertilizers with a low water-solubility are ground to a small size to facilitate their rapid dissolution and better utilization. For example, a raw phosphate rock ground to a particle size of about 150 μm diameter is generally far more effective than a phosphate coarse particle.

Agronomy

Agronomy is a branch of agricultural science which deals with the theory and practice of field crop production as well as soil and water management. It is also concerned with the improvement and management of special purpose plants such as turf grass for lawns, recreational areas, highway embankments, drainage ditches and waterways.

Agronomy deals with the properties, uses and conservation of soils. The genesis, classification, morphology, physico-chemical and biological properties of the soil and its relationship with water are important in the consideration of soils.

The management of soils and water for efficient production of specific crops is of major interest in agronomy (Fig.A.24). An agronomic classification of plants specifies the utility of that crop, for example, grain crops, fodder crops, catch crops, etc.

Fig.A.24: Field crop cultivation, soil management and water management are major interests of agronomy.

Agropedic horizon

Agropedic horizon is another term for **anthropic horizon**, or the cultivated horizon.

Agro-service center

An agro-service center or a **farm service center** is a place where information is disseminated or services regarding farm inputs like seeds, fertilizers, pesticides and agricultural implements provided . Agro-service centers are generally operated by government bodies, agro industries, individual entrepreneurs, local bodies, manufacturers of fertilizers and equipments, etc.

Agrosil colloidal silicate

Agrosil colloidal silicate is a synthetic soil conditioner that consists of partially dehydrated sodium silicate precipitated with acids, electrolytes such as phosphates or sulphates and an organic additive. The purpose of these substances is to exert biotic, chemical or physical influences on the soil, its structure, as well as the water regime. Agrosil colloidal silicate is added to soil to improve the soil structure.

Agrostology

Agrostology is a branch of science that deals with the study of grasses, their classification, management and utilization.

Agrotain

Agrotain is the trade name of NBPT (N-n-butyl thiophosphoric triamide), which is a urease inhibitor. It is recommended for pre-planting surface application of urea and urea-containing fertilizers.

Ag soil

Ag soil is a soil type with two horizons stacked one above the other, such that the black A horizon is above the G horizon. The underlying G horizon is gleyified because of a high water table underneath.

A horizon

Horizontal layers of soil, with their own texture and color, are **soil horizons**. A horizon is one of the master soil horizons. It is the upper layer of the soil profile and generally is made up of organic matter, micro-organisms like bacteria, fungi, actinomycetes, etc., and is darkened as a result. (See also Soil horizons.)

AI

AI is short for **aridity index**.

Air-filled porosity

Air-filled porosity (Fa) is a measure of the fraction of the soil bulk volume filled by air (Fig.A.25) and represents the relative air content of the soil.

Fa is defined as:

$$Fa = \frac{Va}{Vt} = \frac{Va}{Vs + Va + Vw}$$

where Va is the volume of air, Vt is the total volume of soil core (comprising solid, air and water), vs. is the volume of solids, and Vw is the volume of water.

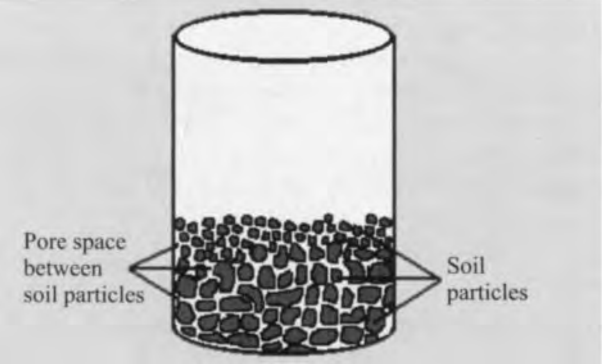


Fig.A.25: Pore spaces in soil are filled with air, when there is no water.

While reporting air-filled porosity, information on soil metric potential is relevant. Assuming that the pore space is wholly filled with water, the air-filled pore space at minus 6 kPa metric potential would be equal to the volume of macropores.

Air-filled porosity (Fa), as a percentage of the total volume, is calculated using the tension table procedure for any specific metric potential and the following equation:

$$Fa = \frac{(W_s - W_p)}{V_t \times 0.01}$$

where W_s is the weight of the saturated soil core, W_p is the weight of the core at specific potential and V_t is the volume of the core.

The difference method (based on the soil dry bulk density, D_b, and the soil water content) is also used to determine Fa of the core at any gravimetric water content that is calculated knowing the total porosity (S_t) from the equation:

$$S_t = 1 - (D_b/D_p)$$

where D_p is the density of the mineral soil 2.65 g/cm^3.

$$Fa = S_t - \text{Water content } (\%) \times D_b$$

Akiochi: See Akiochi soils

Akiochi soils

Akiochi, a Japanese term, describes a disease affecting rice plants wherein the crop does not attain maturity because of root damage caused by hydrogen sulphide toxicity, and/or deficiencies of (a) silicon and magnesium, (b) bases, and (c) nitrogen and potassium at later stages of plant growth.

Flooded soils contain hydrogen sulphide formed due to reduction of sulphate and anaerobic decomposition of organic matter, and are called Akiochi soils.

Albedo

Albedo, a term describing the reflecting properties of surfaces, is the ratio of the radiant flux reflected by a surface to the incident flux. White surfaces have albedos close to one and black surfaces have albedos close to zero. For the measurement of soil moisture, neutron probes containing radioactive materials (such as beryllium or radium) are used and they work on the principle of reflection by water molecules present in the soil. Photosynthesis depends on the absorbance and reflectance of solar energy by the foliage. Surfaces of snow, water and forest have different albedos.

Two types of albedos are common. The first type is the **bond albedo** which determines the energy balance of a planet and is defined as the fraction of total incident solar energy that the planet reflects back into the space. The other type, **normal albedo**, more properly called the **normal reflectance**, is a measure of the relative brightness of a surface when viewed and illuminated vertically.

For solar system objects, bond albedos range from 0.76 for cloud-shrouded Venus to as low as 0.01 to 0.02 for some asteroids and satellites. The value for earth is 0.33. The bond albedo value depends on the spectrum of the incident radiation.

Normal reflectance, which strongly depends on the wavelength, is referred to as a '**perfectly white Lambert surface**'- a surface that absorbs no light, and scatters the incident energy isotropically. Magnesium oxide, magnesium carbonate and some other bright powders approximate this condition.

In physics, albedo represents the probability of a neutron being reflected from the same surface.

Albic horizon

Albic horizon is a shallow mineral horizon from which clay and free iron oxides are removed, or in which iron oxides are so separated that the sand or silt particles become almost colorless.

A typical example of an albic horizon is the E horizon of podzol. It overlies a horizon of accumulation such as a spodic, argillic or natric horizon, or a fragipan, or an impermeable layer that can cause a temporary water table.

Albite

Albite is a white or bluish-white feldspar of the plagioclase feldspar group and it belongs to the triclinic system. It has a general formula Na ($AlSi_3O_8$). Albite occurs frequently as a late stage mineral associated with gem pocket, bearing lithium-rich pegmatites. The plate variety of albite is called **cleave landsite.**

Albite and **anorthite** are components in the complex plagioclase series. At high pressure, albite breaks down to jadeite ($NaAlSi_2O_6$) and quartz (SiO_2).

Albolls: See Mollisols

Albumins

Albumin is a type of **protein**. Proteins, based on solubility, are classified as albumins (water-soluble), **globulins** (water-insoluble but soluble in salt solutions), and **prolamines** (soluble in alcohol-water mixtures). Albumins can be coagulated by exposure to heat.

Aldoses

Monosaccharides containing an aldehyde group are called aldoses whereas those containing a ketone group are called **ketoses**.

Alfisols

Alfisol is one of the 12 orders categorizing world soils. It consists of leached residual soils with a clay-rich B horizon. These soils are slightly-to-moderately acidic. Alfisols have umbric or ochric epipedons as well as argillic horizons and hold water at < 1.5 MPa tension for at least 90 days when the soil is warm enough for plants to grow outdoors.

Alfisols develop in humid and sub-humid climates. They are distributed approximately equally across the tropical, temperate and boreal environments, and are often found under forest vegetation. They comprise 9.6% of the earth's ice-free land area. The high precipitation causes clay to move downward and form the clay accumulation horizon (Bt horizon) below. A good amount of available water facilitates plant growth during warm seasons in such soils.

Alfisols have a mean annual soil temperature of < 8°C or a base saturation in the lower part of the argillic horizon of 35% or more when measured at a pH of 8.2.

Alfisols are naturally productive soils that do not need irrigation or fertilizers. They develop under deciduous forests or savannah environments in mid-to-lower latitudes.

Alfisols can sustain traditional **slash and burn** subsistence agriculture and are moist enough to be intensively cultivable during the growing season. Relatively young soils contain weatherable primary minerals, clay minerals of 1:1 and 2:1 types and exchangeable bases. Red soils of Hyderabad and Bangalore in India are examples of alfisols.

The suborders of alfisols are aqualfs, boralfs, udalfs, ustalfs and xeralfs.

Algae

Algae are the simplest of green plants and their study is termed **algology** or **phycology**. The population of algae varies from a few hundred to several millions per gram of soil. The main groups of algae are green algae, **blue-green algae**, yellow-green algae and diatoms. Algae form the first step in the colonization of land by plants, adding organic material and vital trace elements necessary for the growth of higher plants.

Algae are predominantly aquatic photosynthetic organisms (Fig.A.26), which transform light energy into energy-rich organic compounds. In soil, algae do not receive light but get their energy by oxidation of other materials.

Fig.A.26: Picture of a water body almost totally covered with algal growth (except as shown by the arrow).

Formerly regarded as plants, algae are now classified as members of the **kingdom Protista**. Algae are a heterogeneous group of cryptogamic plants comprising thirteen large phyla and several smaller groups, which are yet to be studied fully.

Algae are unicellular or multicellular (filamentous, ribbon-like or plate-like). The most familiar types are slimy, fibrous masses that grow in stagnant water. They tolerate a wide range of moisture conditions.

Some algae grow symbiotically with fungi, and are called lichens. **Lichens** are crucial to the early accumulation of organic matter on exposed rocks and parent materials forming the soil. Some blue-green algae fix atmospheric nitrogen and maintain nitrogen levels in soils used for paddy production.

Substances like copper sulphate are toxic to algae and serve as **algicide**. Organisms living on algae are called **algicolous**. Green algae, added to water cultures, seem to improve the growth of tobacco roots and their immunity to fungal infections.

Though algae have their own distinct morphological, cytological and reproductive properties, the basic biochemical mechanisms are very similar to other plants; all possess chlorophyll and carry out photosynthesis. Their nutrient requirements, carbohydrates, proteins and end product assimilation process are very similar to those of higher plants.

The temporary rapid growth of algae in fresh water is known as **algal boom**.

Algal boom: See Algae

Algicide: See Algae

Algicolous : See Algae

Alginates

Alginates are a type of commercially exploited seaweed hydrocolloids, the other two being agars and **carrageenans**, which are also important hydrophilic colloids.

Alginates are considered anionic polymers of mannuronic and guluronic acids and contain carboxyl groups (in contrast with agars and carageenans which mainly have sulphate groups). Thus, alginates are similar to pectin in terrestrial plants.

Algology : See Algae

Alkali

An alkali is a soluble hydroxide of a metal, particularly of one of alkali metals. The term is also applied to any substance which has an alkaline reaction. With a pH above 7, it turns red litmus blue. The alkali industry produces sodium hydroxide, sodium carbonate, salt cake, sodium bicarbonate and corresponding potassium compounds. The measurement of the concentration of alkali present is determined by titration with a standard acid using an indicator.

Alkali feldspars

Alkali feldspars are one of the two groups of **feldspars**, which include microcline, orthoclase and sanidine. In alkali feldspars, potassium is dominant with a smaller proportion of sodium and negligible calcium. The other group of alkali feldspars is **plagioclase feldspars**.

Alkaline soil

A soil with pH greater than 7.0 is called alkaline soil.

Alkali soil

Soils having an exchangeable sodium percentage (ESP) higher than 15, electrical conductivity higher than 4 dS/m and pH usually above 8.5 are called alkali soils. They are also called **sodic soils** or ***kallar*** or ***usar*** **soils**. The toxicity, nutrient deficiency and high alkalinity of the soil (pH above 9) directly injure some plants. The high alkalinity immobilizes calcium which precipitates with atmospheric carbon dioxide to calcium carbonate. It causes toxicity of boron and deficiencies of zinc, iron and, to a lesser extent of, manganese and copper. It also affects adversely the **sorption behavior** of these elements in the soil. An excess of boron or bicarbonate in irrigation water and exposure of alkaline calcareous subsoil, when land is levelled for irrigation, worsens the situation. Indeed, most plants actually grow better or have fewer problems if the soil is moderately acidic.

Alkali soils are treated with gypsum, or with acid-forming materials like iron pyrites which release calcium from the native calcite of the soil. This is followed by leaching with good quality water. This treatment serves to replace and remove the soil exchangeable sodium beyond the root zone, thus reducing soil pH, ESP and making micronutrients more soluble for better plant absorption.

Alkalization

Alkalization is the process by which exchangeable sodium content of the soil is increased. It results in soil compaction, through collapse of soil structure. There is also an increase in the soil pH above 8.5.

Alkaloids

Alkaloids are basic nitrogenous organic compounds of vegetable origin containing at least one nitrogen atom in a ring structure in the molecule. Usually these are derived from nitrogen ring compounds such as pyridine, quinoline and pyrrole. Though some are liquids (they are usually colorless), crystalline solids with a bitter taste, combine with acids without water elimination. They are soluble in alcohols and insoluble in water. Some examples are atropine, morphine, nicotine, caffeine, cocaine and strychnine.

Allantoin nitrogen

Allantoin is one of the components of ureides formula $C_4H_6N_4O_3$. The enzyme allantoinase present in legume nodules converts allantoin to allantoic acid. Many tropical legumes (soybean, for instance) transport from their nodules, a large amount of their fixed atmospheric nitrogen in the form of ureides, allantoin and allantoic acid.

Allelochemical effects, reduction of: See Allelopathy

Allelopathy

Allelopathy is the chemical inhibition of one plant (or organism) by another, caused by the release of substances that inhibit growth or germination. The effect manifests itself as a partial or complete inhibition of growth, or of seed germination. The donor plant releases toxic biochemical compounds to the soil, water or atmosphere, which are absorbed by the receptor plants. It occurs widely in natural plant communities and is one mechanism that causes soil degradation. Allelopathy is virtually a chemical warfare between plants. Black walnut, for instance, inhibits plant growth around its base.

Allelopathy is generally related to problems of crop production (a) on certain types of soil, (b) in stubble mulch farming, (c) with some crop rotations, (d) with crop monoculture, and (e) with forest site replanting.

Some effective allelopathic chemicals are simple phenolic acids, coumarins, terpenoids, flavonoids, alkaloids, cyanogenic glycosides and glucosinolates. Secondary compounds implicated in biochemical interactions among plants are also involved in several protective and defensive functions for the plant.

Chemicals are released into the environment by (a) oxidation of volatile chemicals from parts of the living plant, (b) leaching of water-soluble toxins from the above ground plant parts in response to rain, fog or dew, (c) exudation of water-soluble toxins from the below ground plant parts, (d) release of toxins from parts of non-living plants through leaching of toxins from the litter of sloughed root cells, or (e) microbial by-products resulting from litter decomposition. To have lasting effects on other plants, these chemicals must accumulate sufficiently in the immediate environment, or persist for some time, or be continuously released.

Allelochemicals are released as a gas or liquid from the plant roots, leaves, stems or fruits. The inhibition of one species by another is **direct allelopathy**. **Indirect allelopathy** is the inhibition of intermediate organisms (often a bacterium, alga or fungus) on which the inhibited plant depends for nutrients or water. **Auto allelopathy** is the inhibition of a species by self produced toxins.

Allelochemical effects can be reduced by adopting appropriate crop rotations, improving the organic matter of the soil, leaving cropped areas fallow for a period of time to allow decomposition of allelochemicals, and planting resistant cultivars or plant species.

Companion plants, which produce organic matter, or inoculation with micro-organisms that readily metabolize toxins, may be useful in perennial crop ecosystems.

Allelopathy is different from competition; the latter involves removal or reduction of vital factors like nutrient, moisture, light, space, etc. from the environment by competing species.

Alley cropping

Alley cropping refers to a farming system in which arable crops are grown in alleys, that is, in spaces between two crops of leguminous shrubs or trees. Alley cropping hastens restoration of soil fertility and enhances productivity.

Allocative efficiency: See Efficiency

Allochthonous limestone

Allochthonous limestone is one of the two sources of limestone, the other being **autochthonous limestone**. The mechanical disintegration, transportation and re-deposition of limestone from naturally existing limestone sites to a new location create allochthonous limestone, the change being usually brought about by water. This action forms clastic deposits.

Allogamy

Allogamy is a type of fertilization in plants. It involves transfer of pollens from the anther of a flower of one plant to the stigma of a flower of another plant. It is also called **cross-fertilization** or **cross-pollination**.

Allophane

Allophane is a general term for amorphous, *aluminosilicate* gels of a wide range of composition, commonly found in volcanic soils. They have a very high phosphorus retention capacity. Most clay minerals have a layer-lattice structure, but a small group of allophanes form hollow spherical crystals.

Allophane and imogolite are most commonly found in relatively young soils (< 10,000 years) formed on volcanic ash and pumice. Allophane exists as a hollow, nearly spherical particle with a diameter of 3.5 to 5 nm. An allophane with a silica to aluminum ratio of 0.5 and having a chemical formula of

$$2H_2O,\ 4OH\ 3Al^{vi}\ 2O,\ 4OH\ (2Si,\ Al)^{iv}\ 3O,\ 2OH,\ H_2O$$

contains most of its aluminum in a six fold coordination and has charge properties very similar to those of imogolite, bearing very little permanent negative charge (due to isomorphous substitution), but a variable positive and negative charge due to the proton association or dissociation at the surface hydroxyl (OH) groups. At the other extreme, an allophane with a Si:Al ratio of 1 and having a chemical formula of

$$H_2O,\ 2OH\ Al^{vi}O,\ 2OH\ H_2O\ (2Si,\ Al)^{iv}\ 3O,\ 2OH,\ H_2O$$

contains half of its aluminum in the tetrahedral sheet and half in the octahedral sheet. Although a large layer charge arises because of the substitution of aluminum for silicon, it is neutralized to a variable extent, depending on the ambient pH, by the association of protons at the surface OH groups. Thus, allophanes and imogolite have pH dependent surface charges at pH > 4.5.

Alluvial soil

Soils that are created by the action of water streams or rivers in the recent past are called alluvial soils. Usually they show no horizon development. Some of the world's most fertile soils are alluvial soils. Deficiencies of nitrogen, phosphorus and zinc are common in these soils.

Alluvium

Streams and rivers deposit sediments of various particle sizes ranging in size from small stones to big boulders. Such deposition by the action of water is called alluvium.

Some of the world's most fertile soils are derived from alluvium, and those developed in the recent past are **alluvial soils** (Fig.A.27). In Scotland, the alluvial riverside plain is called **carse** and a riverside meadow or flat land in a river valley is called **haugh**.

Alpha alumina

Alpha alumina (α-alumina) is one of two forms of white or colorless oxides of alumina. It is a stable form of aluminum oxide and is used as a catalyst or catalyst carrier. The other form is γ-alumina. (See also Alumina.)

Alpha particle

An alpha (α) particle is an elementary particle consisting of two protons and two neutrons firmly bound together. The specific energy of back scattered α-particles is used to analyze mineral compositions or geological formations.

An α-particle is identical to the nucleus of helium (${}_2^4He$) and is either ejected by the same radioactive nuclides or arises as a product of some nuclear exchange reactions, such as (n, α) or (p, α) reactions, or by double ionization of accelerated helium atoms in an accelerator, where n and p stand for neutron and proton, respectively.

Each α-particle has a mass of 6.644×10^{-27} kg, that is, 4.00273 a.m.u., and an electric charge of +2. The particle is highly stable and its binding energy equals 28.11 mev; its spin and magnetic moments are zero. The current of an α-particle emitted from nuclei of ${}^{235}U$, ${}^{226}Ra$, ${}^{232}Th$, ${}^{222}Rn$, ${}^{210}Po$, etc. is called **alpha radiation**.

The range of α-particles emitted depends on its energy and the absorbing medium. Owing to strong ionization and excitation effects, an α-particle loses its energy very rapidly. In air, the proportionality of the range (R) of an α-particle is represented by

$$R = av^3$$

where a is the constant ($= 9.7 \times 10^{-26}\ m^{-2}\ s^{+3}$) and v is the velocity; R is thus about 3 to 9 cm. As the stopping power of the medium correlates with the square root of its atomic mass, the range (which is in a few tens of mm for liquids and solids) of an α-particle can also be calculated for other substances. Thus, α-radiation is normally not hazardous to humans unless ingested directly into the body.

The high energy α-particles also interact with the nuclei of an absorbing medium by Rutherford elastic scattering from atomic nuclei or by an exchange of nuclear reaction. Alternatively, the energy can be converted into Bremsstrahlung. However, the probability of such processes occurring rapidly decreases with the decreasing energy of the particles.

Alpha radiation

A current of α-particles emitted from nuclei of ${}^{235}U$, ${}^{226}Ra$, ${}^{232}Th$, ${}^{222}Rn$, ${}^{210}Po$, etc. is called alpha radiation.

Altered peat

A peat where organic matter is decomposed beyond recognition is called altered peat.

Alternate farming

A crop rotation system that includes a ley is known as alternate farming or **ley farming**.

Fig.A.27: Alluvial soil, which is the most fertile soil, is largely deposited along river banks due to floods or the flow of water.

Alternate furrow irrigation

Alternate furrow irrigation involves irrigating alternate furrows in a field. This method is ideal in areas of acute water scarcity where production of normal yields is a must. Alternate furrow irrigation allows more rapid coverage of the field during an irrigation period and requires less labor. It also leaves the soil dry enough to absorb water during the rains, and reduces run-off and erosion. The time interval between the two sessions of irrigation must, however, be short.

Alternate host

An alternate host, also known as the **secondary host**, is the host plant of a pathogen (usually a fungus). It is called so because the pathogen completes a part of its life cycle on this host. For example, species of *Berberis* and *Mahonia* plants serve as alternate hosts for *Puccinia graminis tritici,* the fungal pathogen, causing the black stem rust disease of wheat.

Alternative agriculture

Generally farming involves use of chemical fertilizers, pesticides, etc. with a view to obtaining a higher yield. Alternative agriculture or alternative farming mainly relies on the use of organic manures, biological agents, recycled waste material, etc., bypassing the use of chemicals and fertilizers. A common example of alternative agriculture or alternative farming is **organic farming**.

Alum

Alum is a double sulphate of a monovalent and trivalent salt. It is represented as:

$$K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$$

or

$$(NH_4)_2 \cdot SO_4 \cdot Al_2(SO_4)_3 \cdot 12H_2O$$

Alum acts as a flocculating agent. It is used in sewage treatment and in purification of drinking water. Alum is also used in the preparation of mordant and as a fireproofing agent.

Aluminum sulphate is sometimes erroneously called alum in some industries (such as in the paper industry).

Alumina

Alumina is a white or colorless oxide occurring in two forms, α-alumina and γ-alumina. The γ-alumina turns into a stable α form on heating. Naturally occurring alumina is called **corundum** or **emery**.

The gemstones ruby and sapphire are aluminum oxides colored by minute traces of chromium and cobalt, respectively. The highly protective film of oxide formed on the surface of aluminum is yet another structural variation, a defective form of rock salt.

Pure aluminum oxide is obtained by dissolving bauxite ore in sodium hydroxide solution to eliminate insoluble impurities. Seeding the solution with material from a previous batch precipitates the hydrated oxide, which on further heating gives γ-alumina at 500 to 800°C and pure α-alumina at 1150 to 1200°C. The latter is one of the hardest materials known. It is used widely as an abrasive substance in both its natural and synthetic forms. Its refractory nature makes alumina bricks an ideal material for furnace linings and high temperature cements.

Alumina occurs in phosphate rocks along with iron and other impurities in small percentages. Alumina and iron in phosphate rock make the superphosphate moist and sticky. The maximum acceptable alumina and iron in the rock for farming is 3 to 4%.

Aluminum

Aluminum, the third most abundant element in the earth's crust, is a silvery-white lustrous metal belonging to Group 13 of the Periodic Table (Fig.A.28). The metal is highly reactive and is protected by a thick transparent oxide layer that gets formed quickly in air. Aluminum and its oxides are amphoteric.

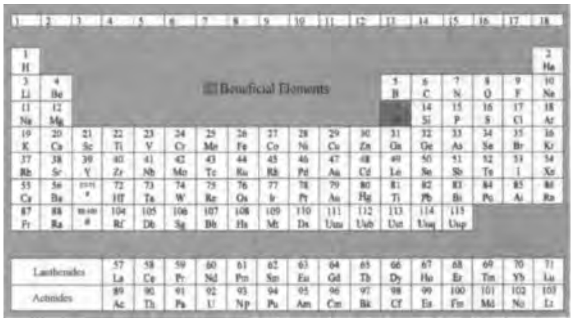


Fig.A.28: Position of aluminum, a beneficial element, in the Periodic Table.

Pure aluminum, which exists in a large number of alloys, is extracted from purified bauxite by electrolysis. Its lightness, strength (when alloyed), corrosion resistance and electrical conductivity make aluminum suitable for a variety of uses, including in the construction of vehicles, aircrafts, buildings and overhead power cables.

Aluminum (Al) is an important soil constituent. It is toxic to most plants at a soil pH below 6.0.

Aluminum ion forms octahedral coordination with water molecules and hydroxyl ions. If soil is not strongly acidic, one (or more) of the water molecules ionizes, releasing the hydrogen ion (H^+) into the solution and increasing the soil acidity.

The toxic level of soluble and exchangeable aluminum can be substantially reduced by first raising the soil pH in the range of 5.2 to 5.5 and by further liming to make it in the range of 6.0 to 6.5.

In acidic soils, aluminum may compete for uptake with copper and make the soil copper deficient. Molybdenum is adsorbed strongly by oxides of aluminum and iron, thereby making the molybdenum unavailable to plants. Increasing aluminum in the soil solution also restricts the uptake of calcium and magnesium by plants.

Aluminum ions are toxic to the roots of many plants such as cotton, tomato, alfalfa, celery, barley, corn, sorghum, and sugar beets. Aluminum toxicity is probably the most important growth limiting factor in many acid soils.

The symptoms of aluminum toxicity caused by excess soluble aluminum are not easily recognize in crop plants. White-yellow interveinal blotches form on leaves causing them to dry out and die. Aluminum toxicity also reduces the growth of both shoots and roots.

An excess of aluminum interferes with cell division in plant roots, inhibits nodule initiation (by fixing the soil phosphorus to forms that are less available to plant roots), and decreases root respiration. Aluminum interferes with enzymes controlling the deposition of polysaccharides in cell walls and increases cell wall rigidity by cross-linking with pectins. It reduces the uptake, transport, and use of nutrients and water by the plant.

Aluminum-injured roots are characteristically stubby and brittle. The root tips and lateral roots thicken and turn brown. The root system as a whole, appears coralline, with many stubby lateral roots but no fine branching.

The toxicity problem of aluminum is not economically correctable with conventional liming practices. A genetic approach has the potential to solve the problem of aluminum toxicity in acid soils.

Aluminum sulphate

Aluminum sulphate is a white or colorless crystalline compound. The hydrated variety of aluminum sulphate has 18 water molecules, $[Al_2(SO_4)_3 \cdot 18H_2O]$ and occurs naturally as a rare mineral **alunogenite**. Aluminum sulphate, which is prepared by dissolving aluminum hydroxide or china clay (alumino silicates) in sulphuric acid, decomposes on heating to sulphur dioxide, sulphur trioxide and aluminum oxides. The aluminum ions present in aluminum sulphate hydrolyze in water and produce hydrogen ions. Hence, the solution becomes acidic. Anhydrous aluminum sulphate, like its hydrated form, is soluble in water but insoluble in ethanol.

Aluminum sulphate acts as a flocculating agent and is very important in sewage treatment and purification of drinking water. It is also used in the preparation of mordants and as a fireproofing agent. In the paper industry, it is sometimes erroneously called **alum** which is a double sulphate of a monovalent and trivalent salt described as:

$$K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$$

or

$$(NH_4)_2 \cdot SO_4 \cdot Al_2(SO_4)_3 \cdot 12H_2O$$

When applied to soils, aluminum sulphate dissolves and decomposes to sulphuric acid. It is used to acidify neutral or alkaline soils.

Aluminum sulphate is popular with floriculturists in the production of azaleas, carnations and other acid tolerant ornamental plants.

Plants can develop aluminum toxicity, when aluminum sulphate is used indiscriminately.

Alunogenite

Alunogenite is a naturally occurring form of hydrated aluminum sulphate $Al_2(SO_4)_3 \cdot 18H_2O$.

AM

AM is a substituted pyrimidine (2-amino-4-chloro-6-methyl pyridine) that acts as a nitrification inhibitor. It controls nitrogen loss by inhibiting the nitrification process in soil and helps the effective utilization of fertilizer nitrogen. This action by AM inhibits the growth of *Nitrosomonas* and retards conversion of NH_4^+ to No_3 for several months. Another effective compound used for the same purpose is **N-serve** [2-chloro-6 (trichloromethyl) pyridine], also known as **nitrapyrin**.

AM, as an inhibitor, loses its activity because of volatilization, leaching and also warm temperatures. (See also Nitrification inhibitors.)

Amargosite

Amargosite is another name for **bentonite**. It is a soft, porous, light-colored rock consisting largely of colloidal silica. It is composed chiefly of clay minerals of the montmorillonite group which swell extensively when wet.

Ameliorant

Ameliorant is a substance added to soil to improve its physical and/or chemical properties, thereby increasing crop yield. For example, the addition of lime to acidic soils or the addition of gypsum to sodic soils improves crop yields. The process of addition of ameliorants to the soil is **amelioration**. Amelioration by tillage, liming, manuring, etc. increases land value.

Amelioration: See Ameliorant

Amendment

Amendment is a material added to reclaim abnormal soils like acidic or saline-sodic soils. It involves a part (or most) of the exchangeable sodium in saline-sodic soils (which is harmful to plants and which disperses clay particles) being replaced by more fovorable calcium ions in the root zone. The addition of lime to acidic soils for crop production is an example of an amendment. Thus, amendment is a substance added to the soil to improve its physical and chemical properties for better farming.

Amensalism

Some organisms produce a substance which is inhibitory to other organisms. The inhibitory effect of such a substance is called amensalism (similar to allelopathy.) For example, the fungus *Penicillium* inhibits bacteria.

American gallon

American gallon, used in the United States, is a unit of volume for measuring liquids. It is equivalent to 3.79 liters.

American Munsell color chart

American Munsell color chart is a color scheme used for the accurate determination of soil color. Because soil color differs with moisture levels, most color examinations are carried out on moist samples to provide some basis of uniformity. Soil colors are determined accurately and very easily by comparing them with the American Munsell color chart scheme.

Amide fertilizer

Ammonia, produced by the reaction of nitrogen and hydrogen in the presence of a catalyst, is the starting material for making nitrogenous fertilizers. These fertilizers are grouped into 4 categories, depending on the chemical form of nitrogen, namely ammoniacal fertilizers, nitrate fertilizers, combined ammoniacal and nitrate fertilizers and amide fertilizers. Thus, an amide fertilizer contains nitrogen in the amide form (mainly carbon compounds.) It is water-soluble and easily decomposed by soil micro-organisms. The nitrogen in an amide fertilizer gets serially converted into ammoniacal nitrogen and nitrate.

$$3H_2 + N_2 \xrightleftharpoons{\text{Catalyst}} \underset{\text{(Ammonia)}}{2NH_3}$$

$$2NH_3 + CO_2 \longrightarrow NH_2COONH_4$$

$$NH_2COONH_4 \longrightarrow \underset{\text{(Urea)}}{NH_2CONH_2} + H_2O$$

$$CaC_2 + N_2 \longrightarrow \underset{\text{(Calcium cyanamide)}}{CaCN_2 + C}$$

Urea, $CO(NH_2)_2$ (also called **carbamide**) and calcium cyanamide fall in the category of amide fertilizers. Urea contains 46% nitrogen and is the cheapest and most popular fertilizer for meeting the nitrogen requirement of crop plants. It is hygroscopic in its crystalline form and is difficult to handle. But it stores and spreads well in the form of granules and prills. Urease, an enzyme, converts urea into ammonium carbonate which releases ammonia. When the release of ammonia occurs on (or near) the soil surface, ammonia is lost to the air. If the release occurs near the seeds, the seeds may fail to germinate. Roots may get affected by the toxicity of ammonia. Crops can be affected by a high concentration of ammonia.

Calcium cyanamide, $CaCN_2$, (21 to 22% nitrogen) contains lime and does not make the soil acidic. When cyanamide decomposes in the soil, it forms ammoniacal nitrogen at a slow rate. The other intermediate products during cyanamide decomposition cause plant toxicity. Hence, calcium cyanamide, which is an expensive source of nitrogen, has to be applied 2 to 3 weeks before sowing.

Amides

Amides are organic nitrogenous compounds containing the $-CONH_2$ group. They are obtained by replacing the $-COOH$ group of acids by $-CONH_2$. For instance, formic acid ($HCOOH$) becomes formamide or methanamide ($HCONH_2$) while acetic acid (CH_3COOH) becomes acetamide or ethanamide (CH_3CONH_2.) The suffix 'ic' in the name of the acid is replaced by the suffix 'amide' or by 'e' of the parent alkane.

On heating, ammonium salt makes amides of the corresponding carboxylic acid. Urea is the diamide of carbonic acid and is an important source of fertilizer nitrogen.

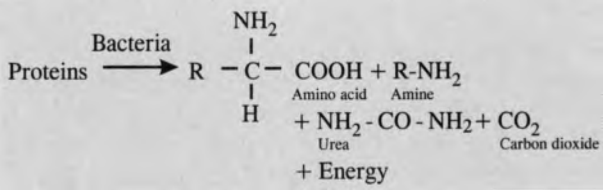
Inorganic compounds containing NH_2^- ions, as for example, in KNH_2 and $Cd(NH_2)_2$, are also known as amides that are formed by the reaction of ammonia with electro-positive metals, such as sodium or potassium.

$$2Na + 2NH_3 \longrightarrow 2NaNH_2 + H_2 \uparrow$$

Aminization

The process by which heterotrophs (including bacteria, fungi, and actinomycetes) hydrolyze complex soil organic molecules to release amines and amino acids is known as aminization. Bacteria and actinomycetes often dominate in neutral and alkaline conditions, while fungi are more active under acid conditions.

Most of the nitrogen undergoing aminization during the growing season of a plant originates from degradation of proteins and amino acids. This happens in decomposing crop residues and microbial cells, with lesser amounts originating from the decomposition of more resistant sources like lignoproteins and humates. The end-products of the activities of one group furnish the substrate for the next until the material is decomposed.

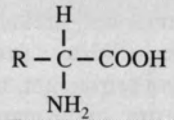


$$\text{Proteins} \xrightarrow{\text{Bacteria}} \underset{\text{Amino acid}}{R-\overset{\displaystyle NH_2}{\underset{\displaystyle H}{C}}-COOH} + \underset{\text{Amine}}{R\text{-}NH_2} + \underset{\text{Urea}}{NH_2\text{-}CO\text{-}NH_2} + \underset{\text{Carbon dioxide}}{CO_2} + \text{Energy}$$

Amino acids

Proteins, which constitute around 50% of the dry weight of living matter, are essential constituents of all living cells. These are polymers composed of simple monomers called α-amino acids, linked by peptide linkages.

Amino acid is a carboxylic acid with an amino group $-NH_2$; α-amino acid has the amino group on the α-carbon atom, which is the carbon atom next to the carboxyl group. The general formula of amino acids is



$$R-\overset{\displaystyle H}{\underset{\displaystyle NH_2}{C}}-COOH$$

where R is an alkyl or aryl group.

Autotrophic organisms, principally green plants, synthesize amino acids. The simplest naturally occurring amino acid is glycine (H_2NCH_2COOH). About 20 commonly occurring amino acids have been identified as building blocks of most plant and animal proteins.

Amino acids are linked by peptide bonds formed between the carboxyl group of the first amino acid and the amino group of the second amino acid. Many such amino acid molecules join together to form peptide linkages and hence the polypeptide. The sequence of these amino acids in the polypeptide determines the shape and structure of proteins and their properties and biological role.

Amino urea

Amino urea is another name for **guanidine**. It is an analogue of urea and is made by reacting urea with ammonia under pressure or by heating calcium cyanamide with ammonium iodide.

Ammonia

Anhydrous ammonia is the basic building block of almost all nitrogen fertilizer materials. Most of the world's ammonia is produced synthetically by a direct reaction of the elements by the **Haber-Bosch process**. The process involves an exothermic and reversible reaction that proceeds with a concurrent decrease in volume.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

There are certain conditions for the above reaction to proceed optimally. These are: (a) temperature of 500°C, (b) pressure of 270 to 350 atmospheres, (c) a catalyst containing finely divided iron with molybdenum or calcium as a promoter, finely divided osmium or uranium, finely divided nickel over pumice stone or ferric oxide with traces of silica and potassium oxide, and (d) pure gases (as otherwise the catalyst gets poisoned).

Free ammonia is extremely toxic to micro-organisms, animals and higher plants. Ammonia produced as a part of normal metabolism is immediately converted into a less harmful substance like urea and is excreted in urine. Ammonia can readily penetrate cell membranes whereas the ammonium ion is impermeable. There is a close relationship between the pH and the concentration of the free ammonium (NH_4^+) ion. The capacity of soil to retain ammonia increases with increasing soil moisture and clay content.

Ammonia is the least expensive and most widely used nitrogen fertilizer. It is used in the manufacture of other fertilizers like urea, ammonium sulphate and ammonium chloride.

Ammonia is also used in the manufacture of nitric acid, hydrazine hydrate, urethane, acrylonitrile and sodium carbonate (**Solvay process**). In addition, ammonia is used as a refrigerant, in nitriding of steels, in the petroleum industry, in the manufacture of explosives and rocket fuel, as a yeast nutrient, etc.

Anhydrous ammonia, which has great affinity for water, contains approximately 82% nitrogen. This is the highest nitrogen content that any nitrogen fertilizer can have. As anhydrous ammonia is a gas at atmospheric pressure, to avoid its loss to the atmosphere during application, ammonia is injected at least 7 to 20 cm below the soil.

The simplest nitrogen solution is aqua ammonia which contains 25 to 29% ammonia by weight. Since ammonia volatilizes above 10°C, aqua ammonia is injected into the soil to a depth of 5 to 10 cm.

Ammonia, anhydrous: See Anhydrous ammonia

Ammoniacal fertilizer

An ammoniacal fertilizer contains nitrogen in its ammoniacal (NH_4^+) form. Chemical (or synthetic) fertilizers are the most important sources of nitrogen. Anhydrous ammonia, for instance, is the building block for most chemically derived nitrogen fertilizer materials.

For convenience, nitrogen compounds are grouped into three categories, namely the ammoniacal, the nitrate and the slow release fertilizers. This classification is based on their availability to plants.

The major ammoniacal nitrogen fertilizers are urea, aqua ammonia, anhydrous ammonia, ammonium nitrate, ammonium chloride, etc.

Table-A.2 shows the composition of some common ammoniacal nitrogen fertilizers.

Table-A.2: Composition of some common ammoniacal nitrogen fertilizers

Fertilizer	%N	%P_2O_5	%S
Anhydrous Ammonia	82	-	-
Aqua ammonia	20–24	-	-
Ammonium nitrate	33–34	-	-
Ammonium sulphate	21	-	24
Ammonium nitrate sulphate	30	-	5–7
Urea	45–46	-	-
Urea sulphate	30–40	-	6–11
Urea sulphur	30–40	-	10–20
Urea ammonium nitrate solution	28–32	-	-

Ammonia liquor

Ammonia liquor is another name for **aqua ammonia** or **ammonia solution**. It is made by absorbing ammonia in water, and its commercial grades generally contain about 80% ammonia.

Ammonia oxidation

When heated electrically to around 750 to 900°C in the presence of a platinum or platinum rhodium gauze catalyst, ammonia gets oxidized by atmospheric air.

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$$

This reaction is exothermic and the heat generated maintains the catalyst temperature. The nitric oxide (NO) formed is further oxidized to nitrogen dioxide (NO_2) by atmospheric air, and the cooled gas (50°C) is absorbed in water in the presence of air to give nitric acid.

$$2NO + O_2 \longrightarrow 2NO_2 \xrightarrow[O]{H_2O} 2HNO_3$$

The efficiency of ammonia conversion, expressed as the percentage of ammonia converted into nitric oxide, depends strictly on the catalyst activity, selected temperature, pressure, mixing efficiency of the incoming air with ammonia, and the velocity of the gas flowing through the catalyst. Among the non-platinum catalysts are the oxides of cobalt, iron or chromium.

Nitric acid made as above is of 98% purity and has a specific gravity of 1.50.

Owing to the absorption of ammonia, the ammonium ion produced in the soil is oxidized to nitrite by the bacterium *Nitrosomonas* and then to nitrate by *Nitrobacter*. This oxidation by micro-organisms is called **nitrification**. The process is rapid unless the soil is strongly acidic, cold or wet.

Ammonia production by coal gasification: See Ammonia production processes

Ammonia production, other process techniques for: See Ammonia production processes

Ammonia production processes

Synthetic ammonia is the principal source of all nitrogen fertilizers. Almost all commercial fertilizer nitrogen is supplied by or is derived from ammonia.

Ammonia is either directly applied to the soil or is applied as an aqueous solution with other nitrogenous fertilizers like ammonium nitrate or urea.

The process of synthesizing ammonia was developed by Fritz Haber in collaboration with Carl Bosch, and has come to be known as the **Haber-Bosch process**. It is based on the catalytic reaction of hydrogen with nitrogen at a high temperature and pressure.

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

Nitrogen is taken from the air. Hydrogen is derived either directly or as a by-product. The raw materials required for hydrogen manufacture are water, natural gas, fuel oil or petroleum fractions, coal and coke oven gas.

More than 60% of the hydrogen is derived from methane or natural gas, fuel oil or petroleum fractions by steam reforming and partial oxidation. Coal gasification was a source of hydrogen until World War II.

In the commercial production of ammonia, the selection of feed stock is the most important factor in determining the capital investment and production costs.

The availability and cost of raw materials are also among factors to be taken into account while deciding on the construction of a new plant for the production of hydrogen (Table-A.3.)

Table-A.3: Feedstock versus process/technique for hydrogen products.

Feedstock	Process/technique to produce H_2
Water	Electrolysis
Natural gas/ Associated gas	Partial oxidation/steam reforming
Naphtha	Steam reforming/partial oxidation
Fuel oil / LSHS (Low Sulphur Heavy Stock)	Partial oxidation
Coal	Partial oxidation
Coke oven gas	Reforming /partial oxidation / low temperature separation

The major feedstock in the production of hydrogen includes water, natural gas, naphtha and heavy residual coke gas or coal. The major steps include electrolysis, partial oxidation or gasification, desulphurization, primary reforming, secondary reforming, shifts in high and low temperature, carbon monoxide and carbon dioxide removal, methanation, compression and ammonia synthesis. The various methods of getting pure hydrogen for ammonia synthesis are briefly discussed below:

(i) **Electrolysis**: Hydrogen is obtained from water by alkaline or acid electrolysis. Several ammonia plants have been built to produce ammonia from hydrogen derived from the electrolysis of water. These plants are located where power is available at a low cost, such as Norway, Egypt, Zimbabwe, Peru, Iceland and Canada.

Purified water mixed with potassium hydroxide (added to increase the conductivity) is electrolyzed in electrolytic cells. These cells in an alkaline medium vary in their efficiency in producing hydrogen. But the power consumed is around 4.3 kWh/m^3 of hydrogen. The process generates one volume of oxygen per two volumes of hydrogen or about 0.7 ton of oxygen per ton of ammonia produced. The other byproduct is heavy water, as pure water contains 0.0135% heavy water (D_2O). Heavy water is used in nuclear reactors.

The cost of producing ammonia by the electrolytic hydrogen process is not as dependent on the size of the plant, as it is on the cost of electricity. It is much simpler to produce ammonia by electrolytic hydrogen than by processes involving other feedstock.

$$H_2O \xrightarrow{\text{Electrolysis}} H_2 + \frac{1}{2}O_2$$

Hydrogen is also a byproduct of the electrolytic production of chlorine from caustic soda. Such feedstock is used by several small ammonia plants. The amount of hydrogen produced is too small to supply normal plants.

(ii) **Partial oxidation process**: Hydrogen is produced from hydrocarbons by partial oxidation at high temperatures. In this process, hydrocarbons that are heavier than naphtha can be used as feedstocks for ammonia production. Natural gas and naphtha can also be used. The plant cost for partial oxidation process is considerably higher than that for steam reforming. However, the partial oxidation process offers a wider choice of feedstock with greater tolerance for impurities. The feedstock requirement is typically about 0.76 tons of heavy oil per ton of ammonia.

Among the main partial oxidation processes are those named after **Texaco**, **Shell** and **Koppers-Totzek**. Partial oxidation is carried out at 1200 to 1500°C without a catalyst. The complex chemical reactions involved are represented by:

$$C_mH_nS_r + \frac{1}{2}mO_2 \xrightarrow[\text{1200 to 1500}^\circ\text{C}]{\text{Partial oxidation}} m\,CO + (n - 2r)\,H_2 + rH_2S$$

After the side reactions arising from hydrocracking, steam gasification, reforming and water gas shift, the typical composition of the resulting gas is 46% H_2, 47% CO and 4% CO_2 (on dry basis) with small amounts of H_2S and nitrogen. A considerable amount of soot (carbon) remains suspended in the gas.

The Koppers-Totzek process is also used for coal. The Shell and Texaco processes are similar. The Shell gasifier operates at 3.5 to 6 MPa pressure and the Texaco gasifier operates at up to 9 MPa pressure. The gasification pressure in partial oxidation processes has been gradually increased in the range of 60 to 90 atmospheres, which helps to save energy for compression. The problems that limit the operating pressure of the gasification process are (a) the loss of mechanical strength of the Fe/Cr oxide catalyst used for high temperature shift, at 6.0 MPa, and (b) the compression of oxygen required for gasification. Safety is a great concern because the reactivity of oxygen increases with pressure. A new catalyst, developed by BASF, uses Co/Mo sulphides which overcome the mechanical strength losses at high steam partial pressure.

There are more than 48 ammonia plants based on the Texaco partial oxidation technology. The raw gas is freed of the carbon formed during gasification, by scrubbing with water. The raw gases after desulphurization are sent to shift conversion, where carbon monoxide is converted into carbon dioxide and hydrogen through steam.

$$CO + H_2O \longrightarrow CO_2 + H_2$$

Ammonia production using air (instead of oxygen) for partial oxidation or gasification has been commercialized by Texaco. The air gasification concept can be applied to a complete range of feedstock materials from natural gas and refinery gas, through liquid hydrocarbons, to coal and coke. The excess nitrogen from ammonia synthesis gas is recovered by cryogenic condensation.

(iii) Coal gasification: Until World War II, coal-based ammonia production predominated the industry. Later, it gave way to other processes when cheap natural gas and steam-reforming processes became available. About 10% of the world's ammonia production is based on coal, coke or lignite. Coal gasification process for ammonia production can be classified according to the method of gasification used – fixed-bed (**Lurgi**), fluidized bed (**Winkler**) or entrained bed (Koppers-Totzek and Texaco.) The so-called 'fixed' bed is more accurately a 'moving' bed gasification. Coal lumps (5 to 30 mm) charged at the top descend against the upward gas stream. These get dried, pre-heated, carbonized and finally gasified by the oxygen and steam entering from the bottom. Coal ash is discharged at the bottom through a grate, as slag. This method requires less oxygen and less heat compared to other methods. Also, it avoids the grinding and drying of the coal. The Lurgi method operates at 3 MPa pressure.

The limitations of the fixed or moving bed gasification method are that (a) the coal has to be in the form of lumps (5 to 30 mm), (b) the coal has to be of a non-caking variety or must be heated to prevent caking, and (c) the by-product formed (tar, phenolic compounds, light oils, etc.) must be removed or disposed of. Incidentally, the fine coal particles formed during the preparation of the sized coal feed are burned in an auxiliary plant to generate steam.

In the fluidized bed gasification process (Winkler), coal is ground to a particle size 15 mm or less and introduced into the fluidized bed through feed screws. Steam and oxygen are injected near the bottom of the fluidized bed. The latter is isothermal (1000°C) in contrast to the gradual temperature increase of coal in the moving bed process. Hence, there is no tar or liquid product and the gas contains only hydrogen and carbon monoxide with less than 1% methane. Large amounts of gas are entrained in the gas stream. The process produces 6 to 12% carbon containing char, which is removed from the bottom. The two advantages of the Winkler gasifier are that it works with almost any grade of coal or lignite and is adaptable to high capacity units. However, the process produces ammonia at low pressures (1 to 3 atm), thus adding to costs. The final gas needs electrostatic precipitator for cleaning up.

Most of the present coal-based ammonia plants use the Koppers-Totzek process. This is essentially a partial oxidation process (like most coal gasification processes) and is adaptable to heavy oil, light hydrocarbons or natural gas. In this process, coal is dried and ground to pass through a 200 mesh sieve. The powdered coal is picked up by streams of oxygen and blown into the gasification chamber. Steam enters through annular openings around the burners. The gasification is complete in about one-tenth of a second at temperatures in the range of 1000 to 1200°C. Part of the ash produced is fused and removed from the bottom and another part is entrained in the gas. The gas contains about 56% CO, 31% H_2, 11% CO_2 and less than 0.1% CH_4. The ash is removed by wet scrubbing and electrostatic precipitation. The remainder of the ammonia synthesis gas preparation is similar to that under partial oxidation of fuel oil.

The disadvantages of the process are that it requires coal to be finely ground, and it involves operation at low pressures (1 to 3 atm) and high oxygen consumption.

The Texaco process differs from the Koppers-Totzek process in that the finely ground coal is slurried with water (35 to 40% water). The preheated slurry is fed along with oxygen into a gasifier that can operate at up to 80 atm and a temperature of around 1300°C. The fused ash, quenched with water, is removed from the bottom as a slurry. The hot gas is cooled and the soot and fly ash are removed by scrubbing. The sequence of the remaining steps of synthesis gas preparation is the shift conversion of carbon monoxide, and the removal of hydrogen sulphide and carbon dioxide by the wash of cold methanol and liquid nitrogen. The principal effluents from the process are coal slag, waste water, hydrogen sulphide, carbon dioxide, a mixture of carbon monoxide and nitrogen from nitrogen wash, and small quantities of tail gas from ammonia synthesis.

(iv) **Steam reforming:** Steam reforming is carried out in two stages, using primary and secondary reformers. In primary reforming, natural gas feed is converted to hydrogen and carbon monoxide, by the feed's reaction with steam. In secondary reforming, the reaction continues and air is introduced to assure the required amount of nitrogen for ammonia synthesis. The feedstocks need purification before being subjected to reforming.

Natural gas is purified by removing carbon dioxide and hydrogen sulphide. Depending on the source, natural gas may contain entrained dust or droplets of oil or water, which are to be removed by separators, filters, etc. After initial purification, natural gas is compressed to reformer pressure and passed over activated carbon at ambient temperature or over hot zinc oxide (290 to 400°C) to remove sulphur by absorption. In some cases, both activated carbon or zinc oxide (ZnO) treatments are used.

$$ZnO + H_2S \longrightarrow ZnS + H_2O$$

Chlorides, present in some natural gases, poison the low temperature shift catalysts and are removed by absorbents. If the feedstock contains non-reactive sulphur, hydro treating is carried out. The preheated gas or vaporized naphtha is mixed with hydrogen (recycled synthesis gas) and passed through a "hydrotreater" containing a cobalt-molybdenum catalyst. This catalyst converts sulphur compounds into hydrogen sulphide (H_2S.) The gas then goes to a sulphur removing catalyst, like zinc oxide.

$$RSH + H_2 \longrightarrow H_2S + RH$$

Sulphur, chlorides and other catalyst poisons can enter the ammonia plant in the steam or in the air, to the secondary reformer. Precautions need to be taken to avoid this. One method is to keep the sulphur content in natural gas below 0.5 ppm. The main sulphur compounds in natural gas are hydrogen sulphide and mercaptans. In addition, a layer of guard absorbent may be placed on top of the catalyst, particularly in the case of a low temperature catalyst.

The primary reforming step is to convert the bulk of the hydrocarbon feed to hydrogen and carbon monoxide by the reaction of steam.

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2$$

Nickel is used as a catalyst. A shift conversion also occurs to some extent.

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

The methane-water reaction is endothermic and requires a large amount of heat. Promoters such as potassium may be added to increase the strength of the base composition, its durability and porosity.

The gas that leaves the primary reformer usually contains 5 to 15% methane on dry weight basis. The secondary reforming process aims at conversion of methane to hydrogen, carbon monoxide and carbon dioxide and the supply of required nitrogen for ammonia synthesis. Reforming is done by adding air in the amount required to give an N:H atomic ratio of 1:3 in the synthesis gas. The oxygen in the air burns part of H_2, CO and CH_4, thereby raising the temperature high enough for rapid completion of the reforming process. When air is the source of nitrogen to the secondary reformer, heat is supplied from that generated in combustion reactions together with the heat in the preheated air and in the gas from the primary reformer. The gas leaving the secondary reformer contains around 56% hydrogen, 12% carbon monoxide, 8% carbon dioxide, 23% nitrogen, and less than 0.5% methane and argon. It also contains steam from nearly half of the total volume of gases on dry weight basis.

Carbon monoxide conversion to carbon dioxide is carried out in two steps. They are (a) a high-temperature conversion, and (b) a low-temperature shift conversion. Potassium carbonate with various additives is used to promote the absorption of carbon dioxide in most ammonia plants. The carbon monoxide from the secondary reformer is cooled to around 375°C which is the optimum temperature for the shift conversion reaction.

$$CO + H_2O \longrightarrow H_2 + CO_2$$

Carbon monoxide is converted into carbon dioxide and hydrogen, by passing over an iron oxide with a small amount of chromium oxide catalyst bed in the presence of steam. This exothermic reaction is carried out in two steps with heat removal between the steps as the reaction is more rapid at high temperatures (300 to 400°C) and equilibrium is more fovorable at low temperatures (200 to 275°C.) Most of the low temperature shift catalyst contains zinc and alumina in addition to copper.

After shift conversion of carbon monoxide to carbon dioxide, the gas may contain 18% carbon dioxide. From the year 1940 to 1960, a 20% solution of mono ethanolamine was used to absorb carbon dioxide. Since 1960, most plants have started to use potassium carbonate solution with additives that promote absorption and inhibit conversion. These improved processes are known as the **Catacarb process** and the Benfield process. The major advantage of potassium carbonate solution is the lower heat requirement for stripping carbon dioxide from the solvent. A modified process known as **Vetrocoke process**, which uses a mixture of potassium carbonate and sodium carbonate with arsenic oxide, is more efficient. This process absorbs carbon dioxide in the plant more efficiently but results in the emission of relatively large amounts of CO_2 to the atmosphere, thereby causing pollution. An increased carbon dioxide concentration in the atmosphere contributes most to greenhouse effect and acid rain. Special care should be taken in the Vetrocoke process because it uses potassium carbonate solution activated by arsenic oxide (As_2O_3) as an absorbent. Careless operation of such plants can lead to contamination of the soil and underground water sources.

The gas after carbon dioxide absorption contains about 0.3% carbon monoxide and less than 0.1% carbon dioxide. These gases must be removed prior to the ammonia synthesis step by methanation, lest they decrease the activity of the ammonia synthesis catalyst and cause deposition of ammonium carbonate in the synthesis loop. These methanation reactions are reverse of the reformer reactions. And a nickel based catalyst is used where hot gases are passed over the catalyst at a temperature of 300 to 350°C.

$$CO + 3H_2 \longrightarrow CH_4 + H_2O$$
$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

These reactions are exothermic. The synthesis gas after methanation contains about 74% hydrogen, 24% nitrogen, 0.8% methane and 0.3% argon, on a dry weight basis. This gas is to be compressed to pressure ranging from 10 to 80 MPa depending on the ammonia synthesis process.

Reciprocating compressors, which were once in general use, are still used for small plants (less than 500 tons per day). However now, centrifugal compressors driven by steam turbines, are used in most new plants.

Because reciprocating compressors are driven by electric motors, they are more efficient (~87% efficiency) than the centrifugal compressors (~70% efficiency), but are more expensive and their maintenance costs are also higher.

Ammonia synthesis: The synthesis gas calls for the removal of water before the gases enter the synthesis converter because of the adverse effect of water on the catalyst. Most modern plants use molecular sieve dryers to remove water in the synthesis gas to less than 1 ppmv. The sieves are usually located at the inter-stage of the synthesis gas compressor.

The purified synthesis gas mixture containing hydrogen and nitrogen in the ratio of 3:1 reacts at a temperature of the order of 500°C and a pressure of 270 to 350 atmospheres over an activated iron oxide catalyst.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

The catalyst is mainly ferroso-ferric oxide (Fe_3O_4), promoted using potash, aluminum, calcium or magnesium. The catalyst also could be poisoned by sulphur, arsenic, phosphorus, chlorine and heavy hydrocarbons.

A typical ammonia synthesis reactor is a steel cylinder of a height of 10 to 18 m and a diameter of 80 to 140 cm. Ammonia synthesis converters differ, depending on the type of flow - whether axial, radial or cross. The converters also differ in the way temperature control of the reactants is achieved, and on how low reaction heat recovery is done. Though initially, quench converters were popular, indirect-cooled converters are currently used where heat exchangers are used to cool the gas. Catalyst efficiency is improved by increasing the surface area per unit volume with a small particle size. A radial flow converter provides a larger gas flow area compared to the axial flow converter. All modern, low-energy designs of ammonia converters use radial or cross flow designs with indirect temperature control.

The conversion of synthesis gas is incomplete in a single pass, but a large amount of ammonia is produced by its removal from the gas stream and by recycling the unreacted synthesis gas. The gas that leaves the converter contains around 12 to 18% ammonia, depending on the pressure. The conversion per pass increases with pressure. This gas is cooled, first by heat exchange with the incoming gas, and then by air or water. The cooled ammonia gas is finally condensed to a liquid form by refrigeration. The degree of cooling required depends on the pressure of the ammonia gas. At high pressures, most of the ammonia can be condensed by water cooling. At low pressures (15 to 20 MPa), refrigeration is essential for condensation. For atmospheric storage, the gas needs to be cooled to minus 33°C. The gas remaining after ammonia condensation is recycled to the converter by using a compressor.

Ammonia manufacture consumes intense energy for such major operations as compression of air, synthesis gas, refrigeration, etc. The relative energy consumption per ton of ammonia produced, assuming the consumption with natural gas as the feedstock is as follows:

Natural gas	1.0
Naphtha	1.1
Fuel oil	1.15
Coal	1.45

The manufacture of one ton of ammonia requires about 980 NM^3 of natural gas, one ton of naphtha or fuel oil or 3.8 tons of coal. Against a thermodynamic requirement of energy to get one ton of ammonia (4.46 million Kcals), the energy consumption by the steam reforming process is 9.6 million Kcals. Technology is being developed to reduce the overall energy inputs for ammonia synthesis. The various issues being addressed include recovering lost heat, bringing down synthesis pressure (with an improved catalyst) and impurities in the synthesis gas, reduce pressure drops by better converter designs, and the use of improved purification methods and better design of cold exchange or heat exchange equipment. It is now possible to produce ammonia with an input energy of 8 million Kcals/ton of ammonia produced.

Production of ammonia by the steam-reforming process is relatively clean and presents no problem to the environment. In ammonia manufacturing plants, several hazardous substances (toxic, flammable, explosive) get handled at a wide range of temperatures and relatively high pressures. Pre-emptive environmental protection measures should be taken, like with plant design, the construction material used and plant operation.

Other process techniques: The present day low-energy designs for ammonia production use indirectly cooled converters. The design and layout of various plants available differ considerably. The major plant technologies used today are based on the **Kellogg's horizontal converter** and **Topsoe series 200 converter**. These gas-based plants use two catalyst layers with an intermediate heat exchanger for the feed, all in a single vessel.

Kellogg technology uses a horizontal cylindrical converter in which catalyst beds are arranged along side each other. The gas flows vertically through rectangular beds. The catalyst beds and the interchanger are mounted on a trolley system, which can be inserted into the vessel.

The Topsoe series 200 converter is a radial flow converter. It has two catalyst beds with annular cross sections. The gas flows radially inwards. A heat exchanger is installed at the first beds outlet. The gas enters at the bottom and flows through an annular space between the shell and the catalyst bed. This annular flow of gas keeps the temperature low and prevents the attack of hydrogen of the shell. The gas is heated in the interchanger before it enters the first catalyst bed. The effluent gas from the first bed is cooled in the interchanger and it flows through the second bed. The ammonia axial-radial converter permits part of the gas to flow axially through the catalyst and the remainder radially through the catalyst bed. This converter design can be retrofitted into old converters.

Uhde technology uses three catalyst beds. The first two beds and an interchanger are housed in one vessel. High pressure steam generated by a waste heat boiler cools the gas before it enters the catalyst bed placed in another vessel. The effluent from the third bed goes through a high pressure steam boiler.

To control the concentration of inerts in the recycle gas, it is necessary to draw a purge stream from the synthesis loop. The purge gas has the composition of 61% hydrogen, 20% nitrogen, 13% methane, 4% argon and 2% ammonia. Recovering and recycling hydrogen from this purge gas can reduce the quantity of hydrogen to be produced by steam reforming. The cryogenic process, the membrane separation process and the pressure swing adsorption processes have been commercially used in ammonia plants for the recovery of hydrogen. Hydrogen recovery of 90 to 98% can be achieved in the cryogenic process while membrane separation process gives a recovery of 85 to 90% hydrogen. Hydrogen recovery of 70 to 80% is achieved in the pressure swing adsorption process.

In 1988 ICI set up two identical 450 tons per day ammonia plants based on the **Leading Concept Ammonia (LCA) process** in Britain. The LCA process is different from the traditional steam reforming process. The LCA concept has a 'core' unit consisting of key process operations and a separate utility area containing power and steam systems, refrigeration, carbon dioxide recovery and other utilities. Natural gas is desulphurized and passed through a feed gas saturator where it comes in contact with circulating hot process condensate. The ammonia synthesis reactor operates at a pressure of 8.0 MPa using a cobalt-promoted catalyst. The gas enters at 225°C and leaves at 380°C.

The **Linde Ammonia Concept** is a combination of a hydrogen plant, nitrogen plant and an ammonia synthesis loop. The hydrogen plant uses a primary reformer, shift converters and a pressure swing adsorption unit to get ultra pure hydrogen. Pure nitrogen from an air separation plant is mixed with pure hydrogen to give inerts-free ammonia synthesis gas. The process has the following three features that differentiate it from the conventional steam-reforming process: (i) Elimination of secondary reforming. (ii) The use of an isothermal shift reactor for carbon monoxide shift conversion. (iii) A pressure swing adsorption unit to remove carbon dioxide, methane and small residual amounts of carbon monoxide from the hydrogen stream producing 99.999 mole percent pure hydrogen.

The advantages of the Linde Ammonia Concept are as follows. (i) The isothermal shift reactor allows conversion to 0.7% carbon monoxide on dry basis in a single step. (ii) The catalyst bed is kept at a constant temperature of about 250°C by a spiral wound cooling coil. (iii) The isothermal reactor technology has been in use at many places worldwide. The pressure swing adsorption unit is able to supply pure hydrogen even in the case of a disturbance upstream in the reformer. This is in contrast to the conventional plant where disturbances in the carbon monoxide shift or carbon dioxide removal areas cause a shutdown due to high temperature in the methanator.

The PARC process combines air separation (to produce nitrogen) with steam reforming, HT shift and pressure swing adsorption (PSA) to make synthesis gas. In the proprietary PSA unit, nitrogen purge is used to enhance hydrogen recovery and to fulfilll the stoichiometric nitrogen requirement. A Rankine cycle is used to generate electric power from the heat of the high temperature shift converter. This process eliminates the need for secondary reforming, LT shift, carbon dioxide scrubbing and methanation. If carbon dioxide is required for urea manufacture, a carbon dioxide scrubbing unit is added in front of the PSA unit. The overall energy efficiency ranges from 7.0 to 7.6 Gcal/ton of ammonia, depending on plant specification.

The **Topsoe economic process** uses optimized units of the ammonia process rather than radically new schemes. The test runs of this process have shown the production of about 7Gcal/ton of ammonia produced. Further improvement in the pre-reformer, positioned upstream of the primary reformer allows reformer feed to be heated to a higher temperature at a low steam: carbon ratio without deposition of carbon. In addition, Topsoe has developed a shift conversion catalyst based on copper, which does not promote a Fischer-Tropsch reaction at a low steam dry gas ratio.

New developments are related to two steps of ammonia synthesis: (a) construction of the reactor, and (b) development of a new catalyst. While developing a new catalyst, fovorable properties of ruthenium as an ammonia synthesis catalyst are important.

The major differences between the two catalysts (the conventional iron based and ruthenium based catalyst) are that the ruthenium based catalyst (a) is required in a much lower volume, and (b) operates at a lower pressure and at a higher temperature. Lower mole percent of hydrogen and nitrogen and a high partial pressure of ammonia are allowed in the process. The expected immediate energy saving is about 0.2 to 0.3 Gcal/ton of ammonia. The stability of this new ruthenium catalyst must be proven before it replaces the iron based catalyst. Until now, two carriers have been experimented. These are: a special graphite by Kellogg and a ceramic support by Topsoe.

Kellogg Advanced Ammonia Process (KAAP) is based on a precious metal-based ammonia synthesis catalyst, jointly developed by M.W. Kellogg and British Petroleum. This new catalyst, which uses ruthenium supported on a proprietary graphite structure with various co-promoters, was seen to provide 10 to 20 times the activity of a conventional iron-based catalyst. The KAAP ammonia plant has the following technical features: (a) a single-case synthesis gas compressor, (b) a radial flow, intercooled converter design, (c) a low-pressure synthesis loop, and (d) a high activity ammonia synthesis catalyst.

The KAAP reactor is a four-bed, intercooled, radial flow, hot wall vessel. The first bed uses a charge of conventional magnetite catalyst to take advantage of the high ammonia reaction rate at a low ammonia concentration. The other three beds are charged with the new catalyst. A series of intercoolers and external steam generators are provided for heat integration. The feed to the KAAP reactor contains 15% ammonia which is increased to more than 21% at the exit of the reactor.

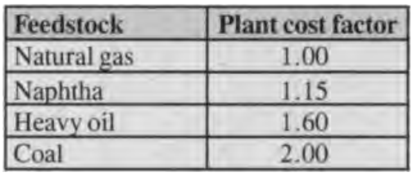
The advantages of the KAAP technology compared to those of the current low-energy technology are the following: (i) The synloop energy consumption is reduced by 40%, which when translated to the overall plant energy reduction is about 1.0 GJ/ton. (ii) The overall plant capital cost is reduced by about 5%.

The **Topsoe S-250 converter system** also uses two radial flow converters in series with waste-heat boilers between the converters and after the last converter. This system saves energy to an extent of 0.11 Gcal/ton of ammonia over the previous Topsoe converter S-200.

This new converter has (a) a low pressure because of the radial flow, (b) use of small particle size catalyst, (c) high conversion per pass due to indirect cooling, and (d) good operability and easy temperature control. The new converter system offers either the same performance with a smaller catalyst volume or higher conversion by full use of the third bed.

Ammonia production is highly capital intensive. Its investment costs greatly depend, among other things, on the bidding location and on the relative strength of international currencies, and also on the market for construction of chemical plants. The processes have been standardized for ammonia production by steam reforming of natural gas, naphtha and other hydrocarbons in plants using centrifugal compressors. Standard designs for 900, 1040, 1360 and 1500 tons per day (tpd) have evolved. The majority of new plants are in the range of 1000 to 1500 tpd capacity.

There are relatively fewer plants to produce ammonia by partial oxidation of heavy oil or coal. The basic elements of the cost of production of ammonia using four different starting materials are as follows:



Feedstock	Plant cost factor
Natural gas	1.00
Naphtha	1.15
Heavy oil	1.60
Coal	2.00

In practice, plants from 100 to 600 tpy (tons per year) of ammonia production capacity are considered small scale plants. While ammonia production is a mature technology, there is room for improvements in its efficiency and reliability by making use of (a) optimization of pre-reforming and adiabatic reforming processes, (b) new methods in electrically driven compressors (like three dimensional impellers), (c) better design of furnace elements (burner nozzles, insulation) and heat exchangers, (d) improved steam generation methods, (e) integrated gas turbine drives with steam turbines, (f) more efficient process condensate stripping to produce medium-pressure steam, (g) improved ruthenium catalyst and its alternatives, (h) easier and economically viable dynamic control systems, and (i) reduced emissions of carbon dioxide and oxides of nitrogen to meet stringent environmental regulations.

Storage and transportation: Most ammonia is shipped from the plants where it is produced to other locations for direct use as fertilizer or for further processing into finished fertilizers, or for use as a raw material for non-fertilizer products. Ammonia is mostly transported by sea. Ships that carry it also carry other liquefied gases, such as liquefied petroleum gases (LPG). Ammonia is almost invariably transported in the liquid state and, therefore, it must either be compressed or refrigerated, semi-refrigerated or pressurized. Fully refrigerated storage tanks are equipped to maintain the temperature at about minus 33°C. In semi-refrigerated storage tanks, ammonia is kept at a moderately low temperature of 0 to 5°C at which the pressure is about 400 to 500 kPa. Unrefrigerated pressure storage tanks usually are designed for pressures of up to about 1.8 MPa, which should be adequate for any ambient temperature normally encountered in most climates.

Transportation of anhydrous ammonia by pipelines is economically attractive in some cases. Examples of long distance ammonia transportation by pipelines are found, for instance, in the United States, Russia and Mexico. Anhydrous ammonia is also transported by rail and road.

Ammonia solution

The solution of ammonia in water is called ammonia solution, commonly referred to as **aqua ammonia**. It is also called aqueous ammonia, **ammonia liquor** or **ammonium hydroxide**. It is the simplest nitrogen solution made by forcing compressed NH_3 (anhydrous ammonia) gas into water.

Ammonia-sulphur solution

Ammonia-sulphur solution is made from anhydrous ammonia and sulphur. The typical commercial solutions are temperature dependent and contain 74.2% nitrogen and 10% sulphur.

Ammoniated sulphate

Ammoniated sulphate, also called **ammonium dihydrogen phosphate sulphate**, is a double salt of $NH_4(H_2PO_4)$ and $(NH_4)_2 SO_4$. It is made by neutralizing a mixture of H_2SO_4 and H_3PO_4 by gaseous ammonia.

Ammoniated superphosphate

Ammoniated superphosphate is a powdered or granulated grey material with an acid odor. Anhydrous or aqueous ammonia is mixed with ordinary superphosphate obtained by treating phosphate rock with sulphuric acid:

$$Ca(H_2PO_4)_2 + CaSO_4 + 2NH_3 \longrightarrow 2CaHPO_4 + (NH_4)_2SO_4$$

To 9.1 kg of phosphorus (in the form of P_2O_5), 2.7 to 3.2 kg of ammonia is added. Where concentrated superphosphate is used, 2 kg of ammonia is added for every 9.1 kg of phosphorus.

Ammoniated superphosphate contains 2 to 6% nitrogen and 6 to 21% phosphorus (14 to 49% P_2O_5.) Ammoniation of superphosphate offers an inexpensive way of adding nitrogen to a fertilizer, which reduces the water-soluble phosphorus content to less than 20% in ordinary superphosphate whereas nearly 50% in triple superphosphate. Nitrogen promotes phosphorus uptake by plants by (a) increasing the tip and root growth, (b) altering the plant metabolism and (c) increasing the solubility and availability of phosphorus. Ammoniacal fertilizers facilitate absorption of phosphorus better than nitrate fertilizers do.

Ammonium superphosphate becomes easy to store when made free-flowing by mixing with non-caking agents like limestone, sand, rice hull, granite dust, kaolin clay or tobacco stems. It is not effective as a fertilizer for wheat and rice in laterite soil, but gives higher response in black cotton soil, alluvial and calcareous soils.

Similar to ammonium phosphate sulphate, ammoniated superphosphate forms an acid in the soil. In humid regions, soils develop acidity as a result of leaching, erosion and crop removal. This feature is being used successfully even in low fertility agricultural soils.

Ammoniating solution

Ammoniating solution is ammonia or a solution of ammonium nitrate or urea in **ammonia liquor**. It is used for ammoniating superphosphate or its derivatives. (See also Nitrogen solution.)

Ammoniation

Ammoniation is the process of introducing ammonia (ammonia liquor or aqua ammonia) into fertilizer materials like superphosphate to form ammoniated compounds, such as ammonium polyphosphate and ammoniated superphosphate. Various products are formed depending on the (a) proportion of ammonia used, (b) resulting reaction temperatures, (c) time of standing and (d) other components in the mixture. Ammonia first reacts with the free acid present in the superphosphate and mono-calcium phosphate forming other compounds.

Ammonia volatilization

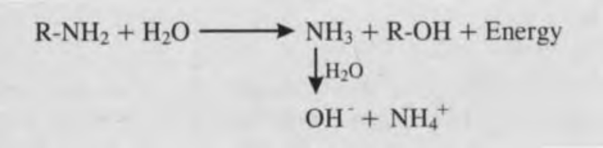
When ammonium ion is in a basic solution, ammonia volatilization leads to a loss of nitrogen from soil or water to the atmosphere in the form of ammonia gas. The amount of ammonia lost is proportional to the quantity of ammonium ion (NH_4^+) and ammonia in the soil solution and the soil pH. The losses are highest from the surface when ammonium fertilizers or urea are applied on calcareous (high carbonate content) soils. On non-fertilized soils, the ammonia losses are smaller (< 10%) compared to as much as 30% when urea or ammonium fertilizers are applied.

To minimize the loss by volatilization, the applied fertilizer should be covered by a layer of soil or washed with water. The loss can be reduced by inhibiting the urease enzyme activity by adding urease inhibitors (like phenols, quinones, various insecticides and substituted urea.)

Generally, ammonia volatilization in calcareous soils is greater with urea fertilizers than with ammonium salts; the exception is of ammonium sulphate or diammonium phosphate that forms an insoluble calcium salt as a precipitate. Ammonia losses increase with moisture and with the increased application of fertilizers, compared to those by dry nitrogen sources. The volatilization is greater with broadcast application on a wet surface soil compared to subsurface and surface band methods.

Ammonification is the conversion of organic nitrogen to its ammonium form in the presence of bacteria like *Bacillus, Proteus* and other heterotrophs. This conversion is termed **mineralization**. The rate of ammonification is faster if the soil is warm, well aerated and moist.

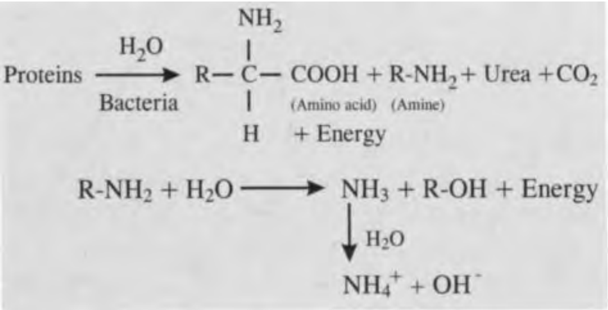
In ammonification, the amines and amino acids, produced by the aminization of organic compounds (like protein) are decomposed by heterotrophs to release ammonium. This step is called **ammonification** and is represented as follows:



$$R\text{-}NH_2 + H_2O \longrightarrow NH_3 + R\text{-}OH + \text{Energy} \xrightarrow{H_2O} OH^- + NH_4^+$$

Ammonification

Ammonification is a biological process by which organic forms of soil nitrogen are converted into ammonia or ammonium ions. The final reaction in this process is the hydrolysis of amino groups. The amines and amino acids released in aminization are reacted upon by other heterotrophs, releasing nitrogen in an inorganic ammonium (NH_4^+) form. Both aerobic and anaerobic micro-organisms can carry out this reaction. A diverse population of bacteria, fungi and actinomycetes is capable of releasing ammonium ions.



$$\text{Proteins} \xrightarrow[\text{Bacteria}]{H_2O} \underset{\text{(Amino acid)}}{R-\underset{H}{\overset{NH_2}{C}}-COOH} + \underset{\text{(Amine)}}{R\text{-}NH_2} + \text{Urea} + CO_2 + \text{Energy}$$

$$R\text{-}NH_2 + H_2O \longrightarrow NH_3 + R\text{-}OH + \text{Energy} \xrightarrow{H_2O} NH_4^+ + OH^-$$

The released ammonium ion may be (a) nitrified, (b) utilized by plants, (c) lost by **ammonia volatilization**, (d) adsorbed on complex clay materials, (e) fixed in the crystal lattices of 2:1 expanding clay minerals, or (f) immobilized by soil micro-organisms. The rates of ammonia release are more rapid in aerobic than in anaerobic environment. (See also Ammonia volatilization; Nitrification.)

Ammonium bicarbonate

Ammonium bicarbonate, also called **ammonium hydrogen carbonate** (NH_4HCO_3), is a low nitrogen containing fertilizer (17%N), used largely in China. It is produced by heating ammonium hydroxide with excess carbon dioxide and evaporating the water formed.

Ammonium bicarbonate is a hygroscopic, white, crystalline compound soluble in water but insoluble in alcohol and acetone. It decomposes above 35°C to ammonia, carbon dioxide and water vapor, releasing irritant fumes. Only 30% of the applied nitrogen of this fertilizer is recovered by plants owing to the unstable nature of ammonium bicarbonate.

Ammonium bisulphite

Ammonium bisulphite is a solution grade fertilizer, available commercially as a 55 to 60% solution. It is made by absorbing sulphur dioxide (obtained as a by-product from smelting operations) in aqueous ammonia solution. This non-pressurized solution provides both sulphur and nitrogen. It has a salt-out temperature of 0°C.

Ammonium bisulphite is compatible with liquid fertilizers, such as aqueous ammonia and polyphosphate solutions, and can be stored in containers made of steel, aluminum or plastic.

Ammonium carbonate

Ammonium carbonate, $(NH_4)_2CO_3$, is an intermediate product formed during the synthesis of urea. Ammonium carbonate on decomposition yields urea and water.

Ammonium-carbonate-gypsum process for producing ammonium sulphate

The production process involves the reaction of ammonium carbonate with gypsum, removing the precipitated calcium carbonate by filtration, evaporation and crystallizing ammonium sulphate followed by centrifuging the liquor.

This method, also known as the **Merseburg Process**, is based on combining ammonia and carbon dioxide to first produce ammonium carbonate, which is then reacted with gypsum or anhydrite to yield ammonium sulphate and calcium carbonate in an exothermic reaction :

$$2NH_3 + H_2O + CO_2 \longrightarrow (NH_4)_2CO_3$$

$$CaSO_4 \cdot 2H_2O + (NH_4)_2\,CO_3 \longrightarrow CaCO_3 + (NH_4)_2\,SO_4 + 2H_2O$$

The exothermic process has many advantages, such as the availability of a byproduct (calcium carbonate) used in cement production and agriculture. This process does not require any sulphur supply. The major disadvantage is the large energy (steam) requirement for ammonium sulphate recovery from the dilute solution.

At the Sindri plant in India, ammonia is absorbed in water and carbonated at a pressure of about 2.1 kg/cm^2 in a series of two aluminum towers. The prepared liquor strength corresponds to approximately 170 g of ammonia and 225 g of carbon dioxide per liter. In FACT (The Fertilizers and Chemicals Travancore Ltd.), Travancore, India, jet absorbers are used for preparing ammonia solution and ammonium carbonate liquor in conjunction with a carbonating tower.

Natural gypsum or anhydrite, when used, is ground so that about 90% of the material passes through a 120 mesh sieve. When gypsum, as a byproduct of phosphoric acid plants is used, impurities are removed by repulping the filter cake prior to washing and dewatering on a drum or disc filter.

Reactions of ammonium carbonate and gypsum solutions are carried out in a series of wooden vessels or mild steel vessels having steam coils and agitators to give a total retention time of 4 to 6 hours. The slurry produced is filtered and the calcium carbonate cake washed and dewatered. The solution is evaporated and the crystals are centrifuged and dried in a rotary drier at 120°C.

Ammonium chloride

Ammonium chloride, like all other ammonium salts, is used as a fertilizer. It contains 24 to 26% nitrogen and is available as white crystals or granules. A coarse form of this fertilizer is preferred to the powdered form for direct application. Its crystals are used in compound fertilizers.

Ammonium chloride is a good source of nitrogen for cotton, rice, wheat, barley, maize, sorghum, sugar cane and fiber crops. It is easy to handle. In some cases, however, the material tends to become lumpy and difficult to spread.

Ammonium chloride is used either directly for fertilization or in a variety of compound fertilizers, such as ammonium phosphate chloride or ammonium potassium chloride or in combination with urea or ammonium sulphate.

As a fertilizer, ammonium chloride has an advantage in that it contains 26% nitrogen, which is higher than that found in ammonium sulphate (20.5%). In terms of per unit cost of nitrogen, ammonium chloride is relatively cheaper than ammonium sulphate and has some agronomic advantages for rice. **Nitrification** of ammonium chloride is less rapid than that of urea or ammonium sulphate. Therefore, nitrogen losses are lower and yields, higher.

However, ammonium chloride is a highly acid forming fertilizer and the amount of calcium carbonate required to neutralize the acidity is more than the fertilizer itself. Further, it has a lower nitrogen content and a higher chloride content compared to urea and ammonium nitrate, making it harmful to some plants.

Several methods are used to produce ammonium chloride. The most important is the **dual-salt process** (**modified Solvay process**) wherein ammonium chloride and sodium carbonate are produced simultaneously using common salt and anhydrous ammonia as the principal starting materials. When ammonium chloride is mixed with phosphatic and potassic fertilizers, a large amount of soil calcium is lost as its conversion into soluble calcium chloride causes it to leach out easily.

Like ammonium sulphate, ammonium chloride can be applied to wet land crops. In terms of the agronomic suitability, it is generally rated as equal to other straight nitrogenous fertilizers.

Ammonium chloride is, however, not ideal for grapes, chilies, potatoes and tobacco as the added chlorine affects the quality and storability of these crops.

Industrial uses of ammonium chloride are in dry-battery manufacture and as a flux for soldering and brazing.

Ammonium chloride production processes

Ammonium chloride is used as a fertilizer either as such or in combination with other fertilizers.

Manufacturing methods for producing ammonium chloride are (a) the dual-salt processes, whereby ammonium chloride and sodium carbonate are produced simultaneously, (b) direct neutralization of ammonia with hydrochloric acid, and (c) miscellaneous methods.

(a) Most of the ammonium chloride for fertilizer use is made by the **dual-salt process**. In this process, ammonium chloride is salted out by the addition of solid, washed sodium chloride rather than by decomposition by lime to recover ammonia. This is the **modified Solvay process.**

In the original **Solvay process**, an ammoniacal solution of 30% sodium chloride is treated with carbon dioxide in large absorption towers to form ammonium carbonate:

$$2NH_3 + H_2O + CO_2 \longrightarrow (NH_4)_2CO_3$$

Additional carbonation produces ammonium bicarbonate:

$$(NH_4)_2CO_3 + CO_2 + H_2O \longrightarrow 2NH_4HCO_3$$

The addition of sodium chloride gives sodium bicarbonate and ammonium chloride:

$$NH_4HCO_3 + NaCl \longrightarrow NaHCO_3 + NH_4Cl$$

The sodium bicarbonate centrifuged or filtered from the ammonium chloride solution is calcined to produce sodium carbonate and carbon dioxide, which is recycled.

In the Solvay process, equilibrium is reached at about 75% completion, and the mother liquor is reacted with lime to give ammonia:

$$2NH_4Cl + Ca(OH)_2 \longrightarrow CaCl_2 + 2NH_3 + 2H_2O$$

The calcium chloride formed can be sold or discarded, depending on the market.

In the modified Solvay process, the mother liquor, after the removal of sodium bicarbonate, is ammoniated, cooled below 15°C and salted out using washed solid sodium chloride. The precipitated ammonium chloride is centrifuged, washed and dried. The fine crystals can be granulated by roll compaction. Large ammonium chloride crystals of 2 to 3 mm size have been developed by cooling, nucleation and crystallization, under closely controlled conditions in specially designed vessels.

The slurry from the crystallizer is centrifuged, washed and dried to about 0.25% free moisture in a rotary drier at 105°C. After the removal of ammonium chloride, the liquor is reammoniated to start a new cycle of operations.

As the demand for soda ash is comparatively lower than that for nitrogen fertilizers, ammonium chloride from this source is not likely to meet the nitrogen fertilizer needs.

(b) **Direct neutralization method**: High purity ammonium chloride is made by anhydrous ammonia vapor directly reacting with hydrochloric acid gas:

$$NH_3(g) + HCl(g) \longrightarrow NH_4Cl$$

This neutralization reaction is carried out under reduced pressure in rubber lined steel vessels. Concentrated hydrogen chloride gas is passed through an aspirator where it is diluted to about 20% concentration. Ammonia is admitted through another sparger or by tangential nozzles in the base of the reaction vessel. Air agitation is employed. A reduced pressure of 250 to 300 mm of mercury and a slurry temperature of 75 to 80°C are the typical operating conditions.

Operation under vacuum provides cooling and elimination of abnoxious acid vapors, in addition to attendant costs and maintenance charges. The acid and ammonia feeds are adjusted to achieve a steady pH of 8. The control system cuts off the acid when the pH falls below 7 to protect the rubber and plastic lined reactors and centrifuges from corroding. The slurry containing 80% solid ammonium chloride is withdrawn and separated by centrifuging. In some cases, drying is done by blowing hot air through the crystals before discharge. Alternatively, a top-feed filter-drier can be used instead of the centrifuge.

The mother liquor from the centrifuges is pumped back to a saturator. The gases evolved from the liquor are scrubbed to prevent corrosion. The liquor from the condenser-scrubber system is returned to the mother liquor tank. In the direct reaction between hydrochloric acid and ammonia, traces of chlorine can cause explosions by the formation of nitrogen trichloride, warranting adequate safety precautions.

Anti-caking agents such as certain fatty acid derivatives or inert powders, when added to the crystallizer or sprayed on the crystals, reduce caking tendencies on storage. Granulation by roll compaction provides material for direct application.

(c) **Miscellaneous processes**: Ammonium chloride can also be made by reacting ammonium sulphate with sodium chloride:

$$(NH_4)_2SO_4 + 2NaCl \longrightarrow Na_2SO_4 + 2NH_4Cl$$

In another process, which is quite expensive and used only for producing small quantities of ammonium chloride, sulphur dioxide or sulphite liquor reacts with ammonia and sodium chloride:

$$SO_2 + 2NH_3 + H_2O + 2NaCl \longrightarrow 2NH_4Cl + Na_2SO_3$$

Ammonium chloride is formed in NPK fertilizers by the action of potassium chloride with ammonium nitrate or sulphate, as per the following reaction:

$$NH_4NO_3 + KCl \longrightarrow KNO_3 + NH_4Cl$$
$$(NH_4)_2\,SO_4 + 2KCl \longrightarrow 2NH_4Cl + K_2SO_4$$

These reactions go to completion in most granulation processes involving these NPK fertilizers.

Ammonium chloride containing 24 to 26% nitrogen can be either crystalline or granular. Coarse crystals or granular materials are used for direct application and fine crystals are used for making compound fertilizers.

Ammonium citrate

Ammonium citrate is a white, granular, water-soluble salt of ammonia and citric acid. It is used in a neutral solution for determining the phosphorus content of phosphate fertilizers (such as calcium hydrogen phosphate ($CaHPO_4$)), that are insoluble in water but dissolve in complexing citrate solutions.

The fertilizer residue, after extraction of water-soluble phosphorus, is re-extracted with a neutral or strongly alkaline solution of 1 normal (1N) ammonium citrate for a prescribed period, and the slurry filtered. Citrate-soluble phosphorus is the phosphorus content in the filtrate and is expressed as a percentage by weight of the fertilizer.

The extraction of phosphate with 1N ammonium citrate is carried out routinely for 30 minutes, first at room temperature and then at 40°C. For neutral ammonium citrate solution, a temperature of 65°C is preferred.

Some European countries use an alkaline ammonium citrate solution, which extracts smaller amounts of phosphorus. Some experts consider it to be better correlated with phosphorus uptake and plant growth. However, most countries use a neutral normal ammonium citrate solution for extracting citrate soluble phosphorus.

Ammonium dihydrogen phosphate sulphate: See Ammoniated sulphate

Ammonium fertilizers

Ammonium sulphate, ammonium nitrate, ammonium phosphate, ammonium chloride, anhydrous ammonia and ammonia solution are among the important ammoniacal fertilizers. These nitrogenous fertilizers are combinations of ammonium and other elements with anions like nitrate, chloride, sulphate, phosphate, etc., which are water- soluble and easily assimilated by plants.

The ammonium part has to be nitrified (for conversion into its nitrate form) for plant absorption in the early stage of growth. Only paddy can absorb ammonium as such to meet its nitrogen needs. The ammonium ion is readily adsorbed on the colloidal complex of the soil and gets fixed and resistant to leaching.

Ammonium fertilizers render soils acidic as microbes oxidize ammonium cations to nitrate anions. These fertilizers require to be applied in combination with neutralizing calcium carbonate:

$$2NH_4^+ + 4O_2 \longrightarrow 2NO_3^- + 2H_2O + 4H^+$$

The amount of lime needed depends on the acidity of the fertilizer anions (Cl^-, SO_4^{2-}) and on how much ammonium is oxidized.

Table-A.4 gives the theoretical acidity values (lime requirement) of some ammonium fertilizers.

Table-A.4: Acidity (lime requirement) of some ammonium fertilizers (theoretical)

Fertilizer	Lime requirement kg/kg N
Ammonium chloride NH_4Cl	5.30
Ammonium nitrate NH_4NO_3	1.80
Ammonium sulphate $(NH_4)_2\,SO_4$	5.35
Calcium ammonium nitrate $CaNH_4(NO_3)_3$	0

Ammonium fixation

Ammonium fixation or the **fixation of ammonium ion** is a phenomenon by which certain clays (illites, montmorillonites, etc.) bond ammonium ions tightly between the mineral lattices that are neither exchangeable for other ions nor available to plants. However, near the edges of the clay lattice, external ions may replace some of the ammonium ions if clays are expanded, and such nitrogen may become available for plant growth. The number of ammonium ions fixed on the edges of the clay lattices increases as more ammonium is added. The ammonium ions fixed are less than the adsorbed quantities of ammonium. The clay fixation of ammonium ion (NH_4^+) provides some protection against rapid nitrification (followed by leaching.) The important fractions in fixing ammonium ions are coarse clay (0.2 to 2 μm) and fine silt (2 to 5 μm).

The moisture content, soil temperature and presence of other ions like potassium affect the fixation of ammonium ions. Generally, freezing and drying increase ammonium fixation. The presence of potassium ions restricts the fixation of ammonium ions as potassium fills the fixation sites. For this reason, adding potassium fertilizers, before the application of ammonium or ammonia-producing fertilizers, reduces ammonium fixation.

Ammonium form, immobilization of

Immobilization is the use or reuse of soluble nitrogen (NH_4^+ and NO_3^-) by plants or microbes. Most of the soil nitrogen added as a fertilizer, is immobilized into organic materials, (mostly as protein), in higher plants or microbes.

Ammonium hydrogen carbonate

Ammonium hydrogen carbonate is another name for **ammonium bicarbonate** (NH_4HCO_3.) It is a low nitrogen containing fertilizer (17% N), used largely in China. It is produced by heating ammonium hydroxide with excess carbon dioxide, followed by evaporation of water. (See also Ammonium bicarbonate.)

Ammonium hydroxide

Ammonium hydroxide is also known as **ammonia solution**, **aqua ammonia**, **aqueous ammonia** or **ammonia liquor**. It is the solution of ammonia in water and is commonly referred to as ammonium hydroxide. It is the simplest nitrogen solution made by forcing compressed ammonia (anhydrous ammonia) gas into water.

Ammonium metaphosphate

Metaphosphates are salts of metaphosphoric acid that react with ammonia to form ammonium metaphosphate. Ammonium metaphosphate is also made by reacting phosphorus pentoxide with ammonia.

Ammonium metaphosphate is a white fluffy powder with about 80% phosphorus and 17% nitrogen. Metaphosphoric acid or salts are often present in a polymerized form. In the vapor phase, the acid exists as a dimer and in solution it occurs as a trimer or tetramer.

Ammonium molybdate

Ammonium molybdate, $(NH_4)_6Mo_7O_{24}\cdot 2H_2O$ is an important molybdenum fertilizer. It is an ammonium salt of molybdic acid and contains about 50% molybdenum.

Ammonium molybdate is generally mixed with NPK fertilizers, depending on the crop requirement (generally 50 to 1000 gm per ha). The fertilizer is also applied as a foliar spray, but coating or soaking seeds with ammonium molybdate is the easiest method of application, which requires very little fertilizer.

Ammonium nitrate

Ammonium nitrate (NH_4NO_3) is among the most common nitrogenous fertilizers, with half of its nitrogen in an ammoniacal form and the rest in nitrate form.

The nitrogen from ammonium nitrate is immediately available to plants, whereas the ammoniacal nitrogen becomes available only after its nitration. Fertilizer grade ammonium nitrate solution in water containing 20% nitrogen is sold in large quantities, because of its high water solubility and easy soil applicability. The fertilizer can also be used in its compound forms, such as calcium ammonium nitrate and ammonium sulphate nitrate.

The nitrogen in ammonium nitrate is more rapidly available than that in urea or ammonium sulphate. Crops take up nitrogen mainly in the form of nitrate. The ammoniacal nitrogen must be converted to nitrate in the soil before it becomes effective. Urea causes seedling damage due to volatilization of ammonia. Ammonium nitrate and ammonium sulphate are strongly acid-forming fertilizers.

Although pure salt ammonium nitrate is a fine white crystal, it is usually available as white granules or prills of 1.2 to 3.3 mm size and contains 32 to 35% nitrogen by weight. The crystalline form is highly hygroscopic and is readily soluble in water. Because of this high solubility in water, it is less effective for flooded rice than urea or other ammoniacal nitrogen fertilizers. It is also more prone to leaching than other ammoniacal products. It is also a very powerful oxidizing agent which can explode when exposed to heat or flame. Because of this hazardous property, ammonium nitrate and its compounds are stored in a dry place in sealed bags. The granular form, however, is easily stored. It can also be spread on soil with ease.

Ammonium nitrate, like other **ammonium fertilizers**, can leave behind an acid residue in the soil. It takes 0.8 kg of lime to neutralize the acidity produced by 1 kg of ammonium nitrate fertilizer.

Ammonium nitrate and urea are the most widely used sources of nitrogen from among all solid fertilizers available. A two bale crop of cotton removes 56 kg of nitrogen per hectare in the seed alone and 16.8 kg of nitrogen per hectare in the lint. To supply this amount of nitrogen, the addition of 224 kg per hectare of ammonium nitrate is required. A 2240 kg per hectare tobacco crop removes 123 kg of nitrogen per hectare, and 5600 kg per hectare crop of rice removes 90 kg of nitrogen per hectare.

Ammonium nitrate is used as a major source of nitrogen for crops in the USA. It is a good nitrogen plant food for all field and vegetable crops and can be applied to the soil before or at the time of planting. It also makes for a good N-fertilizer for **side dressing** or **top dressing**.

An aqueous solution of urea and ammonium nitrate, called **UAN** is used as a liquid nitrogen fertilizer. 'Ammonite' is a trademark for a mixture of ammonium nitrate (98%) and coating agents (2%).

Ammonium nitrate-lime fertilizer

Ammonium nitrate-lime fertilizer is a non-acid forming mixture of ammonium nitrate and lime. It is manufactured at Hopewell, Virginia, in the USA and is sold under the trade name '**ANL**'. It contains 20% nitrogen, 10% calcium (as CaO) and 7% magnesium (as MgO.) It is usually prepared in a pellet or prilled form suitable for mixing, with other fertilizers, direct application and shipping out.

Ammonium nitrate limestone

Ammonium nitrate limestone is a white to grey, chalky powder. It is also known as **calcium ammonium nitrate**, a nitrogenous fertilizer. If made from dolomitic limestone, it contains 20% nitrogen, 6% calcium and 4% magnesium. The color of the powder depends on the limestone used in the manufacturing process.

Ammonium nitrate production processes

Ammonium nitrate is the most popular form of nitrogen fertilizer in Europe. It is being replaced by liquid fertilizers and anhydrous ammonia in Canada and the United States of America.

Ammonium nitrate contains 33 to 34% nitrogen, half of which is in an ammonium form and the remainder in a nitrate form. It is applied directly or in combination with calcium carbonate, limestone or dolomite. The combination is called **calcium ammonium nitrate** or **ammonium nitrate-limestone** (**ANL.**) It is also an ingredient in many liquid fertilizers.

Ammonium nitrate is produced by several slightly different processes that utilize the basic product, ammonia, to produce nitric acid, which in turn is neutralized by more ammonia to form ammonium nitrate (Fig.A.29). The process chemistry is simple, the reaction between anhydrous ammonia and nitric acid being,

$$NH_3\,(g) + HNO_3\,(aq) \longrightarrow NH_4NO_3$$

The reaction is highly exothermic and proceeds with high speed. The concentration of nitric acid used ranges from 45 to 60%, depending on the process. Except where ammonium nitrate is used as a liquid fertilizer, ammonium nitrate solution is concentrated and processed into prills or granules.

Ammonium nitrate is a strong oxidizer and can support combustion. When dry ammonium nitrate is heated between 170°C (melting point) and about 250°C, the following exothermic reaction occurs.

$$4NH_4NO_3 \longrightarrow 2NO_2 + 8H_2O + 3N_2$$

If the nitrogen dioxide gas is not allowed to escape freely, another highly exothermic reaction can occur.

$$NH_4NO_3 + 2NO_2 \longrightarrow N_2 + 2HNO_3 + H_2O$$

Above 250°C, nitric acid and ammonia are formed. This reaction is endothermic.

$$NH_4NO_3 \longrightarrow HNO_3 + NH_3$$

The explosive decomposition of ammonium nitrate can be described by the following reaction:

$$2NH_4NO_3 \longrightarrow 2N_2 + O_2 + 4H_2O$$

Production technology of ammonium nitrate: Solid ammonium nitrate is produced as prills, granules or crystals. Its production involves the following steps: (a) neutralization, (b) concentration, (c) finishing, (d) process condensate treatment, and (e) vapor treatment with heat recovery.

(a) **Neutralization**: When sufficient steam is available, the use of an atmospheric type of neutralizer is preferred. Acids of more than 50% concentration are

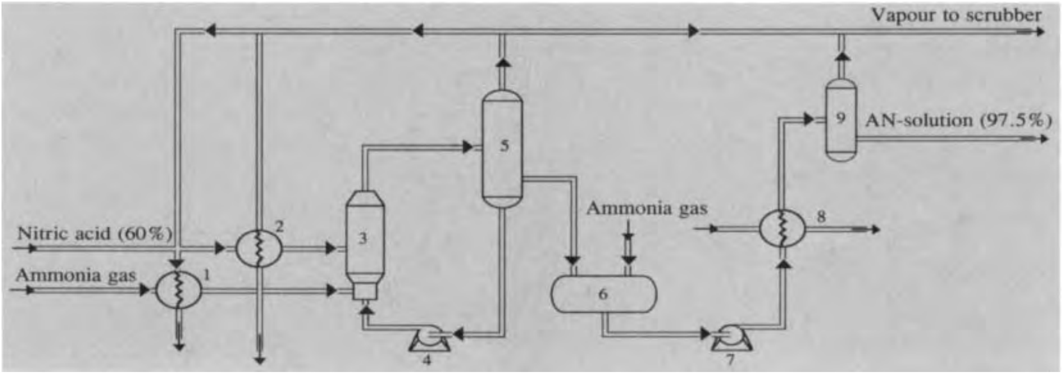


Fig.A.29: Flow chart of ammonium nitrate production 1. Ammonia preheater, 2. Nitric acid preheater, 3. Reactor, 4. Circulating pump, 5. Flash evaporator, 6. Neutralizer, 7. AN-pump, 8. Reboiler, 9. Flash evaporator. (Source: "Fertilizer Manual, 1998, UNIDO, IFDC and Kluwer Academic Publishers, The Netherlands. With permission.)

used for neutralization. When a crystalline product is desired, neutralizations are performed under vacuum. The temperature in the neutralizer for atmospheric pressure neutralization is low (about 145°C).

In a pressure-neutralized process, the neutralizer usually operates at a pressure of 4 to 5 atmosphere and at a temperature of 175 to 180°C. A 50 to 60% concentration of nitric acid is used. Ammonia is fed into the neutralizer in a gaseous form. The neutralizer is operated at a low pH of 3 to 4 to avoid loss of ammonia. More ammonia is added to adjust the pH to 7. The concentration of ammonium nitrate in the neutralized solution is in the range of 80 to 87%. It is evaporated further to a concentration of 94 to 98% by using steam. A final evaporator-concentrator is used to increase the concentration from 99.5 to 99.8%.

Practically all types of evaporators and separators are used in this process. Most fertilizer grade ammonium nitrate is treated with inorganic stabilizers to retard the 32°C crystal transition and to improve storage properties. The most popular salt used for phase stabilization is magnesium nitrate. It is added to hot ammonium nitrate solution prior to its reaching the final concentration. Other salts used as stabilizers include the sulphates of aluminum and iron, ammonium sulphate-calcium nitrate, ammonium phosphate and permalene-34 (a mixture of boric acid, diammonium phosphate and ammonium sulphate). Caking of the product is avoided by coating the prills and granules with very small amounts of anti-caking agents such as oil/amine mixtures.

Several finishing processes such as graining, flaking, granulation, crystallization and prilling are used. In low-density prilling, about 95% ammonium nitrate solution is fed into the prilling tower and the prills formed are cooled and dried. The prills are porous and have an apparent density of around 1.29 g/cm^3 compared to high- density prills with a density of 1.65 g/cm^3. Low density prills are used in explosives and as blasting agents.

The high-density prillng process uses more than 99% concentrated solution of ammonium nitrate. This process needs expensive fume abatement equipment and has low flexibility for producing different nitrogen containing products. The product size is limited and the prills are less hard.

The granulation process, unlike the prilling process, has the advantage of producing different particle sizes. A rotary pan, a rotary drum and fluid bed processes are used in granulating ammonium nitrate.

Industrial neutralization processes for ammonium nitrate: Various industrial neutralization processes for ammonium nitrate are: (a) Uhde neutralization under vacuum or atmospheric pressure, (b) Uhde neutralization under 0.2 to 0.25 MPa pressure, (c) Hydro-agri neutralization under 0.4 to 0.5 MPa pressure, (d) Carnit neutralization at 0.7 to 0.8 Mpa, and (e) pipe reactor neutralization (AZF).

Uhde neutralization under vacuum or atmospheric pressure process calls for a relatively low investment cost. The 304L stainless steel reactor is slightly pressurized to prevent ammonium nitrate solution from boiling due to the heat of the neutralization reaction. The ammonium nitrate solution is evaporated in a flash evaporator to remove some water and cooled to reach a 95% concentration of ammonium nitrate. The neutralization conditions are 0.03 to 0.12 MPa pressure and a temperature of 130 to 145°C. Uhde neutralization under 0.2 to 0.25 MPa pressure process was mainly developed to balance heat requirements. The heat of reaction is used to concentrate ammonium nitrate via a heat exchanger. In the **hydro-agri neutralization process**, neutralization is carried out under a pressure of 0.4 to 0.5 MPa and a temperature of 175 to 185°C. The process calls for reactors made of specialized materials like titanium or low carbon 304L.

The **CARNIT process** operates at 185°C at a reactor output pressure of 0.75 MPa. The neutralization is carried out in: (a) alkaline solution for which a low carbon stainless steel reactor is used, and (b) acidic solution for which a titanium reactor is installed. The alkaline hot solution passes through a steam boiler and a falling film evaporator made of low carbon stainless steel. The concentrated solution is recycled to the reactor where additional nitric acid is added before flashing and scrubbing.

In the **AZF-Grand Paroisse prilling process**, neutralization is carried out in a pipe reactor using gaseous ammonia and preheated nitric acid to directly give ammonium nitrate melt of up to 97% concentration. A concentrated 95 to 97% ammonium nitrate solution overflows from the tank to the pump tank. If the ammonium nitrate solution is less than 96%, it is first concentrated in a falling film evaporator.

The important industrial finishing processes include the (a) AZF-Grand Paroisse prilling process, (b) GIAP neutralization/prilling technology, (c) granulation processes, and (d) production of straight granulated ammonium nitrate.

In AZF Paroisse prilling, the ammonium nitrate solution from the pipe reactor (after the neutralization step) is first concentrated to 99.8% in an air swept falling film evaporator, with steam condensing in the shell. The solution is sprayed from the top of the prilling tower. Fans located at the top ensure a counter current flow of cooling air against the falling droplets. The prills are collected at the bottom for discharge to drying, cooling and screening operations. For porous ammonium nitrate prills, 95% solution is used to dissolve the off-specification material. The main producers of high density prills are Russia and other Republics of the erstwhile Soviet Union.

GIAP neutralization/ prilling technology is a high density prilling process. In this process, neutralization is carried out at 70 to 90°C to get 89 to 92% ammonium nitrate solution. This solution is further concentrated to 99.7 to 99.8% of ammonium nitrate and fed to the spray heads of special design to form 'uniform' prills. The spray heads in conjunction with a fluidized cooling bed can provide up to 85% prills of 2 to 3 mm diameter.

Stabilizers are added to the ammonium nitrate solution and the prills are conditioned prior to bagging. The main features of this process are its simple operation and high reliability.

The disadvantages of prilling are its difficult emission control, limited product size and lower product hardness. Granulation processes are flexible and allow easier emission control. Granulation gives a coarser product than prilling, thereby minimizing the segregation of bulk blended fertilizers.

The advantages of granules are that these are free flowing materials which allow mechanized handling and distribution; they also have a high bulk density, reduced amenability to dust formation and leaching losses. The particle size of prills (usually <2.5 mm) is much smaller than that of granules. In addition, the crushing strength of prills is lower, their porosity higher and their bulk density lower. These physical properties imply unfavorable agronomic effects in fertilizer application techniques. Larger sized prills are possible only by increasing the tower height, which entails increased investment costs.

The following granulation processes are available for the production of straight ammonium nitrate (of 30 to 34.5% nitrogen content): (a) cold spherodizers, (b) drum, (c) pug mill, (d) pan, (e) fluid bed, and (f) fluidized drum. However, the concentration of ammonium nitrate melts (wt %) is different, and is as follows: (a) drum, 96 to 96.5, (b) pug mill, 95.5 to 96, (c) pan granulation, >99.5, (d) fluid bed granulation, >99, and (e) fluidized drum granulation, >97.5. In all methods, additives are essential for granulation and for improving storage properties.

In the granulator, a hot, virtually moisture-free melt is sprayed onto the moving bed of solids to solidify on the cool particles. Round granules get formed by agglomeration. As the size increases, they move upwards and roll over the rim of the rotating pan. The granulation temperature is controlled by the rate at which the solids are fed into the pan. The recycle ratio is about 0.5/0.7:1 for ammonium nitrate. The granules formed have an irregular surface and are smoothened by cooling and polishing. The cooled granules are conveyed to a screen. Over-sized materials from the screen are fed to a crusher, and crushed materials, under-sized granules and dust from cyclones are recycled. A wet scrubber may be used for recovery.

The **fluidized drum granulation** process consists of a rotary drum fitted with lifters and a fluidized bed installed inside the granulator. It is swept with conditioned air as per the need. The seed material fed to the granulator undergoes a size increase, and cooling and/or drying, as the case may be, occurs in the granulator in a series of cycles. The number of cycles required to obtain the desired particle size is determined by the residence time in the drum and is controlled by an adjustable overflow threshold.

Various additions such as micronutrients, fillers or other specific additives can be added with the sprayed product. The heat balance and granulation behaviour determine how much recycle material has to be dissolved in the ammonium nitrate melt and how much can be recycled as dry matter to the drum.

The **crystallization process** is very similar to the prilling process up to the point of evaporation. The liquor containing 80 to 85% solids is transferred from the vacuum evaporator to a vacuum crystallizer where crystal growth is controlled to yield large crystals for fertilizer use at about 40°C. The crystals along with the slurry are centrifuged. The crystals are dried in a rotary drier and the mother liquor is returned to the evaporator.

The **Stengel process** is based on vapor phase reaction in a packed stainless steel reactor. This process, which is not of commercial importance, produces a flaked product unlike the other processes, which give a spherical shaped pellet or granule.

Pollution control requirements have become stringent in recent times. This is more so for high-density ammonium nitrate prilling in view of high melt temperatures as well as the large volume of air exhausted from prill towers. The air fumes exhausted from the prilling tower contain very small particles of ammonium nitrate. Fuming is more severe in high-density prilling in view of the dissociation of ammonium nitrate at that temperature. The dissociated products recombine in the cooler parts and have particles of submicron size. The problem is less serious with low density prilling because of lower solution temperatures. Even in the granulation processes, the problem is less serious because of much smaller volumes of air being in contact with hot solution. The process vapors containing small amounts of ammonium nitrate and nitric acid may be freed from these impurities by means of droplet separators (demister pads, wave plate separators, etc.) and/or scrubbing systems (packed columns or venture scrubbers).

The emission of ammonium nitrate mists, which may also occur during the neutralization and evaporation processes are, however, difficult to remove due to their submicron size. The process vapors are normally condensed and purified by stripping, ion exchange or reverse osmosis. The exhaust air from prilling or granulation contains ammonia and ammonium nitrate and is not absorbed by applying the usual scrubbing methods and is quite visible as a persistent blue haze. Such a haze can have tremendous environmental consequences. To avoid this haze and to reduce emission of submicron ammonium nitrate aerosols, fiber mist eliminators are installed.

Ammonium nitrate-pulverized dolomite

Ammonium nitrate-pulverized dolomite is a grey colored mixture of ammonium nitrate and pulverized dolomite. It is manufactured at Hopewell, Virginia, in the United States.

Ammonium nitrate sulphate

Ammonium nitrate sulphate has two grades - 30-0-0-5(S) and 27-0-0-11(S). These two grades are available commercially in a granular form, and both are less hygroscopic than ammonium nitrate (NH_4NO_3). The first grade contains 21% ammonium sulphate and 79% ammonium nitrate, and the second has 46.2% ammonium sulphate and 53.8% ammonium nitrate. These are made either by blending in bulk (for direct application) or by neutralizing a mixture of nitric acid and sulphuric acid with ammonia. The two salts, both fast and slow reacting fertilizers, are applied directly to forage, small grains, grass, seed crops, etc.

Ammonium nitrophosphate

Ammonium nitrophosphate is another name for **ammonium phosphate nitrate**.

Ammonium orthophosphates

Ammonium orthophosphates are important members of the phosphate fertilizer family, formed by the reaction of anhydrous ammonia with orthophosphoric acid (H_3PO_4). Monoammonium phosphate (**MAP**) and diammonium phosphate (**DAP**) are the two major forms of ammonium orthophosphates.

Ammonium orthophosphates are applied to soil either directly, or as a solution, or in a suspension form, depending on the proportion of insoluble phosphates present in the soil.

Ammonium phosphate

Ammonium phosphates refer to a generic class of phosphorus fertilizers and are manufactured by reacting anhydrous ammonia with orthophosphoric acid or superphosphoric acid. These are either in solid or liquid form.

Anhydrous ammonia added to liquid phosphoric acid gives monoammonium phosphate (**MAP**) which contains about 11% nitrogen and 21% phosphorus vide the reaction:

$$NH_3 + H_3PO_4 \longrightarrow NH_4H_2PO_4$$

With more ammonia, technical grade diammonium phosphate (**DAP**) containing 16 to 18% nitrogen and 20 to 21% phosphorus is formed by the reaction:

$$2NH_3 + H_3PO_4 \longrightarrow (NH_4)_2HPO_4$$

Ammonium phosphate fertilizers are highly soluble in water and fast acting in soil to give nitrogen and phosphorus in a chemical combination. They form an important base for many compound fertilizers.

Both mono and diammonium phosphates have good physical properties when synthesized from the wet-process phosphoric acid. Storage properties and the ease of granulation depends on the amount of impurities, which form a gel like structure (mainly aluminum and iron phosphates). This gel promotes granulation and serves as a conditioner to prevent caking even at moderately high moisture levels. A small proportion of phosphate rock added to phosphoric acid before ammoniation improves the granulation.

Ammonium phosphates, particularly diammonium phosphates (DAP), are the most popular phosphate fertilizers worldwide because of their high utility and good physical properties. The standard **commodity grade of diammonium phosphate** is 18-46-0. Pure and completely soluble ammonium phosphates are used mainly as liquid fertilizers. In Britain, diammonium phosphate is not sold directly in this form, but is used to make compound fertilizers with a wide variety of plant foods. DAP contains 21% nitrogen and 23% phosphorus (54% P_2O_5).

Diammonium phosphate is unstable at temperatures above 150°C while monoammonium phosphate remains stable even at much higher temperatures. These two fertilizers usually form a part of concentrated compound fertilizers and are rarely used individually in their pure states.

Granular DAP is commonly produced by a slurry process, developed by TVA (Tennessee Valley Authority) or the Jacobs-Dorrco Industrial Process. In the wet process, acid of about 40% phosphorus pentoxide (P_2O_5) is reacted with ammonia in a preneutralizer where the mole ratio of NH_3:H_3PO_4 is controlled at about 1.4. The heat of the reaction raises the slurry temperature to boiling point (about 115°C). The hot slurry containing about 16 to 20% water is pumped into the granulator, where more ammonia is added to increase the molar ratio to approximately 2.0. Moist granules are dried, screened and cooled, while the undersized and crushed oversized ones are recycled. Escaping ammonia is recovered by scrubbing with weak acid. The same equipment is used to produce monoammonium phosphate, wherein the preneutralizer is operated at a molar ratio of about 1.4. The phosphoric acid is then added into the granulator to decrease the ratio to 1.0.

Pure monoammonium phosphate is completely water-soluble and contains 12% nitrogen and 21% phosphorus (as 52% P_2O_5). The production of non-granular monoammonium phosphate has been achieved by a number of processes developed for use as an intermediate in the production of complex fertilizers, by Scottish Agricultural Industries, Fison's Ltd., Swift Agricultural Chemicals, Nissan and ERT Espindesa to name a few. In general, all processes aim at a simple, low cost method by eliminating granulation, recycling and drying. Though the production of powdered monoammonium phosphate is on the decline, it is still in use because of its high phosphorus content (as P_2O_5).

In addition, a group of fertilizers, such as ammonium phosphate-sulphates, **ammonium phosphate-chloride** and ammonium phosphate-nitrate are produced by a number of processes involving the neutralization of ammonia with a mixture of phosphoric acid and plant waste acids like sulphuric acid, nitric acid or hydrochloric acid. These fertilizers are free flowing and non-hygroscopic (or less hygroscopic) compared to the individual components, and have been successfully used in many types of soils.

Ammonium phosphate chloride: See Ammonium phosphate

Ammonium phosphate nitrate

Ammonium phosphate nitrate (**APN**), also called **nitric phosphate** or **ammonium nitrophosphate**, is an acidic fertilizer produced by reacting phosphate rocks with nitric acid. It contains nitrogen in ammoniacal and nitrate forms and phosphorus as phosphate. APN is made either by the **Odda route** or by the **mixed-acid route**, covering a range of formulations with N:P_2O_5 ratios between 0.5 and 2.0. The most popular formulations are 20-20-0, 25-25-0, 20-10-10, 15-20-15 and 12-24-12, where the equivalent acidity is about 491 kg of calcium carbonate ($CaCO_3$) per ton of the fertilizer.

Nitrophosphates are manufactured in granular form for direct application or blending. Calcium nitrate, which is a hygroscopic reaction product, is removed by refrigeration and centrifugation, or is converted to calcium carbonate by injecting carbon dioxide. Some processes employ sulphuric or phosphoric acid, along with nitric acid, to convert a part of the calcium nitrate to calcium sulphate or calcium phosphate. The acidified slurry is then ammoniated. The final product contains an assortment of salts.

The water solubility of nitric phosphates may vary from 0 to 80%, depending on the process used. Nitric phosphate containing 30% or less water-soluble phosphorus is thus not a recommended fertilizer for plants that respond to such phosphorus. Nitric phosphates give best results on acidic soils. They are suitable for turf and sod crops, and sugar cane which has a relatively long growing season.

There are several processes involved in the production of fertilizers containing ammonium phosphate and ammonium nitrate. Most of these are used to produce NPK grades. A slurry of concentrated ammonium nitrate solution (97%) and ammonium phosphate is used to produce ammonium phosphate nitrate in a rotary drum granulator in the **Pechiney-Saint-Gobain process**. The principal product is 17-17-0. Tennessey Valley Authority (TVA) process produces grades of 25-25-0 and 30-10-0. The production rate is 20 t/hour. In **AZF-Grande Paroisse dual pipe-reactor process**, ammonium nitrate solution is directly sprayed on granules in the granulator. APN solutions are made by neutralizing phosphoric acid with NH_3 and NH_4NO_3.

Ammonium phosphate sulphate

Ammonium phosphate sulphate (**APS**), a complex nitrogen-phosphorus-sulphur fertilizer, is composed of 60% ammonium sulphate and 40% ammonium phosphate. It is granular, water-soluble and light grey in appearance. It has good keeping properties and leaves an acid effect on the soil because of ammoniacal nitrogen and sulphate anions.

APS is a popular fertilizer in some areas like the southern parts of India, owing to its non-hygroscopic nature and sulphur content. It is agronomically useful for many crops.

The ammoniacal nitrogen in APS cannot be easily washed away from the soil, because of its adsorption by the soil colloids. Crops like paddy, sugar cane, cotton and potato utilize the ammoniacal form of nitrogen. The phosphorus in APS is water-soluble and suitable for all types of crops (especially short duration crops), as a source of sulphur is present in it to the extent of 15%.

Table-A.5 shows specifications of two grades of ammonium phosphate-sulphate, produced in India.

Table-A.5: APS specifications of two grades in India

Specifications	APS	
	Grade 16-20-0	Grade 20-20-0
Moisture (percent, maximum)	1.0	1.0
Total N (weight percent, minimum)	16.0	20.0
Total ammoniacal N (percent, minimum)	16.0	18.0
Nitrogen in the form of urea (weight percent, maximum)	-	2.0
Ammonium citrate-soluble phosphates (as P_2O_5) - neutral (minimum)	20.0	20.0
Water-soluble phosphate as P_2O_5 (weight percent, minimum)	19.5	17.0
Particle size: 90 percent of the material should pass through 4 mm IS sieve and retain on 1 mm IS sieves. More than 5% material should not have a diameter smaller than 1 mm. Sulphur is generally not specified.		

Source: "Sulphur Fertilizers for Indian Agriculture-A guide book", Edited by HLS Tandon. Fertilizer Development and Consultation Organisation, New Delhi. With permission.

Ammonium phosphate sulphate is produced by two methods. In the first, a mixture of sulphuric and phosphoric acids is neutralized by ammonia before the resulting slurry is granulated. To achieve this, phosphoric acid, sulphuric acid and ammonia are introduced, using appropriate metering and control mechanisms, into the first reaction tank. In the second reaction tank, a finer pH adjustment is made by adding an appropriate amount of ammonia. The neutralized slurry, ammoniated to a mole ratio of 1.8 or 2% and urea are added to raise the nitrogen content to 20%, and granulated. The granules are dried by hot air and screened by double-decked vibrating screens. This results in a granulated free flowing APS.

In the second method, ammonium-sulphuric acid solution from the gypsum ammonium carbonate process is added to phosphoric acid and then the mixture is ammoniated. Again, urea is added, as in the first method, to bring the nitrogen content to the required level. When a 20-20-0 grade is required, an allowance of 2% in ammoniacal nitrogen (18% minimum) is made to accommodate the nitrogen in the form of urea (2%

maximum). A total nitrogen content of 20% is also stipulated. When a 16-20-0 grade is required, the entire nitrogen (16%) is specified to be in the ammoniacal form, whereas for water-soluble phosphate, the minimum stipulated concentrations of nitrogen are 19.5% for the 16-20-0 grade and 17% for the 20-20-0 grade. The sulphur content often remains unspecified in the Fertilizer Control Order (FCO).

Ammonium polycarboxylate

Polycarboxylic acid is an organic acid containing two or more carboxyl groups in a molecule. The ammonium salt of any polycarboxylic acid is called ammonium polycarboxylate. Coal distillation gives carboxylic acids which, on ammoniation, can be used as a fertilizer or blended with other fertilizers.

Ammonium polyphosphate

Ammonium polyphosphate (**APP**) is made by ammoniating hot superphosphoric acid containing about 79% phosphorus pentoxide. It is also produced by a direct reaction of anhydrous ammonia with orthophosphoric acid, eliminating water. It has good storability and can be pumped out when required. The solid granular fertilizer contains 15% nitrogen and 62% phosphorus (as P_2O_5).

Ammonium polyphosphate is used to produce complete liquid fertilizers for direct application. Both liquid and solid ammonium polyphosphates are available. A nitrogen-phosphorus-potassium grade, using the mixture plus muriate of potash and nitrogen solution, is 5-5-8 (N:P:K). The fertilizer contains ammonium orthophosphate, ammonium pyrophosphate and some longer chain polyphosphate components. When applied directly, the crop response is similar to that with liquid fertilizers or water-soluble dry fertilizers. When water solubility of phosphorus is important, liquid fertilizers are considered superior to solid fertilizers that contain some amount of water-insoluble phosphorus. Ammonium polyphosphate is a **chelating agent** as it maintains a higher concentration of micronutrients than is possible with orthophosphate solutions. For example, ammonium polyphosphate can maintain 2% zinc in solution as compared to 0.05% zinc with phosphates.

The process for producing granular ammonium polyphosphate uses heat of reaction of phosphoric acid (54% P_2O_5) with gaseous ammonia to evaporate the water and dehydrate ammonium phosphate, forming a melt. The melt, which can be granulated, usually contains 15 to 25% P_2O_5 as polyphosphate, but it can be increased to almost 50% by preheating the acid and ammonia, or by using a more concentrated phosphoric acid. The melt is granulated in a pugmill or a rotary granulator. The advantage of the process is that the product has very low moisture content and needs no drying. In addition, the products have good storage properties.

Polyphosphate, before being taken up by crop plants, must undergo hydrolysis to form orthophosphates. The hydrolysis is brought about by enzymes such as pyrophosphatase, which are present in the soil. The half-life of the polymeric forms of phosphorus in liquid ammonium polyphosphate is 1.6 to 2.0 days under anaerobic conditions and 5.2 to 8.7 days under aerobic conditions. The corresponding values of solid ammonium polyphosphate are 3.9 to 9.2 days under anaerobic and 12.5 to 27.0 under aerobic conditions.

It is established that hydrolysis rate is highest in laterite, intermediate in sodic and slowest in alluvial soils. The soil factors that affect hydrolysis are pH, temperature, texture and water content. (See also Polyphosphate fertilizers.)

Ammonium polysulphide

Ammonium polysulphide exists only in solution. It is made by passing hydrogen sulphide through a 28% ammonium hydroxide solution and then dissolving additional sulphur in the resulting solution. This solution, which is red to brown to black in color, contains about 45% sulphur and 20% nitrogen and has the odor of hydrogen sulphide. It can be mixed with other liquid fertilizers like anhydrous ammonia, aqua ammonia and urea-ammonium nitrate solutions.

To ensure reasonable stability, the mixed liquid fertilizer should not contain more than 10% of ammonium polysulphide, as it is incompatible with polyphosphate containing liquids.

Ammonium polysulphide is stored under pressure (0.1 kg/cm^2), in view of its high vapor pressure. It is stored under pressure also to prevent the loss of ammonia and the precipitation of sulphur. It is also used for reclaiming highly acidic soils and for treating irrigation water. Another instance of polysulphide is potassium polysulphide [0-0-22-23(S)], which is used in sprinkler and flood irrigation systems, to remove salts and supply potassium.

Ammonium pyrophosphate

Ammonium pyrophosphate is a phosphate fertilizer based on non-orthophosphoric acid. Its common grade is 10-34-0. It is made by reacting pyrophosphoric acid with ammonia.

Pyrophosphoric acid is made by dehydrating phosphoric acid obtained by the wet acid process (Fig.A.30). Polyphosphate denotes two or more orthophosphate ions ($H_2PO_4^-$) combined after the loss of a water molecule per two orthophosphate ions; the simplest form is the pyrophosphoric acid, ($H_4P_2O_7$).

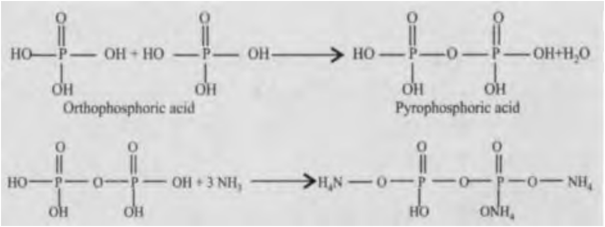


Fig.A.30: Chemical reactions involved in the formation of pyrophosphoric acid and ammonium pyrophosphate.

Triammonium polyphosphate is a liquid containing 10 to 15% nitrogen and 15 to 16% phosphorus (or 34 to 37%

P_2O_5). Granulation during manufacture results in a solid product 11-55-0 which can be applied directly or blended with other granular fertilizers. The addition of a 99.5% urea solution gives a granular urea-ammonium polyphosphate, called **urea-ammonium polyphosphate (UAP)**, with a product composition of 28-28-0 which has 100% water-soluble phosphorus. Liquid ammonium polyphosphate is more popular and is applied either directly or mixed with other liquid fertilizers.

Ammonium polyphosphates are known for their ability to chelate or sequester metal cations. They maintain a higher concentration of micronutrients - 2% zinc ion as against orthophosphate solution, which holds a mere 0.05% zinc ion. (Fig.A.31).

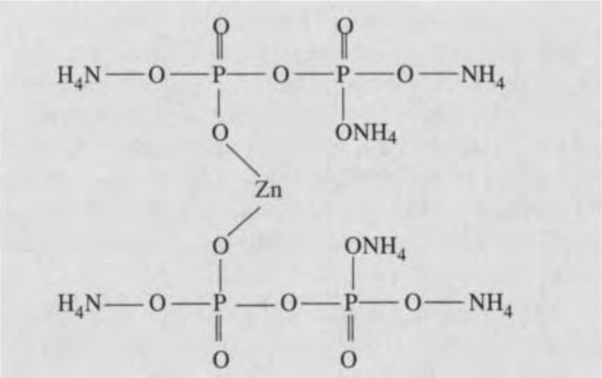


Fig.A.31: Zinc chelate of ammonium pyrophosphate.

Ammonium sulphate

Ammonium sulphate, $(NH_4)_2SO_4$, a water-soluble crystalline salt is a nitrogenous fertilizer containing about 21% nitrogen and 24% sulphur. It occurs naturally as the mineral mascagnite and offers many advantages as a fertilizer, such as low hygroscopicity, good physical properties, excellent chemical stability, good agronomic effectiveness and long shelf life.

Ammoniacal nitrogen is fixed in the soil in an exchangeable form until nitrated by nitrifying bacteria. The ammoniacal nitrogen of ammonium sulphate does not leach out easily. Ammonium sulphate is an acid forming fertilizer, and hence used in neutral or alkaline soils. In its free flowing form, it is directly applied to the soil or blended with other granular materials. Ammonium sulphate also supplies sulphur, which is an essential nutrient for plants.

Ammonium sulphate is a quick-acting fertilizer. It is resistant to leaching as it gets adsorbed on the soil colloids, clay and humus, and replaces calcium. This adsorbed ammonium salt is converted to nitrate by nitrifying bacteria for use by growing plants.

Ammonium sulphate is produced in different ways. The major ones are: (i) Production from synthesized ammonia and sulphuric acid.

$$2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

(ii) Production of ammonium sulphate fertilizer by the **gypsum process** is widely used in many developing countries. In this process, ammonia is used along with pulverized calcium sulphate, carbon dioxide and water. Here ammonia made from nitrogen and hydrogen, reacts with carbon dioxide gas to produce ammonium carbonate. Ground gypsum reacts with ammonium carbonate solution to form ammonium sulphate and calcium carbonate.

$$CaSO_4 \cdot 2H_2O + (NH_4)_2CO_3 \longrightarrow CaCO_3 + (NH_4)_2SO_4 + 2H_2O$$

Ammonium sulphate is commonly transported in polythene or paper bags. It is adsorbed on soil colloids, clay and **humus**, replacing calcium. It is more beneficial than nitrate fertilizers at planting time. This adsorbed portion is slowly released and in about a month most of the ammonium sulphate is converted into the nitrate form, which is used by growing plants.

Since rice crops absorb nitrogen even in the ammoniacal form, ammonium sulphate fertilizer is used as a source of nitrogen for rice in the USA and Southeast Asia. In the USA, ammonium sulphate is also used for potato scab control.

The main disadvantages of ammonium sulphate are its acid forming nature, low nitrogen percentage (21%) and high costs for packaging, storage and transportation.

Ammonium sulphate nitrate

Ammonium sulphate nitrate, $(NH_4)_2SO_4 \cdot NH_4NO_3$ is a double salt fertilizer formed by the neutralization of waste acid by ammonia and subsequent crystallization. It has a higher nitrogen content (about 26%) than ammonium sulphate (21%), and can make soil acidic.

Ammonium sulphate nitrate (**ASN**) is a less hygroscopic fertilizer than ammonium nitrate and thus solves the problem of disposing waste acid and liquors produced in nitrating reactions.

Mixing moist salts containing 62.5% ammonium sulphate and ammonium nitrate also produces ammonium sulphate nitrate. The following three double salts are used routinely.

$$(NH_4)_2SO_4 \cdot NH_4NO_3$$
$$(NH_4)_2SO_4 \cdot 2NH_4NO_3$$
$$(NH_4)_2SO_4 \cdot 3NH_4NO_3$$

If a small quantity (1%) of ferrous sulphate is added during crystallization, ammonium sulphate nitrate is obtained as a free flowing solid; otherwise, it sets into a hard cake during storage.

Tennessee Valley Authority (TVA) produces ammonium nitrate-sulphate containing 30% nitrogen, mainly $(NH_4)_2SO_4$, $3NH_4NO_3$, by ammoniation of a mixture of nitric-sulphuric acid, followed by pan granulation of the resulting slurry. Its storage properties are superior to those of the individual components.

Ammonium sulphate production processes

The use of ammonium sulphate as a fertilizer is relatively small compared to that of urea, ammonium nitrate, UAN solutions and anhydrous ammonia.

The crystal size of ammonium sulphate is governed by the requirement and type of application envisaged by the customer. For bulk blending or direct use in fertilizer, large crystals of 1 to 3 mm are preferred; somewhat smaller crystals are acceptable for direct application. Operating experience as well as additives may be needed to obtain crystals of the desired size.

The factors that contribute to good storage of ammonium sulphate and related fertilizer salts are the following: (i) The product should be of uniform size with a low percentage of fines and less than 0.1% moisture. (ii) The product should not have any free acidity. (iii) The product should be cooled with dry air under controlled conditions after drying, to avoid moisture condensation.

Several methods are used for ammonium sulphate manufacture, depending on local conditions and the availability of raw material. The principal methods are as follows:

(i) Reacting ammonia and sulphuric acid in a reactor/evaporator under atmospheric pressure or vacuum, and recovering the crystals by filtering or centrifuging.

(ii) Scrubbing coke-oven gas or tower gas with sulphuric acid in a specially designed reactor and recovering the crystals via centrifuging or filtration.

(iii) Reaction of ammonium carbonate with gypsum, removal of the precipitated calcium carbonate by filtration, evaporation and crystallization of ammonium sulphate, followed by centrifuging the liquor.

(iv) Evaporating the by-product solution containing ammonium sulphate produced from other processes such as caprolactum manufacturing unit, and separating the almost pure salt by crystallizing and centrifuging or recovering by slurry granulation.

(v) Directly reacting gaseous ammonia with sulphuric acid in a spray tower to form anhydrous ammonium sulphate.

(vi) Simultaneous production of ammonium sulphate and other ammonium salts containing multinutrients in granulated fertilizer processes.

(vii) Other miscellaneous processes such as recovering ammonium sulphate from sulphur dioxide in flue gas or in sulphuric acid tail-gas.

(i) **Direct neutralization**: Anhydrous ammonia and strong sulphuric acid are reacted in a continuous saturator-crystallizer unit operating under vacuum or atmospheric pressure as follows:

$$2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

Ammonia and sulphuric acid are introduced via a slurry recycle line, wherein they react and superheat the recycling slurry. The slurry is subsequently flashed in the upper chamber at a reduced pressure (generally between 55 and 58 cm of mercury). The exothermic heat of reaction is removed by evaporating water either present in the feed acid or added to the system for temperature control of the process. The loss of water in this zone super-saturates the slurry which recirculates to the lower suspension vessel via an internal pipe and comes into contact with small crystals and nuclei. This induces further crystal growth in terms of size rather than in number. The slurry is recycled by a thermal syphon and/or by an external pump.

This type of crystallizer is generally known as 'Krystal' or '**Oslo unit**'. During operation the pH control is required to be maintained within close limits (3.0 to 3.5), as otherwise, thin crystals result. The excessive acidity promotes an overgrowth of crystals in the pipelines. A higher pH or a lower acidity leads to inferior crystals which are difficult to wash and store and may cause ammonia losses as well.

In another type of reduced-pressure crystallizer with a draft tube battle unit, growing crystals are brought to the surface of the flashing slurry. At this surface, super-saturation induces maximum crystal growth, and sufficient nuclei are present to minimize the scale formation inside the unit.

Several types of atmospheric pressure units are preferred to a vacuum crystallizer because of their simplicity and lower capital cost. Ammonia is added via a jet-type mixer or a sparger tube. In another design, a simple absorption column incorporating a few large slotted bubble-hoods is used. In some other cases, a single vessel is employed for both reaction and crystallization and the heat of reaction is removed by evaporation of water. There are designs where separate vessels for reaction and crystallization are used for easy operation and closer control. An optimum balance between the cooling-air energy and the yield of crystals is obtained when the crystallization temperature is in the range of 63 to 66°C.

In most cases, the product is recovered from ammonium sulphate slurry by continuous or automatic batch type centrifuge. The product is washed with water and very dilute ammonia and spin-dried again before drying. For small output, top-feed filters are used since the product can be separated, washed and dried in a single equipment.

Ammonium sulphate liquor is corrosive and wetted parts of the equipment are made of stainless steel or rubber lined mild steel. To improve the shape and size, modifiers are used, such as trivalent metallic salts. Small amounts of phosphoric acid or arsenic compounds are added as corrosion inhibitors.

(ii) **Scrubbing of coke-oven gas or town gas**: Bituminous coals used for gas and coke production contain about 1 to 2% nitrogen as ammonia and the ammonia is recovered (2.5 to 3.0 kg of ammonia per ton of coal used). This ammonia byproduct is associated with high temperature carbonization as in coking plants for iron and steel production. However, in view of the low returns for this operation, recovery of ammonia as ammonium phosphate, ammonium thiocynate, ferrocynide, pyridines or tar is being attempted.

Three methods are known for ammonia or ammonium sulphate recovery: direct, indirect and semi-direct.

In the **direct method**, the whole gas stream is cooled to remove tar and then passed through a saturator where it is washed with sulphuric acid. The ammonium sulphate slurry is then centrifuged, washed, dried and stored. The advantages of this process are high recoveries with low effluents, low investment and low operating costs (including low steam needs). However, in many cases the product is contaminated with tar and pyridines. Where the same reactor is used as a scrubber and crystallizer, flexibility regarding the size, shape and the purity of the product suffers because of the difficulty in maintaining the pH and free acidity required to suppress impurities.

In the **indirect method**, the gases are cooled (by recirculating wash liquor and scrubbing) and passed through a bubble-cap type still to release free ammonia from salts. This free ammonia is either stripped with water to get ammonia solution or is sent to a sulphuric acid washer for getting ammonium sulphate. The advantages of this method are that (a) the ammonium sulphate produced is free from impurities, and (b) the process is flexible and can be used to also make aqua ammonia and its derivatives. However, effluent disposal problems are high and so are ammonia losses due to incomplete reaction and absorption.

The **semi-direct process** is a compromise between the direct and indirect methods. The gas is first cooled and washed to remove tar and other condensates. The ammonia released from the small ammonia still is combined with the main gas stream and heated to 70°C. This gas is scrubbed with a nearly saturated solution of ammonium sulphate containing 5 to 6% sulphuric acid at about 50 to 70°C. This process gives higher ammonia recoveries than those attainable by any other process.

(iii) **Ammonium-carbonate-gypsum process**: This method, also known as the **Merseburg Process**, combines ammonia and carbon dioxide to produce ammonium carbonate, which is then reacted with gypsum or anhydrite to yield ammonium sulphate and calcium carbonate in an exothermic reaction (Fig.A.32).

$$2NH_3 + H_2O + CO_2 \longrightarrow (NH_4)_2CO_3$$

$$CaSO_4{\cdot}2H_2O + (NH_4)_2CO_3 \longrightarrow CaCO_3 + (NH_4)_2SO_4 + 2H_2O$$

The exothermic process has many advantages, such as the production of calcium carbonate as a byproduct which is used in cement production and agriculture. This process does not require any sulphur supply. The major disadvantage is the large energy (steam) requirement for ammonium sulphate recovery from a dilute solution.

At the Sindri plant in India, ammonia is absorbed in water and carbonated at a pressure of about 2.1 kg/cm^2 in a series of two aluminum towers. The prepared liquor strength corresponds to approximately 170 g of ammonia and 225 g of carbon dioxide per litre. In the FACT (Fertilizers And Chemicals Travancroe Ltd.), India, jet absorbers are used for preparing ammonia solution and ammonium carbonate liquor in conjunction with a carbonating tower.

Natural gypsum or anhydrite, when used, is ground so that about 90% of the material passes through a 120 mesh sieve. When the byproduct gypsum of phosphoric acid plant is used, the impurities are removed by repulping the filter cake prior to washing and dewatering on a drum or disc filter.

Reactions of ammonium carbonate and gypsum solutions are carried out in a series of wooden vessels or mild steel vessels having steam coils and agitators to give a total retention time of 4 to 6 hours. The slurry produced is filtered and the calcium carbonate cake washed and dewatered. The solution is evaporated and the crystals are centrifuged and dried in a rotary drier at 120°C.

(iv) **Recovery from industrial byproduct liquors**: Ammonium sulphate is recovered from the waste streams of caprolactum, acrylonitrile and certain other processes

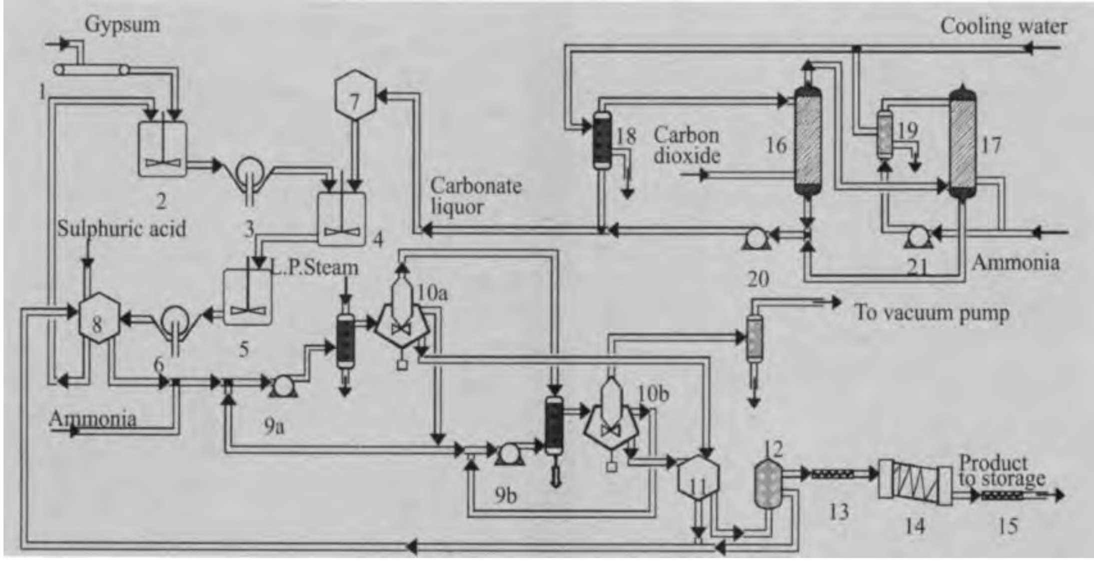


Fig.A.32: Flow chart of the gypsum process of ammonium sulphate production. 1. Gypsum conveyor, 2. Gypsum washing tank, 3. Gypsum dewatering filter, 4. Primary reactor, 5. Secondary reactor, 6. Calcium carbonate filter, 7. Ammonium carbonate storage tank, 8. Sulphate liquor clarifier, 9a and 9b. Evaporator feed pumps, 10a and 10b. Vacuum evaporator crystal, 11. Slurry concentrator, 12. Batch or continuous centrifuge, 13. Dryer conveyor, 14. Rotary dryer, 15. Product conveyor, 16 and 17. Ammonium carbonate towers, 18 and 19. Heat exchangers, 20 and 21. Pumps. (Source: "Fertilizer Manual, 1998, UNIDO, IFDC and Kluwer Academic Publishers. With permission.)

first by concentrating the liquor to around 35% ammonium sulphate. The ammonium sulphate is recovered from the slurry by centrifuging and drying. The process, which is uneconomical because of low concentrations of ammonium sulphate, produces around 1.8 to 4.0 tons of ammonium sulphate per ton of caprolactum.

(v) **Spray-tower ammoniation**: A good amount of ammonium sulphate is made in Japan from spray towers from sulphuric acid and anhydrous ammonia. The acid is sprayed on ammonia vapor inside the tower. The heat of reaction produces a dry amorphous product of less than 300 mesh size. This ammonium sulphate, suitable for granular compound fertilizers, is recovered from the tower by a screw conveyer.

(vi) **Mixed salt production:** Mixed salts of ammonium sulphate and ammonium nitrate are made by ammoniating a mixture of sulphuric acid and nitric acid or by combining these ammonium salts in special ways. Three double salts have been identified and these are $(NH_4)_2SO_4{\cdot}NH_4NO_3$, $(NH_4)_2SO_4{\cdot}2(NH_4)NO_3$ and $(NH_4)_2SO_4{\cdot}3NH_4NO_3$.

One German process produces $(NH_4)_2SO_4{\cdot}NH_4NO_3$ containing 62% ammonium sulphate and 38% ammonium nitrate, by ammoniating the requisite mixture of sulphuric and nitric acids. The mixture is evaporated to a moisture content of 3%. About 1% ferrous sulphate is added to prevent caking. The double salt is granulated after spraying ammonia solution.

In a simpler process, ammonium nitrate solution is evaporated to 95% concentration, cooled to 130°C and reacted with solid ammonium sulphate in a pug mill granulator until a pH of 4.0 is attained. The product is then dried, cooled and bagged. Prilling can also be adopted.

The Tennessee Valley Authority (TVA) produced ammonium sulphate - ammonium nitrate which contains 30% nitrogen. It is used mainly for sulphur-deficient areas. This product is also made by ammoniation of a mixed acid followed by pan granulation of the resulting slurry. Its storage properties are superior to ammonium nitrate or a mixture of solid ammonium nitrate - ammonium sulphate since free ammonium nitrate is absent.

When mixtures of sulphuric acid and phosphoric acid are ammoniated, a variety of mixed and double-salt products can be made. One of the popular compositions is '**ammophos**' containing 16% nitrogen (N) and 20% phosphorus (as P_2O_5). The ammoniated slurry is granulated in a pug mill or a drum unit, then dried and screened. The mixed salt has good storage properties under normal conditions.

Many methods have been developed to recover sulphur from the flue gas, involving scrubbing with ammonia or injection of ammonia into flue gas. From these reactions, ammonium sulphite, bisulphite, sulphate and their mixtures result. Because the demand for ammonium sulphate fertilizer is low, the sulphur from the flue gases is disposed off as calcium sulphate.

Ammonium sulphate recovery by the direct method

Three methods are known for ammonia or ammonium sulphate recovery: direct, **indirect** and **semi-direct methods**.

In the direct method, the whole gas stream is cooled to remove tar and then passed through a saturator, where it is washed with sulphuric acid. The ammonium sulphate slurry is then centrifuged, washed, dried and stored. The advantages of this process are high recoveries and low effluents, low investment and operating costs including low steam needs. However, in many cases the product is contaminated with tar and pyridines. Where the same reactor is used as a scrubber and crystallizer, flexibility regarding the size, shape and the purity of the product suffers because of the difficulty in maintaining the pH and free acidity required to suppress impurities. (See also Scrubbing of coke-oven gas in the production of ammonium sulphate.)

Ammonium sulphate recovery by the indirect method

Three methods are known for ammonia or ammonium sulphate recovery: **direct**, indirect and **semi-direct** processes.

In the indirect method, gases are first cooled (by recirculating wash liquor and scrubbing) and passed through a bubble-cap type still to release free ammonia from salts. This free ammonia is either stripped with water to get ammonia solution or is sent to a sulphuric acid washer for getting ammonium sulphate. The advantages of this method are that (a) the ammonium sulphate produced is free from impurities and (b) the process is flexible and can also be used to make aqua ammonia and its derivatives. However, effluent disposal problems are high and so are losses of ammonia due to incomplete reaction and absorption. (See also Scrubbing of coke-oven gas in the production of ammonium sulphate.)

Ammonium sulphate recovery by the semi-direct method

Three methods are known for ammonia or ammonium sulphate recovery: **direct, indirect** and semi-direct processes.

The semi-direct process is a compromise between the direct and the indirect methods. The gas is first cooled and washed to remove tar and other condensates. The released ammonia from the small ammonia still is combined with the main gas stream and heated to 70°C. This gas is scrubbed with a nearly saturated solution of ammonium sulphate containing 5 to 6% sulphuric acid at about 50 to 70°C. This process gives higher ammonia recoveries than those attainable by any other process. (See also Scrubbing of coke-oven gas in the production of ammonium sulphate.)

Ammonium taranakite

Ammonium taranakite is ammonium aluminum phosphate, $Al_5(NH_4)_4HO(PO_4)_6{\cdot}H_2O$. **Taranakite** represents a group of products formed by phosphate fertilizers reacting with soil constituents.

Ammonium thiosulphate

Ammonium thiosulphate, [$(NH_4)_2S_2O_3$ or **ATS**] is a crystalline salt, the aqueous solution of which is commonly used as a liquid fertilizer. Crystalline ammonium thiosulphate contains 19% nitrogen and 43% sulphur and its aqueous solution contains 12% nitrogen and 26% sulphur.

Ammonium thiosulphate is compatible with nitrogen and nitrogen-potassium solutions, which are neutral or slightly acidic (pH 5.8). It is also used as a suspension. As it is non-corrosive, it can be stored in steel or aluminum drums.

Ammonium thiosulphate is prepared by the reaction of sulphur dioxide and aqueous ammonia, followed by a further reaction with elemental sulphur.

$$4NH_4OH + 2SO_2 \longrightarrow 2(NH_4)_2SO_3 + 2H_2O$$
$$(NH_4)_2SO_3 + S \longrightarrow (NH_4)_2S_2O_3$$

ATS can be applied directly to soils or as a foliar spray through sprinkler irrigation systems. When applied to soils, ATS decomposes into ammonium sulphate and colloidal sulphur. The ammonium sulphate is available immediately to plants, while the sulphur gets oxidized over a period of time to sulphate ion (SO_4^{2-}). It is thus available to plants for a longer time.

Ammonium thiosulphate also acts as a urease inhibitor. When added to a urea-ammonium nitrate solution, it inhibits urease activity for a month or so. In industry, it is also used as a photographic fixing agent, analytical reagent, fungicide and as a brightener in silver-plating baths.

Ammophos

Ammophos is the trade name of one of the most popular brands of ammonium phosphate fertilizers. It contains 16% nitrogen and 20% phosphorus (as P_2O_5).

Ammophos is made by ammoniating a mixture of sulphuric and phosphoric acids. After ammoniation, the slurry formed is granulated in a pugmill or a drum unit, dried, and screened to give a product that is two-thirds by weight of ammonium sulphate and one-third that of ammonium phosphate. This water-soluble product has good storage properties.

Two grades of ammonium phosphate are known. One contains 11% nitrogen and 48% phosphorus (as P_2O_5), the other contains 16.5% nitrogen and 20% phosphorus (as P_2O_5). The first grade is made by neutralizing phosphoric acid with ammonia, and the other is made by neutralizing a mixture of phosphoric and sulphuric acids with ammonia. The first grade of ammophos has a theoretical lime requirement of 5 kg of calcium carbonate per kg of fertilizer, which indicates the acid forming nature of the fertilizer.

Ammonium dihydrogen phosphate sulphate is also called ammoniated sulphate. It is a double salt of ammonium dihydrogen phosphate, $NH_4(H_2PO_4)$ and ammonium sulphate, $(NH_4)_2SO_4$, and is formed by neutralizing a mixture of sulphuric acid and phosphoric acid by gaseous ammonia.

Amorphous humus

Amorphous humus is the dark-colored amorphous colloidal material in soil. It represents a complex fraction of organic matter of plant-animal-microbial origin that resists decomposition.

Amorphous humus, being a colloid, holds water, improves the water retaining properties of the soil and also enhances the soil workability and fertility.

Humus acts as a storehouse of elements which are important to plants and functions as a regulator of soil processes by gradually liberating the nutrients that would have otherwise drained away. A soil rich in humus provides optimum conditions for the development of beneficial micro-organisms and is the best medium for the growth of plants. (See also Humus.)

Amorphous substances

Amorphous substances do not have their constituent basic particles (ions, atoms or molecules) regularly arranged as in crystalline materials. For instance, plasmas, gases and glasses are non-crystalline. Liquids are always in an amorphous state. In gases, the particles are so apart that they can exercise transitional, rotational and vibrational movements and form an assembly of statistically distributed particles. In liquids, the particles exhibit only short-range ordering.

The substances in an amorphous state are **isotropic** which means that their physical properties are the same in all directions.

Solids are subdivided into two categories - crystalline and amorphous. The amorphous solid is rigid and keeps its shape but does not exhibit a crystal structure or crystalline periodicity. Glasses, resins, some plastic substances and metallic glasses are examples of amorphous solids. According to some authors, such substances should be regarded as **super cooled liquids** with very high viscosity ($> 10^{13}$ Pa S).

The obvious uses of amorphous solids include window glass, container glass and glassy polymers; the less recognized uses are as dielectrics and protective coatings in integrated circuits. In optical communications, amorphous solids are used in the form of fibres as a transmission medium.

The variation is the short-range order (and not necessarily the loss of long-range order alone) affects the properties of amorphous semiconductors. One class of amorphous semiconductors is the **glassy chalcogenides**, which contains one or more of the chalcogens - sulphur, selenium or tellurium - as major constituents. These materials have applications in switching and memory devices. Another group contains tetrahedrally bonded amorphous solids, such as amorphous silicon or germanium.

When amorphous silicon or germanium is prepared by evaporation, not all bonding requirements are satisfied. This necessitates a number of dangling bonds to be introduced into the material. These bonds create spaces deep in the gap, which limit transport properties. The thermal annealing below the crystallization temperatures can reduce the number of dangling bonds.

AMP

AMP is short for **adenosine monophosphate**.

Amphiprotic solvent

A solvent such as water that can donate and accept protons is known as an amphiprotic solvent.

$$H_2O + HCl \rightleftharpoons H_3O^+ + Cl^- \text{ (as base)}$$
$$H_2O + NH_3 \rightleftharpoons NH_4^+ + OH^- \text{ (as acid)}$$

Amphoteric

Amphoteric is a compound that can act as both an acid and a base. For example, aluminum hydroxide (also the hydroxides of zinc, tin, lead) is amphoteric because it reacts as an acid with alkalis to give aluminates and also reacts as a base with acids to give salts.

$$\underset{\text{(Acidic)}}{Al(OH)_3} + 3NaOH \longrightarrow Na_3AlO_3 + 3H_2O$$
$$\underset{\text{(Basic)}}{Al(OH)_3} + 3HCl \longrightarrow AlCl_3 + 3H_2O$$

Compounds like amino acids which have both acidic (COOH) and basic (NH_2) groups in their molecules are amphoteric. Water, which can donate and accept protons, is known as an **amphiprotic solvent**.

The existence of amphoteric oxides is considered as evidence of the existence of metalloids.

Amylase

Amylase is an enzyme that hydrolyzes starch. These enzymes, widely distributed in animals and plants, break down starch or glycogen to dextrin, maltose or glucose. Amylase in human saliva is called ptyalin.

Amylopectin

Amylopectin is a **polysaccharide** consisting of various proportions of two glucose units joined by 1-4 linkages. The positions are where the two glucose units are linked to form the corresponding polymer. **Amylose** and amylopectin are examples of this polysaccharide. Amylopectin is less soluble in water and gives red or purple color with iodine.

Amylose

Amylose is a type of **polysaccharide** and is a constituent of starch. Amylose is made up of linear links of several hundred glucose molecules. A water-amylose mixture turns blue when iodine is added to it.

Amylum

Amylum is an ordinary **starch**, that occurs in all green plants. It is a molecule of starch, built out of a large number of a-glucose rings joined by oxygen atoms, and is a major energy source for animals.

Anabaena azollae

Anabaena azollae is a symbiotic cyanobacterium that colonizes the dorsal cavities of leaves of **Azolla**, a floating fern, and fixes atmospheric nitrogen.

***Anabaena-Azolla* symbiosis** : See *Azolla-Anabaena* symbiosis

Anaerobe

Micro-organisms that do not depend on the supply of free oxygen for respiration are called anaerobes. They are capable of living in the absence of free oxygen (gaseous or dissolved) and get the oxygen they need by reducing the oxygen-containing compounds in the soil.

There are two types of anaerobes (a) **obligate anaerobes** which grow only in the absence of oxygen, and (b) **facultative anaerobes** which can grow either in the absence or presence of oxygen. Anaerobes usually live in sewage water and biogas digester chambers.

Anaerobic condition

Anaerobic condition is a reducing condition where no oxygen (or very little oxygen, either gaseous or dissolved) is available to organisms. In the absence of oxygen which is the most common electron acceptor, other substances like nitrate, ferric ion (Fe^{3+}) and carbon act as electron acceptors. Thus, **bacteria** living under anaerobic conditions bring about denitrification wherein nitrate is converted to nitrogen.

In anaerobic conditions, growing plants produce 1-amino cyclopropane-1-carboxylic acid in their roots. These plants are intolerant to a waterlogging environment (poor oxygen transfers to the roots via stems). The acid is translocated to stems and petioles where oxygen is available and where it is quickly converted into ethylene. The presence of a high ethylene content in petioles causes the edges of the leaves to droop (**epinasty**). Leaf wilting may be due to a combination of (a) low water absorption by roots, (b) anaerobic conditions, or (c) water loss from leaves. Anaerobic conditions reduce the transport of growth hormones like gibberellic acid and abscisic acid.

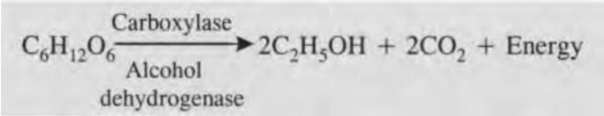
Energy transformation in anaerobic conditions results in poor growth rates. Anaerobic conditions can also promote production of toxic substances like hydrogen sulphide, butyric acid and other volatile fatty acid components of carbohydrate decomposition. These toxins produced in the roots may be transported to the other parts of the plant.

Anaerobic decomposition

Anaerobic decomposition is the incomplete decomposition of organic matter by micro-organisms in an anaerobic environment. Compost, an example of anaerobic decomposition, is used as manure.

Anaerobic respiration

Respiration that proceeds in the absence of oxygen is called anaerobic respiration. Some yeasts and bacteria perform anaerobic respiration. It is also called **intramolecular respiration**.



$$C_6H_{12}O_6 \xrightarrow[\text{Alcohol dehydrogenase}]{\text{Carboxylase}} 2C_2H_5OH + 2CO_2 + \text{Energy}$$

Anaerobiosis

Anaerobiosis is the generation of an anaerobic or oxygen deficient atmosphere. It has a significant effect from an agronomic or biological perspective.

Analysis

Analysis, in general, means to separate something into its constituent parts to facilitate learning more about them. Chemical analysis of a material for instance, involves identification and measurement of the chemical constituents of the material.

There are different types of analyses, such as quantitative analysis, qualitative analysis, instrumental analysis and data analysis. Quantitative analysis involves the measurement of proportions of the components in a chemical mixture. Qualitative analysis determines the nature of pure unknown compounds or components in a mixture.

Qualitative analysis of a fertilizer gives the presence of different nutrients in it, while quantitative analysis gives the percentage composition of the nutrients in the fertilizer. Both chemical and instrumental methods are used in analyzing fertilizers. The analysis helps to designate the percentage composition of the fertilizer expressed in terms of the existing trade practice and law. For example, 28-28-0, indicates the percentage of N,P,K, respectively.

Analysis of variance

Analysis of variance is a statistical method of comparing the averages of observations from different treatments (which include methods, factors, etc.), by comparing the variation among the means with the variation within the observations from the same treatment. If the former is significantly larger (as determined by the **F-test in statistics**) than the latter, the means are declared different and further analysis has to be carried out to determine which method is better. The F-test is also known as the **variance ratio test**.

ANC

ANC is short for **acid neutralizing capacity**.

Anchor roots

Anchor roots are adventitious roots that rise from the internodes to anchor the plant in order to render an upright position. Anchor roots are seen in many crops including corn roots.

Andisols

Andisols are black or dark brown soils with weakly developed horizons, formed from volcanic ejecta as parent material. These form the A horizon which is rich in organic material.

As one among the 12 soil orders, andisols cover less than about 0.7% of the earth's ice-free surface. The parent material of andisols is mostly of volcanic origin and consists of volcanic ash, cinders, pumice and some basalt. Andisols, which exhibit a comparatively low bulk density, are a little more developed than entisols, while retaining the influence of volcanic ejecta.

After extensive **weathering**, andisols can change into another soil order. Rapid weathering is a dominant feature of most andisols which are physically, chemically and mineralogically unique. They are found along the tectonically active Pacific Ring of fire, Central Atlantic Ridge, North Atlantic rift, the Caribbean and the Mediterranean regions, where volcanic or pyroclastic deposits are common. These weakly developed fertile soils are texturally undifferentiated and are characterized by short-range order aluminosilicates not translocated from the upper to the lower horizons.

Andisols are used extensively for crop production in developing countries. Andisols have the following suborders: aquands, cryands, torrands, xerands, vitrands, ustands and udands.

Ando

Ando, the former name for **inceptisols** in the USA, is a dark colored soil rich in organic matter developed in volcanic ash deposits. (See also Soil taxonomy.)

Andrew's method of determining acidity or basicity

Andrew's method of determining acidity and basicity of nitrogenous fertilizers states that each kilogram of fertilizer nitrogen, as ammonia, requires 3.57 kg of chemically pure calcium carbonate for neutralizing the acidity when converted to the nitrate form. (See also Pierre method of determining acidity or basicity.)

Angle of repose

The angle of repose is the angle that the sloping surface of a heap of loose material poured on a horizontal surface makes with the horizontal surface. The International Standardization Organization (ISO) defines it as the angle at the base of a cone of fertilizer formed with the vertical axis, as the material is allowed to fall onto a horizontal base plate under specified conditions.

The particle shape, size and surface texture of a fertilizer influence its angle of repose. Knowledge of the angle of repose is necessary for the design of hoppers, chutes and conveyors that carry the fertilizer, and of the sloped roofs of fertilizer bulk storage buildings.

The ISO procedure for measuring the solid fertilizer static angle of repose (ISO 8398) involves pouring a sample through a funnel into a level base plate, measuring the diameter and height of the conical pile and calculating the base angle of the cone from these measurements (Fig.A.33).

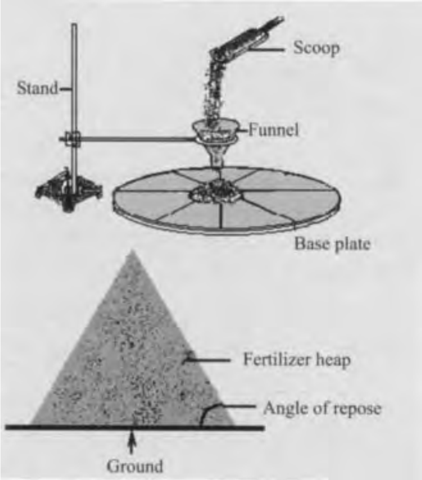


Fig.A.33: An apparatus for determining the angle of repose of fertilizers.

The values of the angle of repose for fertilizers normally range from about 25 to 40°. Spherical products like prilled urea, have a low angle of repose (< 30°) and irregularly shaped products like granular KCl have a high angle of repose (> 35°). Larger materials have higher angle of repose values than fine materials. In most rocks and sands, the angle of repose is 30 to 35°.

Angles of repose for different fertilizers are given in Table-A.6.

Table-A.6: Angles of repose for different fertilizers

Sr. No.	Name of fertilizer	Grade	Angle of repose
1.	Prilled urea	46-0-0	27-28
2.	Granular urea	46-0-0	34-38
3.	Granular ammonium sulphate	21-0-0	36-38
4.	Crystalline ammonium sulphate	21-0-0	29-36
5.	Prilled ammonium nitrate	34-0-0	29-38
6.	Granular diammonium phosphate	18-46-0	27-37
7.	Granular monoammonium Phosphate	11-55-0	28-37
8.	Powdered monoammonium phosphate	10-50-0	30-34
9.	Granular triple superphosphate	0-46-0	28-35
10.	Granular potassium chloride	0-0-60	32-41
11.	Coarse potassium chloride	0-0-60	31-35
12.	Standard potassium chloride	0-0-60	28-32
13.	Granular potassium sulphate	0-0-50	28-35
14.	Phosphate rock (different sources)	-	30-35

Source: "Fertilizer Manual", 1998 UNIDO, IFDC and Kluwer Academic Publishers, The Netherlands. With permission.

Angstrom

Angstrom, a basic unit of length, formerly used to measure wavelength and intermolecular distances, is named after a Swedish physicist, Anders J. Angstrom who studied the solar spectrum. Angstrom is not an S.I. unit and it has now been replaced by nanometer. 1 A° = 0.1 nanometer.

$$1 \text{ Angstrom } (A^{\circ}) = 1\times10^{-10}\text{m} = 1\times10^{-8}\text{cm}.$$

Anhydrite

Anhydrite is a naturally occurring, solid, white mineral called anhydrous calcium sulphate ($CaSO_4$). It differs from gypsum in hardness and in hydration. It is used as a raw material in the chemical industry and in the manufacture of fertilizers and cement.

Anhydrous ammonia

Anhydrous ammonia is an ammonium fertilizer made by the **Haber-Bosch process**, by reacting hydrogen with nitrogen in the ratio of 3:1 at high temperatures (450 to 500°C) and pressure (about 500 atm) in the presence of an iron catalyst promoted by potassium and alumina. The nitrogen derived from air and the hydrogen obtained from (a) synthesis gas, (b) steam reforming of naptha, coal or coke (c) lignite, or (d) electrolysis of water, are purified by standard procedures before use. The anhydrous ammonia thus produced can be directly used as a fertilizer. It can also be converted to ammonium salts which are important fertilizers, by reacting ammonia with nitric, sulphuric and phosphoric acids. Anhydrous ammonia is also reacted with carbon dioxide to get urea which is another important source of nitrogen.

Anhydrous ammonia is an important fluid fertilizer and is the cheapest nitrogen source, having the highest nitrogen content (about 82%) among nitrogenous fertilizers. However, because of safety and environmental considerations, many dealers and users are now switching over to other sources of nitrogen.

Anhydrous liquid ammonia can cause dehydration of tissue and severe damage to the skin, lungs and eyes by its freezing and caustic action. Because of the low vapor pressure (6 bar at 10°C, 9 bar at 20°C and 12 bar at

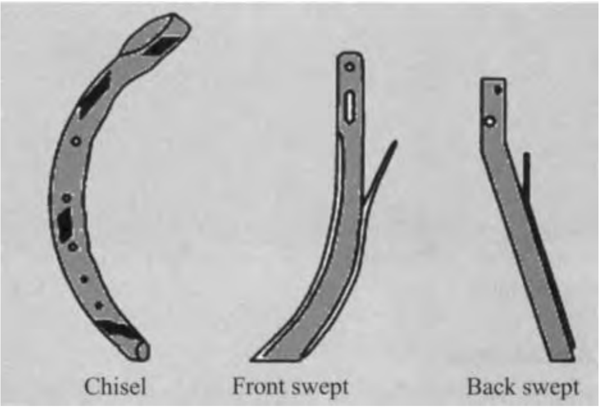


Fig.A.34: Tools used in the application of anhydrous ammonia.

30°C), anhydrous ammonia must be stored and transported in pressure vessels.

Due to the volatile nature of anhydrous ammonia it has to be injected with an applicator 15 to 30 cm below the soil surface to be effective and to reduce ammonia loss (Fig.A.34). Ammonia loss depends on the soil type, its moisture content, and the depth to which the applicator is injected (Fig.A.35).

Ammonia applicators range in size from small 5-row rigs to large rigs that have a swath width of upto 20 m (65 feet) and are pulled by high-powered tractors. Anhydrous ammonia is usually metered by a variable orifice-type meter or by a piston pump.

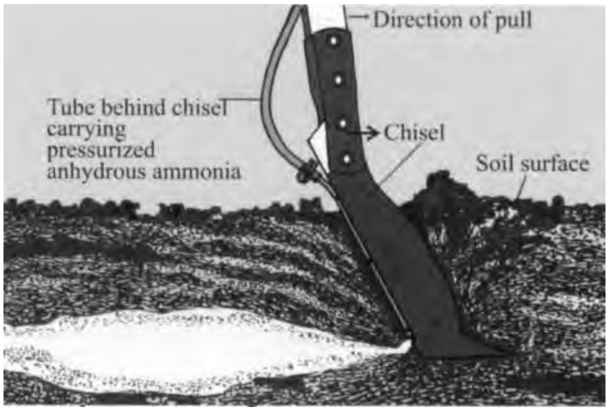


Fig.A.35: Anhydrous ammonia gas released in the soil under pressure (behind the chisel) at a depth of about 15cm gets adsorbed on soil particles.

Physical properties of anhydrous ammonia are somewhat similar to other liquids under pressure like butane or propane gas. Because of the difficulties in handling anhydrous ammonia, water solutions of ammonia, urea, ammonium phosphate or other soluble solid nitrogen materials are used widely. Anhydrous ammonia is also used in the preparation of protein feeds for cattle and sheep, and as a defoliant to hasten the shedding of cotton leaves to facilitate mechanical harvesting.

Anhydrous ammonia sulphur

The sulphur compound in N/P/-/S fertilizer reacts with nitrogen to provide 5 to 20% sulphur to the fertilizer. This sulphur, being an integral part of the fertilizer, may be oxidized more rapidly than when it is added separately. Thus, sulphur is added (up to 10%) to anhydrous ammonia to provide sulphur and nitrogen to growing plants. This compound is called anhydrous ammonia sulphur. When injected into the soil, most of the sulphur separates and is oxidized slowly to sulphate ion. The other sulphur containing fertilizers are urea-sulphur, sulphur fortified superphosphate and sulphur suspensions containing 3% attapulgite clay as a flocculent.

Animal meals

Animal meals are organic manures derived from animal wastes or by-products at butcher shops, slaughterhouses and carcass disposal plants. These include horn meal, bone meal, blood meal, hide meal, feather meal, meat, and carcass meal.

Horn meal (horns, hoofs, claws, etc.) consists mainly of protein and keratin which decomposes slowly. The main constituent of **bone meal** is protein collagen, which is extracted by hot water and steam, and applied mainly as a phosphate fertilizer. **Blood meal** often contains other slaughterhouse wastes such as intestine contents and has a short-term effect on nitrogen supply. The main constituents of **hide meal** are skins and hair, where the effect of the nitrogen supply is quite slow. Sometimes, it is contaminated with toxic chromium salts. **Feather meal**, like horn meal is a slow nitrogen-releasing fertilizer with nitrogen content of around 13%.

Meat and carcass meals are short-term nitrogen suppliers and are converted into organic fertilizers because they contain a high proportion of protein. Table-A.7 gives nutrient contents of some animal waste-based manures.

Table-A.7: Nutrient contents (% dry matter) in animal waste-based manures

Nutrient content	Horn meal	Blood meal	Feather meal	Bone meal	Carcass meal
N	10–14	9–13	12	4–6	6–11
P	0.4–4.0	0.2–1.0	0.3	7–12	2.4–7.0
K	0.2–0.8	0.2–1.5	0.2	0.2	0.3–0.5
Ca	1.5–7.5	1.5–3.0	-	18–25	4–10
Mg	0.5–1.0	0.4	-	0.6	0.2
C/N	3–4	2.4	4	4.5	3.5

Source: "Agrochemicals", 2000, Edited by Franz Muller. Wiley-VCH Verlag GmbH & Co. KGaA. Reproduced with permission.

Anion

An anion is an atom which gains or acquires an electron, becomes negatively charged, and is attracted toward the anode in electrolysis. Thus, a fluorine atom, by taking up an electron in its p orbital, becomes a fluorine ion (fluoride ion).

$$F(1s^2 2s^2 2p^5) + e^- \longrightarrow F^-(1s^2 2s^2 2p^6)$$

Anions are generally drawn from an atom of a non-metal like fluorine (F) or a group of atoms (for example, SO_4^{2-}). The number of electronic charges carried by the anion is called its **electrovalence**.

Salts are usually composed of orderly arrangements of ions which are not free to move easily in a solid. However, when a salt is fused or dissolved in water, the ions become free. When an electric field is applied to the solution, the positively charged ions move to the cathode while the negatively charged ones move to the anode. These ions, upon reaching the electrodes, lose their charge.

Anion adsorption

Both inorganic and organic anions can compete with phosphorus for adsorption sites, resulting in decreased adsorption of the added phosphorus. The strength of bonding with the mineral surface determines the competitive ability of that anion. Generally, weakly held inorganic anions such as No_3^- and Cl^- are of little consequence, whereas specifically adsorbed anions such as OH^-, SO_4^{2-} and MoO_4^{2-} can be competitive with phosphorus adsorption ($H_2PO_4^-$).

Anion adsorption of small cations occurs by surface complexation and by diffuse-ion swarm association. The outer-sphere surface complexation of anions entails coordination to a protonated hydroxyl or amino group or to a surface of metal cation. The anions Cl^-, NO_3^-, SeO_2^{2-}, and to a lesser extent HS^-, SO_4^{2-}, HCO_3^- and CO_3^{2-}, are reckoned to adsorb mainly as diffuse-ion swarm and outer-sphere complex species.

Anion exchange

Anion exchange is the exchange or replacement of one anion by another on the positively charged exchange complex. The exchange of ions of the same charge takes place between a solution (usually aqueous) and a solid (ion exchange resin) in contact with it. The type of exchange, whether cation or anion, is determined by functional groups added to the resin. **Ion exchange resins** are ideally suited to protein purification, antibody isolation and peptide fractionation. They are also used in a traditional inorganic ion exchange. **Anion exchange resins** have ammonium ions in the framework of the resin as the ion exchange site. **Cation exchange resins** have sulphonic or carboxylic acid groups as the exchange site.

An anion exchange resin is used in softening water. When water is passed through anion exchange resins, the electronegative ions present in water (like Cl^-, SO_4^{2-}) are held by the ammonium ions in the resin. The outgoing water is devoid of electronegative ions, and, if subsequently passed through a cation exchange resin, the water practically contains no ions and can be used in place of distilled water. Treating with moderately concentrated solution of caustic soda can regenerate the resin.

The reaction processes in resins occur widely in nature, especially in the absorption and retention of water-soluble fertilizers by soil. The order of adsorption of anions is $H_2PO_4^- > SO_4^{2-} > NO_3^- = Cl^-$

Anion exchange capacity

The anion exchange capacity (**AEC**) of a soil is defined as its capacity to hold or adsorb anions in an exchangeable form to the positively charged sites on clay minerals and organic matter. AEC, expressed as milliequivalents/100 g soil, is an indicator of the positive charge (or the positively charged sites) on clay minerals and organic matter in the soil.

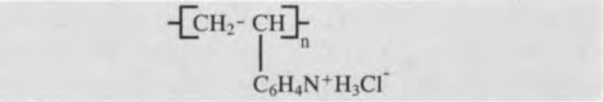
Anion exchange capacity increases as the soil pH decreases. Anion exchange is much greater in soils high in 1:1 clays and soils containing hydrous oxides of iron and aluminum than it is in soils predominantly having 2:1 clays. **Montmorillonite** clay minerals have an anion exchange capacity of less than 5 meq/100 g, while kaolinites can have an anion exchange capacity as high as 43 meq/100 g at pH 4.7.

Anion exchange resin

Anion exchange resin is another term for anion resin.

Anionic resins

Anionic resins or **anion-exchange resins** possess a positive charge on the functional group. During an ion exchange reaction, anions such as HCO_3^-, SO_4^{2-} and OH^- are exchanged. A polyaniline based anionic resin is given in Fig.A.36.



$$-\!\left[CH_2-\underset{\substack{|\\ C_6H_4N^+H_3Cl^-}}{CH}\right]_n\!-$$

Fig.A.36: Polyaniline based anionic resin.

Anionic surfactant

An anionic surfactant is a type of ionic surfactant used for coating fertilizer materials to improve fertilizer quality. Commonly employed anionic surfactants are sulphonates, particularly alkyl aryl sulphonates, and their action is due primarily to their hydrophobic nature. Sodium stearate ($C_{17}H_{35}COO^-Na^+$) is an example of an anionic surfactant. (See also Adjuvant; Anti-caking agents.)

Ankur

Ankur is an aqueous solution of urea (33.5 to 36.0%) and ammonium nitrate (44.5%) with 1% corrosion inhibitor. Ankur is used as a nitrogenous fertilizer (like urea-ammonium nitrate).

ANL

ANL is short for **ammonium nitrate limestone**.

ANL brand fertilizer

ANL is the trade name for a fertilizer which is a mixture of ammonium nitrate (AN) and lime or pulverized dolomite. ANL is manufactured at Hopewell, Virginia, in the USA. When added to the soil, it reduces the hazardous characteristics of AN.

ANL fertilizer contains 20% nitrogen, 10% calcium oxide (CaO) and 7% magnesium oxide (MgO). It is hygroscopic and is protected from atmospheric moisture during storage and transportation by coating the pellets with soapstone (sodium silicate).

Anne method for determining organic carbon

Anne method is one of the two methods for determining organic carbon in the soil. In this method, the organic matter is attacked and destroyed by boiling it slowly in an excess mixture of sulphuric acid and potassium dichromate. The excess potassium dichromate is determined by Mohr's salt ($FeSO_4$) in the presence of diphenylamine as indicator. The results obtained from this method match well with those obtained from the dry method. This method can also be used to analyze plant materials. (See also Walkley-Black method.)

Annual

An annual is a plant that completes its life cycle in one year or less, during which it germinates, flowers, produces seeds and dies. Most cultivated crops like grain, fodder, pulse crops, some oilseed crops (other than coconut, oil palms, etc.) Sunflower, wheat, rice and marigold are examples of annuals (Fig.A.37). **Winter annuals** refer to plants that complete their life cycle during the winter season. Ornamental plants like dahlia and carnations are winter annuals.

Annual ring

Annual ring is the ring that can be seen in a cross section of a trunk in trees. It represents the xylem formed in one year by the fluctuating activity of vascular cambium. The **age of the tree** can be determined by counting the number of cross sectional rings. The study of annual rings is known as dendrochronology.

Annual soil temperature

The annual average temperature of a soil is considered the annual soil temperature. 'Standard' soil temperature is normally measured at the rock or hard-pan, or at a depth of 50 cm unless the soil is 50 cm deep. Average annual soil temperature (AST) is measured at a depth of approximately 90 cm or 180 cm. The temperature values recorded at both the depths are usually very close. The difference between the warmest and the coldest monthly means of temperature is known as annual temperature range (of the soil).

Anorthite

Anorthite is one of the four components of feldspars, expressed as $CaAl_2Si_2O_8$. **Feldspars** are a group of silicate materials. They are the most abundant minerals in the earth's crust. Anorthite or **pure calcium feldspar** belongs to the plagioclase subdivision of feldspars.

Anoxia

Anoxia represents a condition where oxygen is absent. Waterlogged soils create anoxic conditions in which the decomposition of organic matter slows down. In bogs and swamps, for instance, the rate of decomposition is so low that plant remains are preserved for many years. A few micro-organsms prefer anoxic conditions for their growth. *Clostridium* sp, yeasts, etc. are examples.

ANR

ANR is short for **apparent nutrient recovery**.

Antagonistic interaction

Antagonistic interaction or **negative interaction** is a phenomenon where the combined effect of two or more nutrients is lesser than the effect of each of these nutrients, taken separately.

When the presence of a nutrient adversely affects the absorption of another nutrient, the two nutrients are said to interact antagonistically. For example, excess copper affects iron nutrition, or excess amounts of potassium and calcium depress the absorption of boron.

While synergistic effect attracts attention, the antagonistic effect between nutrients is often ignored. What is important is to know (a) the situation when two or more nutrients result in antagonistic effect, and (b) the range over which the change-over takes place from synergism to antagonism and vice versa. This would help in balancing plant nutrients which are considered antagonistic pairs.

Fig.A.37: Sunflower, a major oil seed crop is an annual crop.

Anthracite coal

Anthracite coal is a hard and black variety of coal, with a fixed carbon content in the range of 80 to 98% and a heating value of 14243×10^3 to 16458×10^3 J.

Anthropic

Anthropic or **anthropic horizon**, is a surface horizon (or epipedon), with high basic cation saturation created by human activities such as cultivation or construction. When the cause is agricultural activities, it is called cultivated horizon or **agropedic horizon**. In this, the surface horizon is homogenized by plowing or other means. In terms of color, thickness and organic matter, it has the same appearance and characteristics as mollic epipedon. The change occurring in the soil due to human activity (like plowing, fertilizing or construction) is called **anthropogenic change** or **anthropic change**.

Anthropic change: See Anthropic

Anthropic horizon: See Anthropic

Anthropogenic change: See Anthropic

Antiauxin

Auxins are plant growth promoting substances, responsible for many growth processes. Antiauxins by contrast, compete with auxins for specific receptors.

Antiauxins inhibit the transport of auxins in the plant and thus affect plant growth and morphology. An example of an antiauxin is maleic hydrazide.

Anti-caking agent

Anti-caking agents are materials used for the surface treatment of granular fertilizers to prevent caking.

An anti-caking agent helps maintain the physical condition (such as easy-flow characteristics, storage and handling) of a fertilizer.

Anti-caking substances are categorized as coating agents (which consist of inert powders and liquid coating agents) and internal conditioners. The two categories are described below.

(i) **Coating agents**: These are **conditioning materials** applied uniformly onto fertilizer particles. Most coating agents are either very finely divided inert powders (which adhere to particle surfaces) or liquid coating agents that are sprayed onto the surface.

Inert powders, like clays (kaolin and china), diatomaceous earth (kieselghur) and **talc** (basic magnesium silicate) form mechanical barriers between the material particles and also serve to absorb, spread and inactivate any solution phase that may occur on the particle surfaces. During caking, bonding occurs between the particles; the dust-type anti-caking agent weakens the bonds and reduces the severity of caking.

Inert clay powders are extremely fine (typically, 90% are less than 10 mm, 50% of which are less than 1 mm), adhere well to fertilizer granules and are used effectively on urea, NP and NPK complex fertilizers, but not on ammonium nitrate or other high nitrate products. Diatomaceous earth does not adhere well as does clay, but it has a good absorption property and is an effective anti-caking agent for ammonium nitrate. Major disadvantages of inert powders as anti-caking agents are their dustiness and diluting effect on the main nutrient element.

Inert powders can be made to adhere better by spraying the fertilizer with a small amount of oil or wax-free binders (usually 0.1 to 0.3%). Fairly viscous oils (25 to 200 MPa) give maximum results.

Liquid coating agents are organic surfactants or non-surfactants. They usually function as crystal modifiers to inhibit or weaken the crystal growth on and between the particles, or as hydrophobic barriers to moisture absorption.

Surfactants function by altering the interfacial tension between the solid (particles) and the liquid (surfactant). Their role as anti-caking agents is not clearly understood, but they are believed to (a) provide protection from moisture, (b) spread the liquid film, (c) change crystal make-up or behaviour, (d) inhibit dissolution and crystallization, or (e) modify bond tensile strength.

Surfactants are both ionic and non-ionic. **Ionic surfactants** are those that contain either cationic or anionic molecules or groups in their structure. The commonly employed **anionic surfactants** are sulphonates, particularly alkyl aryl sulphonates, and their action is due primarily to their hydrophobic nature. **Cationic surfactants** are fatty amines, which act by three different mechanisms (a) forming a hydrophobic coating on the surface of the particles, thereby improving water repellence, (b) reducing the capillary adhesion between the particles, and (c) inhibiting nucleation or modifying crystal growth.

Non-ionic surfactants are neutral surfactants that do not ionize in water and do not form positively or negatively charged ions. They are non-toxic and are unaffected by hard water. Non-ionic surfactants, like polyoxyethylene condensates, are poor anti-caking agents and not widely used. Silicone fluids belong to this category.

Non surface-active coating agents are organic compounds. They do not exhibit surface activity but do form a moisture-resistant layer on the surface of the fertilizer particles. Typical non-surface active coating agents include paraffin wax, synthetic polymers and oils.

(ii) **Internal** or **chemical conditioners**: These conditioners are added to fertilizers during processing, usually as hardeners or crystal modifiers, to improve storage properties.

For urea conditioning, the following composition is found effective: Molten urea 0.3 to 0.5% of 37% formaldehyde solution or concentrated urea formaldehyde (containing 26% urea, 59% formaldehyde, 15% water). This reduces the formation of dust in the finishing process because the granules are harder and more resistant to abrasion and breakage than untreated ones.

For ammonium nitrate, the most popular internal conditioner is magnesium nitrate (1.8% magnesium nitrate).

Anticlines

Sedimentary rock layers that are folded into arch shapes are known as anticlines. (See also Fold.)

Antifloat materials

Antifloat materials (like diatomaceous earth) or wetting agents (like liquid surfactants) are the coatings applied to the external surface of a fertilizer to achieve an antifloat effect by breaking the surface tension between water and the coated fertilizer. Special controlled-release fertilizers sink immediately on application and are applied to irrigated crops. **Polyon PCU-AF/Antifloat**, marketed by Sumitomo in Japan and **Multicote**, a resin-coated antifloating urea, are examples of the special controlled-release fertilizer class.

Anti-transpirants

Anti-transpirants are substances that retard the transpiration rate of plants, mainly by affecting the size of the stomatal opening. Monomethyl ester decenyl succinic acid is an example of an anti-transpirant.

AOV

AOV is the abbreviation for **analysis of variance**. (See also Variance.)

Apatite

Apatite is a highly complex hexagonal structured mineral form of calcium phosphate $[Ca_5(PO_4)_3.\ (OH, F, Cl)]_2$. It is the most common of all phosphate minerals. Depending upon the dominance of fluorine, chlorine or hydroxide, apatite is called **fluorapatite**, chlorapatite or **hydroxyapatite**, respectively.

Apatite often occurs widely as an accessory mineral with igneous rocks, such as pegmatite. It also occurs in regional and contact metamorphic rock, especially limestone. Large deposits of apatite are found in Russia.

Apatite, a major source of phosphorus, is used in the production of fertilizers. Enamel of the teeth is composed chiefly of apatite.

Apical meristem

Meristem is the portion of cells of a plant tissue, found mainly at the growing tips of roots and shoots and in the cambium. Meristems are composed of actively dividing cells which form a new tissue.

Apical meristems (Fig.A.38), the most important meristems, are regions at the tips of each shoot and root of a plant in which cell division occurs continually to produce new stem and root tissues. The new tissues produced are known as the primary tissues of the plant. (See also Meristem.)

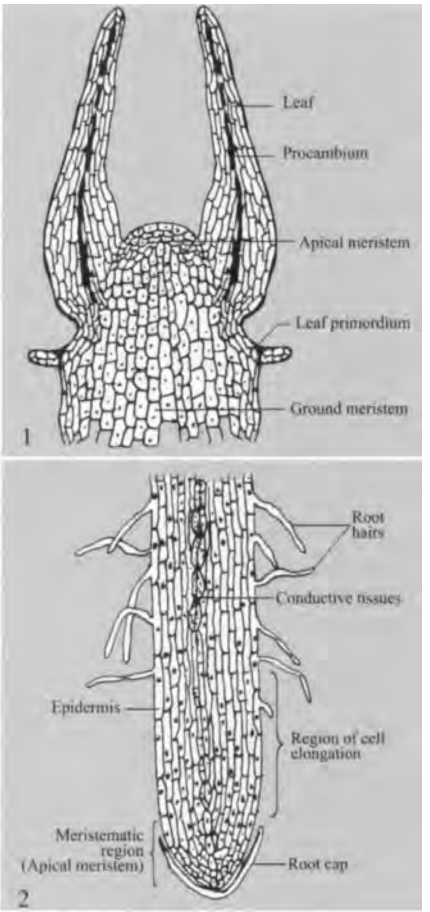


Fig.A.38: Diagrammatic representation of the longitudinal section of shoot (1) and root showing regions of apical meristem (2).

APN

APN is short for **ammonium phosphate nitrate**.

Apocarpous

Apocarpous are flowers that have many separate carpels, *Michelia* as an example.

Apoplast

Apoplasts are interconnected cell walls or extra-cellular spaces. The system of interconnected cell walls is a pathway of solute (water and dissolved mineral salts) movement across the cortex that leads to the stele in a plant system.

APP

APP is short for **ammonium polyphosphate**.

Apparent bulk density

Apparent bulk density (or the **apparent density**) of a fertilizer, is the mass per unit volume of a fertilizer excluding voids between the particles. It is not often measured but is of interest in particle segregation studies and in the development of granulation processes. In the case of fertilizers, it is measured by using a bulk density box or bulk density cup. (See also Bulk density of fertilizer.)

Apparent density: See Apparent bulk density

Apparent free space

Apparent free space refers to the hypothetical partial volume of a tissue through which a solution can pass passively. It becomes a true measure of the free space only if the test solute concentration in the free space is the same as that in the external solution with which the plant tissue has equilibrated. When the solute concentration is higher in the free space than in the external solution under high transpiration conditions, the apparent free space value is also high.

Apparent free space is also that fraction of the root volume into which the external solution appears to diffuse.

Apparent nutrient recovery

Apparent nutrient recovery (**ANR**) is defined as the nutrient absorbed by a crop from a fertilizer and is expressed as a percentage of the nutrient applied. **ANR** tends to overestimate fertilizer recovery and is generally measurable without resorting to a tracer technique.

ANR is defined as follows:

$$\text{ANR} = \frac{\begin{bmatrix}\text{Nutrients removed}\\ \text{from fertilized plot}\end{bmatrix} - \begin{bmatrix}\text{Nutrients removed}\\ \text{from unfertilized plot}\end{bmatrix}}{\text{Nutrient added}} \times 100$$

Apparent recovery efficiency

Apparent recovery efficiency is the same as **apparent nutrient recovery**.

Application of fertilizer

Fertilizer application refers to the act of applying or administering fertilizers, manures or amendments to crops on fields, grasslands, forests or any type of soils. There exist several methods for applying fertilizers. Some of these are **surface banding**, **strip (dribble) banding**, **deep banding**, **high-pressure injection**, **broadcasting**, **side dressing** and **foliar spray**.

Aprotic solvent

Aprotic solvent is a solvent which neither donates nor accepts protons. Carbon tetrachloride is an example of an aprotic solvent.

APS

APS is short for **ammonium phosphate sulphate**.

AQ

AQ, also called **acidity quotient**, is the exchange acidity ratio of litter, given by the ratio of exchange acidity of **humus** to that of the top horizon. It characterizes the influence of humus on soils. An AQ of less than one indicates a healthy soil.

The characteristics of humus fractions are useful in interpreting organic matter dynamics. Carbon to nitrogen to phosphorus ratios in humic acid (**HA**) and fulvic acid (**FA**) fractions help to assess the origin and the turnover of nutrients in the soil organic matter from different depths and zones. HA to FA ratios are frequently used as indices of the degree of humification in soil. These ratios are believed to reflect intense humification caused by biological activity.

Aqua ammonia

Aqua ammonia, also called **aqueous ammonia**, **ammonia liquor** and **ammonium hydroxide** is ammonia dissolved in water to form a clear, colorless liquid with a pungent odor. It is the simplest nitrogen solution made by forcing compressed NH_3 (anhydrous ammonia) gas into water. It has a pressure of less than 0.7 kg/cm^2 and is usually composed of 25 to 29.4 % ammonia by weight (20 to 25 % nitrogen).

Ammonia dissolved in water is present principally as the ammonium ion ($NH_4^{+.)}$Non-ionized molecular ammonium hydroxide (NH_4OH), sometimes referred to as an **associated form of ammonium hydroxide**, is also present. Hydrated molecules of ammonia (NH_3) may also exist as $NH_3 \cdot H_2O$ or $NH_3 \cdot 2H_2O$.

Purified water is used for the reaction of ammonia and water in the production process. The methods for water purification are (a) a conventional sodium-form water-softening ion exchange resin, which replaces all cations present with sodium ions, (b) both hydrogen-form cation resin and hydroxyl-form anion resin, resulting in total de-ionisation of water, or (c) reverse osmosis purification equipment which results in total de-ionization of water.

If water hardness is sufficiently low and/or if suitable filtration is available to remove the precipitate formed during the reaction of ammonia with water, the product can be manufactured without pre-treatment of water. For most water supplies, the precipitate is principally calcium carbonate.

During the reaction of ammonia with water, a large amount of heat is generated, which requires heat exchangers to control the temperature. The resulting aqua ammonia contains ammonium ions (NH_4^+), hydroxyl ions (OH^-), and non-ionized ammonium hydroxide molecules (NH_4OH). The chemical reactions are:

$$NH_3 + H_2O \longrightarrow NH_4OH$$
$$NH_4OH \rightleftharpoons NH_4^+ + OH^-$$

The grade or strength of ammonium hydroxide available commercially is 26 degree Baumé. The Baumé reading refers to a specific gravity scale. A 26 degree **Baumé** (Bé) solution is equivalent to 29.4% by weight of ammonia dissolved in water. Since the Baumé reading varies with temperature, the reading is standardized at minus 9.4°C. The density of the material compared to water is 0.8974. Ammonia products of 29.4% strength are also frequently described as **26° Bé products**, the freezing point of which is about minus 62.2°C.

An aqueous solution has a vapor pressure which varies with temperature. At ambient temperatures, the vapor pressure of 26° Bé material equals atmospheric pressure. This permits the material to be shipped and stored in non-pressurized containers. This is the highest strength material generally available commercially.

Aqua ammonia should be stored in a closed container and kept cool, as otherwise the ammonia gas comes out of the solution and the strength reduces. The nitrogen concentration in aqua ammonia can be increased to 40% by partial pressurization.

Aqua ammonia is corrosive to copper, copper alloys, aluminum alloys and galvanized surfaces. Aqua ammonia is an excellent acid neutralizer. Its pH varies with concentration; typical values of pH are 11.7 at 1%, 12.2 at 5%, 12.4 at 10% and 13.5 at 30% concentration.

Transport and delivery costs limit the production of aqua ammonia (NH_3) to small, local, fluid fertilizer plants. Aqua ammonia is regularly available in concentrations of 19%, 25% and 29%. These are used for direct soil application or as inputs to produce other liquid fertilizers. Ammonia volatilizes quickly at temperatures above 10°C; therefore, aqua ammonia is usually injected into soil to depths of 5 to 10 cm. It should not be used in calcareous soil.

Aqua-gels

Polyacrylates, a form of polymers, are also known as aqua-gel. They are used alone or with starch to promote water storage in soils. The water holding effect, however, varies with pH, water hardness and such dissolved substances as urine or soil nutrients.

Polymer dispersions are employed to protect seeds. They are applied at planting time by spraying, usually along with fertilizers, soil conditioners and mulches (cellulose, straw). They can also be applied after planting. The quantities used depend on the actual formulation, and vary between 10 and 50 g/m^2. Polymer dispersion products may be diluted in a product to water ratio of 1:1 to as much as 1:60. The protective action of polymer dispersions depends upon the quantity used and environmental conditions.

Aqualfs

Aqualfs are a suborder of **Alfisols**.

Aquands

Aquands are a suborder of **Andisols**.

Aqua regia

Aqua regia is an extremely effective oxidizing solvent, capable of dissolving metals like gold and platinum. It is made of a mixture of one part concentrated nitric acid and three parts hydrochloric acid.

Aquents

Aquents is a suborder of **Entisols**.

Aqueous ammonia

When ammonia is dissolved in water, it forms aqueous ammonia. Aqueous ammonia is also called **aqua ammonia**, **ammonia liquor** or **ammonium hydroxide**. It is a clear, colorless liquid with a pungent odor. It is the simplest nitrogen solution, made by forcing compressed anhydrous ammonia gas into water. It has a pressure of less than 0.7 kg/cm^2 (10 lb/in^2) and is usually composed of 25 to 29.4% ammonia by weight (20 to 25% nitrogen).

Aquerts

Aquerts is a suborder of **Vertisols**.

Aquic condition

Aquic condition is a condition brought about when soil remains excessively wet for a large part of the year. Aquic condition is caused by the saturation of soil by a fluctuating water table or by the presence of water on the capillary fringe of the water table. It is a reducing medium.

Aquic soil moisture regime

Aquic soil moisture regime is the soil that is saturated with water and depleted of oxygen. Low chroma mottles are indicative of this condition. (See also Wetlands.)

Aquolls

Aquolls is a suborder of **Mollisols**.

Aquults

Aquults is a suborder of **Ultisols**.

Arable farming

The system in which a land is plowed and sown, once or more than once a year is called arable farming. In this way, it contrasts with pasture lands. Arable farming is commonly practiced.

Arable land

Arable land or **arable layer** is the land fit for tillage or plowing at regular intervals. In a cultivated soil, the arable land may resemble the Ap horizon. In most **rendzinas,** arable land nearly coincides with the pedological profile.

Arable layer: See Arable land

Arborio rice

Rice is classified on the basis of the grain variety. Many famous varieties of rice include California Moish rice, Thai Jasmine rice, Indian rice, black rice (China), etc. Arborio is a rice variety common to Italy. Since it absorbs water or liquid five times its weight, it cooks into a creamy consistency. This rice is white, starchy and round with a distinctly firm center. The rice has a medium length and it is common in risotto dishes.

Arbutoid mycorrhizae

Arbutoid mycorrhizae are the transition stage between ectomycorrhizae and endomycorrhizae. A fungal sheath on the roots of the host plant characterizes these mycorrhizae. Plants show the greatest growth response to mycorrhizae in highly weathered tropical soils, like the leached **oxisols** and **ultisols**. These soils are acidic, low in basic cations, low in phosphorus and may have a high toxic level of aluminum. (See also Mycorrhizae.)

Archebacteria

Archebacteria is a subgroup of bacteria, comprising **methanogens** and species capable of tolerating extremely high temperatures or a salty environment.

Arenaceous

Soils that have a high proportion of sand particles are considered arenaceous. For instance, sandstone is an arenaceous rock. Arenaceous rock is a sedimentary rock composed mainly of cemented grains of sand.

Arenic horizon

Arenic horizon designates an extra grade subgroup characterized by a sandy epipedon 50 to 100 cm thick over an **argillic horizon**.

Arents

Arents are a suborder of **Entisols**.

Argids

Argids are a suborder of **Aridisols**.

Argillaceous soils

Argillaceous soils are clayey soils having a high percentage of clay particles. Mudstone and marl are the examples of argillaceous soils.

Argillan

Argillan is the layer or coating of clay on the surface of soil peds, mineral grains and soil pores. The coatings are classified according to the type of surface, such as grain, aggregate, channel, crack, normal void and chamber vesicle. The argillan coating is also called **clay films**, **clay shins** or **cutans**.

Argillic horizon

Argillic horizon is the clay accumulation horizon indicated by the letters 'Bt'. It is formed below the soil surface and is a mineral horizon characterized by the accumulation of illuvial clay and covered by an eluvial horizon.

The argillic horizon must have a certain thickness which is related to the thickness of the solum. The clay content of the argillic horizon must be higher than that of the eluvial horizon. For example, if the **E horizon** contains 10% clay, the argillic horizon must contain at least 13%; if the former contains 20% clay, the argillic horizon must contain at least 24% clay coating as observed on pore walls, structural units or between the sand grains. The clay is seen in the form of clay films on ped faces, and is also observed on pore walls, structural units or between sand faces.

The argillic horizon can be subdivided into subtypes, which are distinguished by some characteristic features and properties. These subtypes are identified by the following prefixes to the word argillic: **abrupto**, ferro, fibero, fragio, grano, **lixo**, **luvo**, **natro**, **neo**, **nito**, **ortho**, plano, pleintho, **retro** and **stagno**.

Arid land

Arid land is a dry and parched land, often with sparse vegetation, and characterized by deficient rainfall (< 250 mm.) The term is often used to describe a region with insufficient rains to support vegetation without irrigation. In arid regions, droughts are very common because of extremely low rainfall. Estimates of the arid climatic zone vary from 15% to 30% of the world's land surface, depending upon the strict definition of arid climate.

Aridic moisture regime: See Aridic regime

Aridic regime

Aridic regime or **aridic moisture regime** is an area with less moisture and high temperature. All parts of the soil moisture control section of aridic regime are dry. Soil temperature at 50 cm depth is above 5°C for more than six months in a year and the soil is never moist for 90 consecutive days in a year. Soils with an aridic regime are mostly found in zones of arid climate and sometimes semi-arid climate.

Aridic and **torric** are synonymous but used in different legends of classification.

Aridisols

Aridisols are one of the 12 soil orders of the world. They develop in a climate with long dry periods and a few wet spells. These soils have a low water retention capacity. Aridisols occur mostly in hot, temperate or sub-temperate deserts with aridic soil moisture regimes, dry coastal regions, rain shadow plains, and on the leeward side of high mountains.

Aridisols cover about 12% of the ice-free land area of the world, and show a variety of profiles. Some have a lime layer, some others have salt accumulation, and yet others have thick carbonate silica-cemented hardpans. Aridisols range from bare rich to bare poor soils and exhibit a wide diversity in physical, chemical and mineralogical properties.

With clay accumulation, aridisols develop argillic horizons (Bt horizon). Aridity restricts vegetation in such soils and lowers their organic content. Similarly, the lack of water in the soil reduces leaching and increases the basic cation saturation. In some aridisols, leaching is shallow with no salt accumulation. The vegetative cover of aridisols is desert shrubbery and short grasses. Aridisols in cold climates, however, have a different vegetation from that in warmer climates.

Aridisols need irrigation for crop production. They often become productive with the addition of water and fertilizer.

Aridisols are nitrogen deficient because of low **humus** content. They are also deficient in iron, zinc, manganese and copper. However, reduced leaching causes accumulation of potassium; potassium deficiency is, therefore, rare.

The suborders of soils belonging to aridisols are argids and orthids.

Aridity index

Aridity index (**AI**) is a measure of dryness of an ecoregion. It is defined as the ratio of annual moisture deficiency to annual water needs.

$$\mathrm{AI} = \frac{\text{Number of rainy days} \times \text{Mean precipitation per day}}{\text{Mean temperature} + 10}$$

Aridity index is a measure of the effectiveness of the precipitation received. It could be described as a measure of evaporation. Death Valley in California (USA) has an aridity index of 7, which means the sun would evaporate seven times the average rainfall received. On the other hand, the Sahara has an aridity index of 200, meaning 200 times the average rainfall would be evaporated.

Moisture deficiency or aridity index is used to define drought. Drought intensities using standard deviation (s) of aridity index to analyze the occurrence of droughts in arid zone ecologies are defined in Table-A.8.

Table-A.8: Relationship between aridity index and drought.

Departure of aridity index from normal	Result
< ½s	Moderate
½s to 1s	Large
1s to 2s	Severe
> 2s	Disastrous

Source: "Introduction to Tropical Agriculture", Edited by Anthony Youdeowei, et al. Longman Scientific and Technical, Longman Group, UK, Ltd. With permission from Pearson Education Ltd.

Arnon's criteria of essentiality of plant nutrients

Arnon and Stout proposed three criteria that are now used to decide if a plant needs nutrients. They are also called the **Stout-Arnon's criteria of essentiality of plant nutrients**.

Essentiality criteria are that (a) the deficiency of an element results in a plant completing its life cycle, (b) the deficiency is specific to the element in question and (c) the element is directly involved in the nutrition of the plant, such as a constituent of an essential metabolite required for an enzyme activity. Based on these criteria, the following 17 elements are considered essential for the growth of higher plants: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, copper, zinc, molybdenum, boron, chlorine and nickel. Plant nutritionists and soil scientists would rather have a less restrictive definition for establishing the deficiency symptoms, and so four more elements (sodium, silicon, cobalt, and vanadium) are added to the list of the 17 just listed.

It is now established that sodium is essential to plants with a C_4 photosynthetic pathway. Silicon addition has shown to improve the growth of sugar cane. Cobalt is considered essential for microbial fixation of atmospheric nitrogen. All these are beneficial elements for most crops.

Aromatic plants

Aromatic plants are those that yield aromatic and fragrant compounds. Mint, lemon grass, jasmine, rose, lavender, etc. are examples of aromatic plants.

Artesian well

A perpendicular bore sunk into an oblique strata to tap a water-bearing rock or an aquifer lying beneath a relatively impermeable stratum is an artesian well. If the water table at the margins of the aquifer is higher than the outlet of the well, water flows out of the bore under pressure. It may be necessary to cap the well in order to regulate the supply of water for irrigation. Where the well head is above the water level in the aquifer, a condition referred to as a **sub-artesian well** exists, as distinct from a naturally flowing artesian well. Water has to be pumped to the surface for use.

Artificial fertilizers

Unlike natural fertilizers, artificial fertilizers (also known as **inorganic fertilizers**, **mineral fertilizers** or **chemical fertilizers**) are mined or made by chemical processes. An artificial fertilizer is sometimes also called **bag muck** because it is stored in a bag.

Artificial manure

Artificial manure or **synthetic manure** is a compost produced primarily from plant residues. (See also Compost.)

Ash

Ash is a non-volatile solid mineral residue resulting from the burning of organic matter (Fig.A.39).

Ash in analytical chemistry means the inorganic residue of a complete combustion of a material. It consists of mineral matter like SiO_2, Al_2O_3, Fe_2O_3, etc. It is an end product of a large-scale combustion of coal (as in power plants) and is said to be the most plentiful mineral.

Ash can be fly ash, bottom ash and boiler ash. There are many uses of fly ash, such as in cement products, as road filling and as an absorbent of oil spills.

The ash content of organic soils is an important component of the soil matrix. Usually, as ash content increases, the available nutrient content of the soil also increases.

The increase of ash content in pit bag soil may be due to several factors, such as mineralization of organic matter, use of mineral fertilizers, introduction of inorganic elements by ground waters, influx of mineral elements during floods and their deposition from the atmospheric dust.

To evaluate plant nutrient content, the plant material is incinerated at about $600^\circ C$ and its ash content is analyzed. In this process, inorganic elements other than C, H, O and N can be estimated.

Ashing is the burning of material, such as plants. It results in the breakdown of complex compounds into simpler ones and is an important step in analytical work.

Ashing can be effected either by heating the sample (often with sodium carbonate), in which case, it is called **dry ashing**, or by heating with a single or mixed concentrated acid (like perchloric acid, nitric acid or sulphuric acid) in a wet digestion of mineral compounds, which is called **wet ashing**. **Aqua regia** (which is concentrated nitric acid and concentrated hydrochloric acid in the ratio of 1:3) is commonly used in wet analysis.

Ashing: See Ash

ASN

ASN is short for **ammonium sulphate nitrate**.

Aspergillus niger

Aspergillus niger is a fungus of common occurrence. It is commonly used as a phosphate solubilizing microorganism and a compost degrading agent.

Aspergillus niger is widely used in industry for the production of organic acids (citric, oxalic, gluconic) and enzymes (amylolytic and pectolytic). The fungus is also used in biological soil tests. It is used to assess the available nutrient status of a soil by cultivating it in the given soil under controlled conditions.

Assimilation

Assimilation is a familiar phrase in all metabolic processes. It leads to the absorption and utilization of food by living organisms for growth, reproduction and repair. This includes absorption and incorporation of nutrients or other inputs (such as carbon dioxide) into photosynthates by plants.

The conversion or transformation of the absorbed nitrate into amino acids and proteins is an example of assimilation, which is similar to photosynthesis:

$$NO_3^- \longrightarrow NO_2^- \longrightarrow -NH_2 \longrightarrow \text{Protein}$$

The ratio of the amount of photosynthesis occurring in a unit mass of the leaf per hour to the weight of the

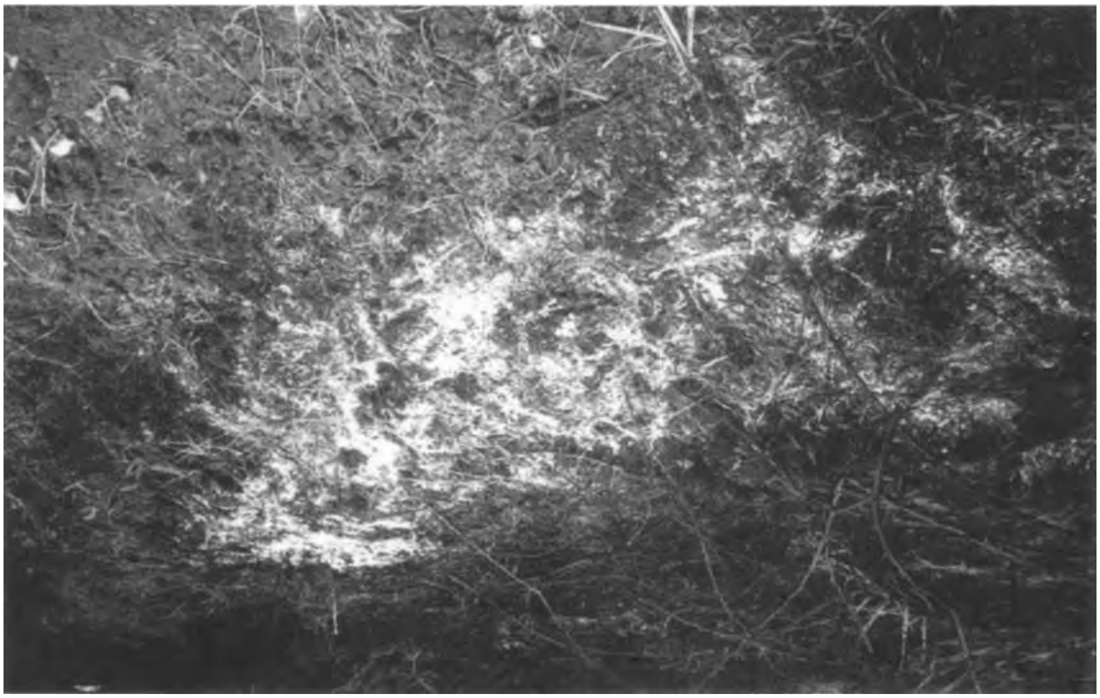


Fig.A.39: Stubbles and crop residues in the field are burnt for field sanitation, the resultant ash supplying mineral elements to the soil.

chlorophyll in the tissue is known as the **assimilation number**. This ratio, in practice, is the weight of carbon dioxide (in mg) absorbed in an hour to the weight of chlorophyll (in mg) in the tissue. The ratio of carbon dioxide absorbed to the oxygen output is the **assimilatory quotient**, which is generally near unity and is represented by:

$$6CO_2 + 6H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2$$

The energy driving power of adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate ($NADPH_2$), which is necessary for the reduction of carbon dioxide to carbohydrate by plants, is called the **assimilatory** or **reducing power**.

Assimilation number: See Assimilation

Assimilatory power: See Assimilation

Assimilatory quotient: See Assimilation

Associated form of ammonium hydroxide

Associated form of ammonium hydroxide is another name for non-ionized molecular ammonium hydroxide. (See Aqua ammonia.)

Associated gas

Associated gas is the natural gas which occurs with crude oil and which is released in the separation plant when pressure is released. The composition of natural gas varies with the pressure at which the separator is opened.

ASTM

ASTM is short for American Society for Testing and Materials. (See also Sieving.)

Atmometer for estimating potential evapotranspiration

Atmometers measure water evaporated from surfaces, such as porous filter papers, porous porcelain spheres or plates. Atmometers are very sensitive to wind speed.

The four classes of atmometers are (a) large evaporation tanks sunk in the ground or floating on protected waters, (b) small, open evaporation pans, (c) porous porcelain bodies, mainly used by plant physiologists in studying evapotranspiration from plants and (d) wet paper surfaces.

Atomic absorption spectrometer

Atomic absorption spectrometry (**AAS**) involves converting a sample at least partially into an atomic vapor and measuring the absorbance of this atomic vapor at a specific wavelength (l), to characterize a specific element. The measured absorbance is proportional to the concentration and is compared under the same experimental conditions to that of a reference sample of known composition.

AAS is used extensively in the analysis of trace elements or micronutrients in fertilized soils as well as elemental contaminants in polluted waters (Fig.A.40).

Fig.A.40: Atomic absorption spectrometer.

The advantages of **AAS** are that it has high sensitivity for as many as 60 elements measurable in the ppm range, and that the measurement is simple, rapid, relatively low-cost and highly specific (with very few interferences).

AAS has four basic components which are (a) a light source, emitting the spectrum of the desired analyte elements, (b) a sample atomization cell, such as a flame or graphite tube furnace, (c) a monochromator to isolate the desired source emission line and (d) a detector/readout system, to allow measurement of change in the source line intensity by sample atom absorption. Many commercial instruments based on either a single or double beam design are available.

ATP

ATP is short for **adenosine triphosphate**.

ATPase: See ATP hydrolase

ATP hydrolase

ATP hydrolase (also called **ATPase**) is an enzyme located in the plasma membrane. It initiates nutrient uptake and hydrolyzes **ATP**. The hydrolysis results in the splitting of water (H_2O) into H^+ and OH^- ions, from which H^+ is extruded into the outer medium, creating a potential difference between two sides of the membrane; the proton motive force thus obtained drives the ion uptake. The plasmalemma-bound ATPase also drives the uptake of anions (NO_3^- and $H_2PO_4^-$).

The hydrolysis of ATP results in the cleavage of either one phosphate or two phosphate groups with the formation of ADP or AMP. The ATPase activity is associated with many energy-consuming processes. For example, in muscular contraction it is associated with myosine when activated by actin. (See also Nutrient uptake.)

Atrazine

Atrazine is the generic name for 2-chloro-4-ethylamino-6-isopropylamino-s-triazine. Atrazine is an example of photosynthesis inhibitors and herbicides.

Atrazine was the first s-triazine used in maize. The use of this herbicide and others in the same group has expanded to selective application in perennial crops and orchids as well as for non-crop and industrial sites.

ATS

ATS is short for **ammonium thiosulphate**.

Attapulgite clay

Attapulgite clay is clay from Attapulgus, Georgia, USA. It is hydrous, needle-like magnesium aluminum silicate $[(MgAl)_5 Si_8 O_{22} (OH)_4 \cdot 4H_2O]$ and is the chief ingredient in Fuller's earth. It is used as a suspending agent in fertilizers, lime, gypsum, etc. and has absorptive and swelling properties.

Attapulgite clay is also used in drilling fluids, decolorizing oils and as a filtering medium.

Attractants

With growing need for an environmentally acceptable pest control method, the use of specific insect attractants has become an important part of pest control technology. Chemical attractants can be used in conjunction with simple, inexpensive sticky traps for monitoring insect pest populations in relation to the economic threshold for control and/or trapping of pests, for luring them to toxic bait, or for creating confusion during mating.

Two general types of attractants have been studied widely. These are (a) sex pheromones, used in intraspecies chemical communication leading to mating and (b) plant kairomones, used in interspecies chemical communication for host plant selection.

Sex pheromone attractants are generally volatile esters, alcohols and aldehydes that facilitate sexual communication and mating over distances up to several hundred meters and can be perceived in nanogram to microgram quantities.

Kairomone attractants are volatile chemicals released by plants, which serve as major cues host plant selection by phytophagous insects. Increasing numbers of kairomones have been identified and found to be useful insect attractants. The most successful mixtures are eugenol with geraniol or phenyl ethyl propionate.

Auger

An auger or **soil auger** is a tool with a pointed tip used for boring holes in the soil for collecting soil samples for analysis. Augers are of two types: worm-type and hollow cylinder type, with a cutting edge or a screw at one end.

Auger fertilizer distributor

An auger-type fertilizer distributor is an implement that can evenly distribute the exact amount of a fertilizer in all directions, rendering width and flexibility to band applications.

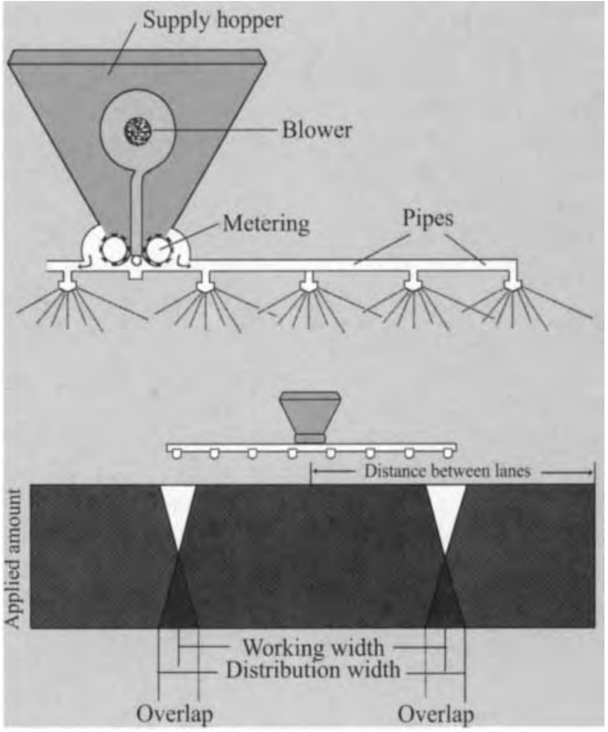


Fig.A.41: Auger fertilizer distributor.

The distributor has spreaders with a mechanical traverse distribution, generally equipped with a screw or auger, called **auger-type spreaders**. The fertilizer flowing from the hopper is conveyed to the auger and is transported to the spreader tubes with adjustable discharge spouts with a working width of 6 to 8 m depending on the boom length (Fig.A.41).

For the application of powdered fertilizers, **auger type spreaders** with identical boom lengths and working widths are preferred. For uniform fertilizer distribution, the exact driving of the distributor in parallel runs is essential. To improve the metering and distribution of mineral fertilizers, electronic control units ensure an automatic discharge of desired amounts of the fertilizer as indicated on the display panel.

Auger type spreader

Auger type spreader is a device used for applying powdered fertilizers. It has electronic control units which ensure an automatic discharge of desired amounts of the fertilizer as indicated on the display panel. (See also Auger fertilizer distributor.)

Autecology

Autecology is the study of environmental relations of individuals or species. (See also Ecology.)

Auto allelopathy

Auto allelopathy is the inhibition of a species by self-produced toxins. (See also Allelopathy.)

Autochthonous limestone

Limestone has two origins. One is autochthonous limestone and the other is **allochthonous limestone**. Autochthonous limestone is formed in-place by the biogenic precipitation from sea water. The primary agents of autochthonous limestone are lime-secreting organisms and foraminiferans, which are marine protogoans with a secreted shell. Fossils of such organisms, having a long geological history, have been found embedded in such limestone and other carbonate material. Thus, limestone itself has been an object of interest to geologists and other scientists. Study of the structure of caves has also revealed that autochthonous limestone in fluvial sediments is in the form of angular softened limestone embedded in clay.

Autoclave

An autoclave is a cylindrical vessel with a double wall chamber, which withstands pressure (like 2.1 kg/cm^2) operations (Fig.A.42). It sterilizes solids and liquids used in the laboratory to overcome contamination. This equipment is essential in microbiology, pathology and tissue culture studies. Sterilization is achieved mainly by an air-free saturated steam inside the autoclave at a temperature of above 100°C. The boiling water produces steam which creates pressure inside the autoclave chamber. The temperature rises as the pressure increases to 1.05 kg/cm^2. When the temperature goes up to 121°C and is retained at this level for a specified time (normally 15 minutes), the vegetative cells and spores are destroyed. If the evacuation of air is incomplete, pressure builds up without a proportional rise in temperature. After the operation, it is necessary to wait for the pressure to decrease to ambient to avoid harm by the boiling water inside the autoclave.

Autogamy

Autogamy is one of the two types of fertilization, also known as **self-fertilization**. Here, the pollens are carried from an anther to the stigma of the same flower or to another flower of the same plant. Autogamy is found, for instance, in wheat, oats and peas.

Autotrophic bacteria

Autotrophic bacteria are **bacteria** that produce organic constituents from inorganic compounds on their own, utilizing energy from sunlight for oxidation processes. Depending on the source of nutrition and energy, soil bacteria are classified as autotrophic, which obtain energy from (a) sunlight (**photoautotrophs**), or (b) the oxidation of minerals such as ammonium, sulphur and iron, and most of the carbon from carbon dioxide (**chemoautotrophs**). Bacteria which oxidize ammonium to nitrite (*Nitrosomonas* spp.) and nitrite to nitrates (*Nitrobacter* spp.) are autotrophic.

Auxins

Auxins are a group of growth-promoting substances, responsible for such plant related processes as promotion of longitudinal growth by cell elongation, stimulation of cell division in **cambium** and roots, maintenance of apical dominance and initiation of root formation in cuttings, as well as in the control of enzyme activity.

Naturally occurring auxins, such as **indoleacetic acid (IAA)** and **4-indole-3-butyric acid (IBA)**, are synthesized in the plant shoot tips. Auxins, important as growth regulators, include (a) indole-3 acetic acid, (b) 4-indole-3 butyric acid, (c) 2-(1-Naphthyl) acetamide and (d) 2-(1-Naphthyloxy) acetic acid.

Synthetic auxins, known by various trade names such as 2,4-D and 2,4,5-T are used as weed killers. Some synthetic auxins are used for inhibiting the sprouting of potato tubers, thereby increasing their storage life. Auxins are also used in the prevention of fruit drop in orchards, synchronous flowering in pineapple and parthenocarpic fruit production.

Auxins have not gained much practical importance as growth stimulators owing to their narrow therapeutic range. Moreover, a small overdose can lead to a herbicidal effect. Therefore, auxin type substances are much more important as herbicides than as growth regulators.

Antiauxins are substances that compete with auxins for specific receptors. They inhibit the transport of auxins in the plant and thus strongly affect plant growth

Fig.A.42: Types of autoclave. 1. Vertical type, 2. horizontal type.

and morphology. **N-m-tolylphthalamic acid, (N-m-t)** improves the yield of tomatoes, cherries, eggplants and lima beans by increasing fructification.

There are four bioassays commonly employed for auxins. These are (a) avena curvature test, (b) avena straight growth test, (c) pea split stem curvature test, and (e) cress root inhibition test.

Auxotrophic micro-organisms: See Auxotrophs

Auxotrophs

Auxotrophs or **auxotrophic micro-organisms** are micro-organisms which cannot synthesize essential growth factors and need to acquire these from external sources. The external sources include organic compounds, vitamins, etc. *Bacillus anthracis* is a thiamine auxotroph, as it does not synthesize the thiamine required for its growth.

Available biogenic element

Available biogenic element is another term for **available element**.

Available element

Available element, also called **available biogenic element**, is one that can be absorbed directly by the plant. Such a substance has to be in a mineral and ionized form. Its availability depends on its solubility in soil water and in solutions in contact with the roots.

The availability (not to be confused with 'exchangeable') of a biogenic element is difficult to determine. Because the availability depends on the combination of three complex factors, namely (a) the plant itself, (b) the force of retention of the element by soil colloids and (c) the content of the element in the soil.

Soil pH can strongly influence the availability of essential and non-essential elements for plant growth, as shown in Fig.A.43.

Available form

A form in which an element can be absorbed by the plant is called the available form.

That water in the soil, which the plant roots can absorb to sustain life, is called **plant available water**. It is the moisture held with water potential between minus 13 to minus15 bars.

In fertilizer terminology, for example, terms like **water-soluble**, citrate-soluble, citrate-insoluble, available form and **total phosphorus** (P_2O_5) are used to delineate different forms of phosphorus available in a

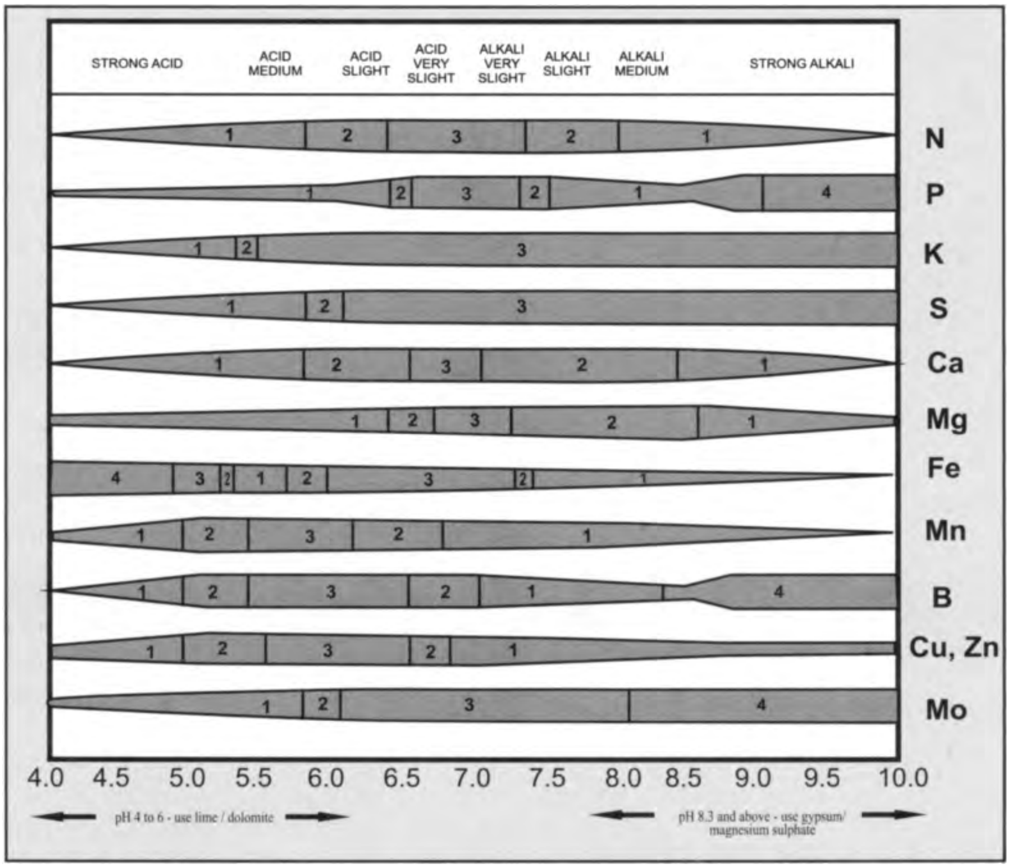


Fig.A.43: A bar diagram showing the effect of soil pH on the availability of plant nutrient elements. Nutrient availability increases or decreases as per the thickness of the bar. The thicker the bar, the more the availability, and vice versa. Similarly, the number code - 1 indicates very little availability, 2, marginal availability, and 3, sufficient availability. Even though the bar is thick, the number code 4 signifies very little availability because of the absence of complimentary elements and soil interactions. Courtesy: Institute of Micronutrient Technology, Pune, India.

phosphate fertilizer. The sum of the water-soluble phosphorus and the citrate-soluble phosphorus represents the amount of available phosphorus (as P_2O_5).

Generally, plant roots and foliage absorb plant nutrients as water solutions of a variety of chemical compounds with varying degrees of water solubility. Thus, water solubility provides a simple conclusive measure of the 'available' nutrients to plants.

Available nutrients

Available nutrients are soil substances that can be readily absorbed and assimilated by growing plants. Available nitrogen is defined as water-soluble nitrogen plus a part of it that can be made soluble or converted into free ammonia. **Available phosphorus** is that part of phosphorus which is soluble in water or in a weak dilute acid, such as 2% citric acid. Available potash is defined as that portion of potash which is soluble in water or in a solution of ammonium oxalate.

Available phosphorus form

A sum of the fraction of water-soluble and citrate-soluble phosphorus available to plants is called available phosphorus.

The content of fertilizers is expressed as '**water-soluble**', '**citrate-soluble**', '**citrate-insoluble**', total available phosphorus (as P_2O_5), etc., because the phosphorus solubility of fertilizers varies.

Available phosphorus in fertilizers represents an estimate of the fraction of the sum of water-soluble and citrate-soluble phosphorus available to plants.

The technique of citrate extraction is useful in determining all phosphates, such as calcium hydrogen phosphate ($CaHPO_4$), which are insoluble in water but soluble in citrate solutions. The most common methods in Europe use ammonium citrate solutions (1N) where extraction is performed in a strong alkaline medium or neutral citrate solution. Very often, the extraction is carried out for 30 minutes at room temperature, and is followed by a treatment at 40°C. For neutral citrate extraction, 65°C is the prescribed temperature. The phosphorus content in the filtrate is termed as citrate-soluble.

Most countries in the world use neutral ammonium citrate solution for extracting the citrate soluble phosphorus.

Available potassium in soil: See Exchangeable potassium

Available water

Available water is the soil water that plant roots can readily absorb. It is the water held in the soil against a pressure of about minus 15 bars. Water held in the soil between field capacity and wilting point is the available water.

To evaluate the total quantity of water accessible to plants (called the **useful available water**, **UAW**), it is necessary to include the rooting depth (P) as well as the bulk density (D) of the soil. Thus,

$$UAW = (PD)\,(c\text{-}w)$$

where c is the field capacity water percentage and w is the wilting point water percentage.

Available water capacity

Available water capacity is the quantity of water that a soil is capable of holding between the field capacity and the permanent wilting point. It is expressed on a volume basis in units of mm of water per 100 mm depth of soil.

The concept of field capacity, while useful for setting up an upper limit to the amount of available water in the soil, is not precise for two reasons: (i) The soil may remain saturated above the field capacity owing to frequent rains for several days. (ii) Soil with a high proportion of micropores continues to drain slowly for several days after the rains. (See also Field capacity.)

A value

The A value for a plant is the quantity of a nutrient available to it in the soil medium. It is determined in terms of a standard fertilizer used, and is expressed as:

$$A = \frac{B\,(1 - y)}{y}$$

where B is the quantity of nutrient in the applied fertilizer and y is the proportion of nutrient in the plant derived from the fertilizer.

The A value is determined by a tracer technique; **Fried and Dean** method for estimating nitrogen in the soil uses a labelled fertilizer. This method involves adding known quantities of ^{15}N labelled nitrogen to the soil, growing plants and determining the relative amounts of soil and labelled nitrogen taken up by the plants. A key assumption is that plants take up the soil nitrogen and the labelled nitrogen in proportion to their effective concentration in the soil.

The isotope dilution technique is used to estimate the availability of soil nitrogen and other plant nutrients in absolute units. This method assumes that (a) the labelled fertilizer is mixed uniformly with the exact volume of the soil foraged by the plant roots, (b) the added nitrogen is not lost selectively from the soil after application, and (c) transformations, such as immobilization and mineralization, occur only insignificantly during the period of study. However, some of these assumptions need further scrutiny.

The A value is used for the assessment of the available soil nutrients like N, P or S. The nitrogen isotope ^{15}N occurs in atmospheric nitrogen at a constant abundance of 0.3663 atom percent. The proportions of leguminous plant nitrogen derived from atmospheric nitrogen and soil nitrogen can be determined if the isotopic abundance of atmospheric nitrogen and the soil nitrogen are significantly different. This can be achieved by incorporating small amounts of nitrogen fertilizer enriched in ^{15}N into the soil.

The symbiotically fixed nitrogen by a legume in the field is estimated by a simultaneous determination of the A value of a non-legume along with the legume crop. The A value of a non-legume crop represents the soil nitrogen as the principal source, while the A value of the nodulating legume crop represents the symbiotically fixed nitrogen, in addition to the soil available nitrogen. The difference in the A values provides an estimate of the symbiotically fixed nitrogen by a legume.

Average soil

Average soil is represented by the NF (numerical estimation of fertility) value of 50. (See also Fertility, numerical estimation of.)

Avogadro's constant: See Avogadro's number

Avogadro's number

Avogadro's number (N_A) = 6.0221367 x10^{23} represents the number of carbon-12 atoms in 12.00 g of carbon-12. Generally, it is the number of molecules contained in one mole or gram molecular weight of a substance.

Presently, Avogadro's number is known as **Avogadro's constant**. There are several methods for determining Avogadro's number, some of which use (a) Brownian movement, (b) radioactivity measurement, (c) Faraday's laws of electrolysis and (d) x-ray diffraction.

AVO meter

AVO meter is another name for a **multimeter**. It is used to measure the resistance or conductivity of soil.

AZF-Grand Paroisse dual pipe-reactor process for ammonium phosphate nitrate production

There are several processes to produce fertilizers containing ammonium phosphate and ammonium nitrate. Most of these are also used to produce the NPK grades.

The AZF-Grand Paroisse dual pipe-reactor process is one of the processes in which ammonium nitrate solution is sprayed directly on fertilizer granules in the granulator to produce ammonium phosphate nitrate (APN) fertilizer. APN solutions are also made by neutralizing phosphoric acid with ammonia and amomonium nitrate.

AZF-Grand Paroisse prilling process for ammonium nitrate production: See Ammonium nitrate, production processes for

Azofication

Azofication is **nitrogen fixation** without symbiosis. The soil bacteria of the *Azotobacter* group use organic matter as the energy source and fix nitrogen for their own use, which returns ultimately to the soil after the bacteria die.

Azolla

The word *Azolla* originates from two Greek words, *Azo* (to dry) and *Ollyo* (to kill), indicating that the fern is killed by drought.

Azolla is a greenish colored fern floating on fresh water and is used as a **biofertilizer**. The reddish color of the fern is due to the accumulation of anthocyanin pigment.

Azolla belongs to the family Azollacae. It flourishes in tropical and temperate fresh water ecosystems. Azolla is closely related to the family Hymenophyllaceae, and specifically to the order Salyniales.

There are seven species of *Azolla*: *Azolla caroliniana, A. nilotica, A. filiculoides, A. mexicana, A. microphylla, A. Pinnata* and *A. rubra.*

Azolla pinnata is the most common species, found in tropical climates. It grows in ditches and stagnant water, and multiplies vegetatively (Fig.A.44). The vegetative multiplication is caused by binary fission. In suitable conditions, *Azolla* doubles in 1 to 3 days, though in fields it takes longer. It fixes atmospheric nitrogen in symbiotic association with *Anabaena azollae*, a blue green alga, which lives in the dorsal cavity of the leaf.

Leaves of *Azolla* are triangular or polygonal in shape and have a dorsal and a ventral lobe. The symbiotic algae, *Anabaena azollae*, live in the cavities of the dorsal lobe. The algae are barrel shaped and have no sheath. The *Azolla* fern and the symbiotic *Anabaena azollae* (algae) both photosynthetically make an important **biofertilizer**. *Azolla* gets carbon photosynthetically and symbiotic *Anabaena azollae* fix atmospheric nitrogen.

Fig.A.44: Azolla grown in pots. It is also grown in ponds for large scale production.

Azolla is recommended for rice fields with stagnant water. It can increase the rice yield by 15 to 20%. The importance of this biofertilizer is its value as an organic input in rice cultivation, which was first demonstrated in Vietnam in 1957.

In China, the nitrogen requirement of rice is met by *Azolla* to the extent of 50%. This is generally applied along with phosphorus at the rate of 150 to 225 kg of **superphosphate** per hectare (24 to 36 kg P_2O_5 or 11 to 16 kg phosphorus/hectare). Indian studies have indicated that the addition of 5 t/ha of *Azolla* can provide an equivalent to 30 kg nitrogen/hectare to the paddy crop.

In countries like India, there are two recommended methods for applying *Azolla*. Application as green manure prior to rice planting is the first method; the second method involves a dual cropping with rice, where the *Azolla* grows simultaneously with the main crop.

Before transplanting rice seedlings, the field is prepared for *Azolla* inoculation by dividing it into subplots of about 300 to 400 sq.m. in each area. These plots are flooded with water and inoculated with fresh *Azolla*. After 2 to 3 weeks, the water is drained out and *Azolla* is incorporated into the soil. In a week's time the rice seedlings are transplanted to the plots. Ideally, an optimum level of temperature and moisture has to be maintained with adequate supply of nutrients, especially of phosphorus.

Azolla cannot be advantageously used in areas that have no water, or, where pests and adverse temperatures prevail. It perishes quickly if removed from water and is thus not amenable to long distance transportation.

Azolla finds use as green manure, as fodder for livestock, as a weed suppressant and as composting material.

Azolla-Anabaena symbiosis

The *Azolla-Anabaena* symbiosis is one in which the fern *Azolla* provides a habitat and carbon source to the **blue-green alga**, the *Anabaena azollae*. In turn, the *Anabaena* lives and grows in the cavity of the *Azolla* fern, fixing atmospheric nitrogen (Fig.A.45). While the fern can grow without **algae**, it is now established that *Anabaena azollae* can also be isolated and grown in free living state.

The algae provide nutrients, whereas the fern provides a protective cavity in each of its leaves for algal colonies. *Anabaena azollae* creates colonies that fix atmospheric nitrogen and produce possibly other substances, promoting growth inside the *Azolla* leaf cavities.

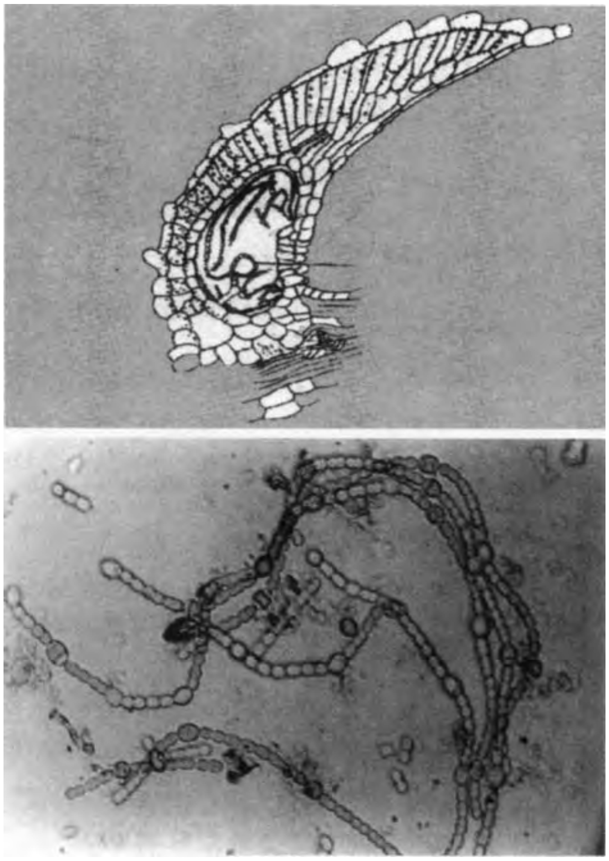


Fig.A.45: Azolla-Anabaena symbiosis. (Top) Anabaena azollae in the cavity of Azolla leaf. (Bottom) Microscopic view of Anabaena azollae. (Courtesy: Dr.P.L. Patil, Pune, India).

Ammonia produced by *Anabaena* is used or stored by the algae, or it is supplied to the *Azolla* partner. This puts *Azolla* in a more advantageous position than other aquatic plants in low nitrogen supply conditions.

Azolla pinnata

Azolla pinnata is one of the seven species of *Azolla*, a fresh-water fern (Fig.A.46). It fixes atmospheric nitrogen in symbiotic association with *Anabaena azollae*, a **blue-green alga**, which lives in the dorsal cavity of the fern leaf.

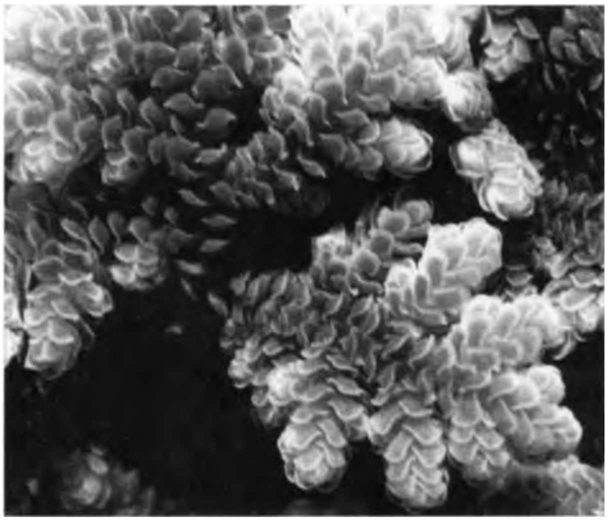


Fig.A.46: A close-up of Azolla pinnata.

Azospirillum

Azospirillum is an associative micro-aerophilic nitrogen fixing bacterium, commonly found in association with the roots of cereals, grasses and monocotyledonous plants. It is suitable for use in tropical conditions because of its high nitrogen fixing capacity, low energy requirement and tolerance to high temperatures (30 to 40°C).

The known species of *Azospirillum* are: *A. lipoferum, A. brasilense, A. amazonense, A. halopraeferns, A. irakense* and *A. melinis*. Different culture media are developed for *Azospirillum*. Its cell is 1 mm in diameter. Its looks like a curved rod and may vary in size. The bacteria are **chemoheterotrophic** and associative.

The bacteria are aerobic organisms which derive food and energy from carbon sources like mono, di, and polysaccharides (L-arabinose, D-glucose, D-fructose, sucrose and pectin). The nitrogen source is through the fixation of nitrogen, amino acids, ammonium, nitrate ions, etc. A nitrogen-free medium is desirable for the growth of *Azospirillum*. In an ammonia-containing medium, *Azospirillum* doubles in an hour, but in a malate-containing medium, it doubles in 5.5 to 7 hours. *Azospirillum* sp. increases mineral and water uptake of the plants it associates with and also helps root development and vegetative cover.

Azospirillum, a **biofertilizer**, is recommended for rice, millets, maize, wheat, sugar cane, sorghum, sunflower, mustard, vegetables, etc. (Fig.A.47). Its **inoculation** has shown positive interaction; nitrogen thus supplied in several field crops has shown an average response equivalent to 15 to 20 kg/ha of applied nitrogen.

Fig.A.47: Azospirillum inoculant. These nitrogen fixing bacteria are commercially available for all non-legume crops.

In a study carried out at Delhi and Dehradun in India, inoculation with *Azospirillum* showed a significant increase of irrigated barley yield with very little or no fertilizer nitrogen application. A dual inoculation of *Azospirillum* and *Azotobacter* could save approximately one-third the quantity of nitrogen fertilizer used.

Azospirillum also produces growth producing hormone-like substances, and is now classified as a PGPR (plant growth promoting rhizobacteria). It is beneficial as an inoculant even in the presence of fertilizer nitrogen.

In order to utilize associative diazotroph under adverse conditions, mutants have been obtained that are tolerant to manganese and aluminum, and that perform better in acidic soils. Several carriers have been tested for the survival of *Azospirillum.* Among these, powdered and sterilized **farmyard manure (FYM)** was seen to support the survival of *Azospirillum* organism for up to 31 weeks. Other combinations tried were FYM + soil and FYM + charcoal. *Azospirillum* biofertilizer has been widely adopted as an inoculant for rice in Tamilnadu, India, where it is supplied in lignite carriers and applied both by dipping the seedlings in inoculant slurry as well as by soil application.

Azote

Azote is a French word, meaning nitrogen. A bacterium is named *Azotobacter* for its atmospheric nitrogen fixing characteristics.

Azotobacter

Azotobacter is a bacterium capable of fixing atmospheric nitrogen. It is one of the dominant non-symbiotic nitrogen-fixing bacteria, encountered in neutral to alkaline soil conditions. These species are free-living obligate aerobes, heterotrophic and Gram negative to Gram variable. They exist as blunt rods and come in varied sizes (2.0 to 7.0 × 1.0 to 2.5 mm). They produce soluble, insoluble or fluorescent colors.

The oval shaped *Azotobacter* is present in large numbers in the rhizosphere. It does not attach itself to roots. Because *Azotobacter* synthesizes its nutritional requirements from organic matter, it is called heterotrophic. As it derives its energy from oxidation of organic substances, it is said to be **chemoheterotrophic**. *Azotobacter* uses mono, di, and polysaccharides, as well as several other organic compounds as carbon sources. It forms cysts to overcome adverse conditions which are characterized by the presence of poly b-hydroxy butyric acid. As the colony (for example, *Azotobacter chroococcum)* gets older, it accumulates polysaccharide or gum, together with a black melanin pigment, which is another characteristic feature of the *Azotobacter* species. These organisms grow when the pH is near neutral, but pH below 6 hampers the process of nitrogen fixation.

Another important characteristic of *Azotobacter* is that it excretes ammonia in the rhizosphere in the presence of root exudates, which helps nutrient uptake by the plant. Plant root exudates contain certain amino acids, sugars, organic acids and vitamins, which serve as energy sources for *Azotobacter.*

Species like *Azotobacter chroococcum* have the ability to synthesize auxins, vitamins, growth promoting substances and antifungal antibiotics. Some important growth promoting substances are indoleacetic acid, gibberellins and B vitamins.

Free-living, nitrogen-fixing bacteria are classified into aerobic, anaerobic and facultative anaerobic types, depending on the growth and survival pattern of the organisms, either in the presence or absence of oxygen. The aerobic bacterium fixes nitrogen (which is an anaerobic process) by protecting the enzyme nitrogenase from oxygen inactivation. This is primarily by virtue of its very high respiratory rate, which constantly removes oxygen from the active sites of fixation. The nitrogenase enzyme is also bound to membrane and the active sites of the enzyme are physically protected from oxygen inactivation.

Azotobacter fixes molecular nitrogen at the rate of 10 mg nitrogen/g of carbon source from the synthetic medium. *Azotobacter* fixes nitrogen even up to 1050 microgram nitrogen/ml of the culture medium, which amounts to 14 to 28 mg nitrogen/g of carbon source. The efficiency of nitrogen fixation, however, changes considerably with the source of carbon present, the strain of bacteria in the soil, the water content and the nature of rhizosphere of the plant.

The following factors influence the bacterium in the soil: (i) A lack of organic matter can inhibit its growth. (ii) The presence of fungi (like *Cephalosporium*) inhibits the growth of *Azotobacter.* (iii) Cellulolytic micro-organisms degrade plant residues and encourage proliferation of *Azotobacter.* (iv) Small amounts of **humus** promote the growth and nitrogen fixation capacity of *Azotobacter.*

Azotobacter biofertilizer (Fig.A.48) is recommended for various monocots and cereals, like rice, wheat, millets, cotton, sunflower, vegetables and flowers.

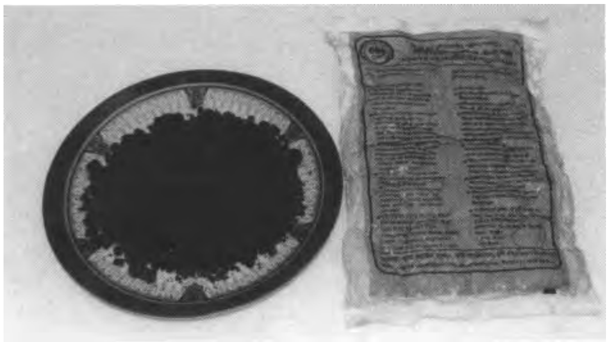


Fig.A.48: Azotobacter inoculant is commercially available in packets for monocot and cereal crops.

The *Azotobacter* biofertilizer can be applied in three different ways: (a) coating seeds with the slurry of the carrier-based culture and a little water, and then drying the seeds in shade before sowing, (b) dipping the roots of seedlings in the slurry. In the second method, when saplings are ready for transplanting, they are uprooted and their roots are dipped in the slurry for 10 to 30 minutes, after which seedlings are planted immediately, and (c) mixing the inoculant with farmyard manure and pouring it near the root zone of plants or broadcasting near the root zone.

The Fertilizer Encyclopedia
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Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

B

Bacillus

Bacillus is a large, gram-positive, rod-shaped, spore-bearing bacterium which has a tendency to form chains and capsules. Bacilli are ubiquitous in soil and air, and are often responsible for food spoilage. Some bacilli have flagella and are motile. The Bacillus group includes anthrax causing *Bacillus anthracis,* N-fixing *Rhizobium* bacteria, *Bacillus thuringiensis, B. popillae, B. sphaericus* and *B. radicicola.*

Bacillus radicicola

Bacillus radicicola is the former name of the *Rhizobium* bacterium.

Bacillus thuringiensis

Bacillus thuringiensis (Bt) is an important insect pathogenic bacterium commercially known as 'Thuricide'. It releases toxic polypeptide crystals which are degradable by the enzyme, protease. The bacterium is pathogenic to the following insects: Lepidoptera, Diptera and Coleoptera.

Bacillus thuringiensis has been exploited commercially and its sprays have been used in the USA since the 1930s. It is the only commercialized transgene. The Bt toxin provides resistance against insects by binding to specific sites in the insect gut. However, insect resistance to Bt is also known.

Bacteria

Bacteria (singular - **bacterium**) are simple, prokaryotic, microscopic organisms that lack chlorophyll. They can be spherical, rod-shaped, comma-shaped, corkscrew-shaped, spiral or filamentous. (Figs.B.1 and B.2). Most of the bacteria range in size from 0.5 to 5.0 μm, and have almost an unlimited capacity to multiply, which happens by simple fission. Bacteria that use atmospheric oxygen to function are classified as aerobic bacteria and those that get their energy by reducing simple compounds like sugars, nitrates and sulphates, are called anaerobic.

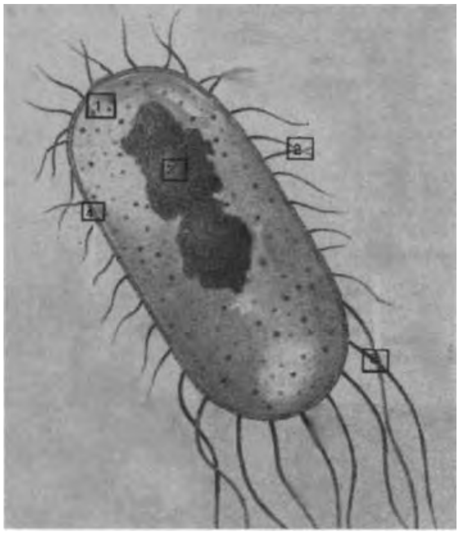


Fig.B.1: A bacterial cell with common structural features: 1. Ribosomes; 2. Pili; 3. Nucleoid; 4. Cell envelope and 5. Flagella.

Facultative bacteria mostly utilize atmospheric oxygen but they can also respire anaerobically under conditions of low oxygen supply, as in waterlogged or poorly drained soils.

Depending on their source of nutrition and energy, soil bacteria are classified as follows: (i) **Autotrophic** bacteria obtain energy from sunlight (**photoautotrophs**) or from oxidation of minerals such as ammonium, sulphur, iron and carbon primarily from carbon dioxide (**chemoautotrophs**). Bacteria that oxidize ammonium ions to nitrite *(Nitrosomonas* spp.*)* and nitrite to nitrate *(Nitrobacter* spp.*)* are examples of autotrophs. (ii) **Heterotrophic** bacteria obtain their energy and carbon directly from the soil organic matter. For example, nitrogen-fixers such as symbiotic ***Rhizobium*** spp., non-symbiotic ***Azotobacter*** spp. and *Clostridium* spp. are heterotrophic. Decomposing and ammonifying bacteria also belong to this group.

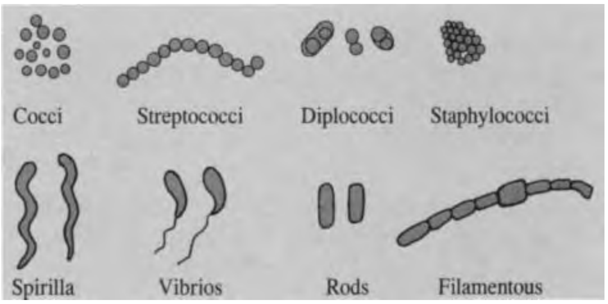


Fig.B.2: Different forms of bacteria

Soil bacteria generally thrive best when they have (a) adequate oxygen in a gaseous or combined form, (b) temperatures ranging between 20 and 40°C, (c) soil moisture above 60% RH, and (d) adequate organic matter and a large amount of exchangeable calcium ion (Ca^{2+}). Though a pH of 6 to 8 is suitable for most soil bacteria, a few species can function at a pH values as low as 3.

Bacteria are largely responsible for the decay and decomposition of organic matter as well as for recycling elements such as carbon, oxygen, nitrogen and sulphur. Some bacteria, including **cyanobacteria** (blue-green algae), get their food through photosynthesis. Some bacteria are **saprotrophs** while others are disease-causing parasites.

Bacteria are divided into two subgroups: **Archebacteria** comprising **methanogens** and species capable of tolerating extremely high temperatures (thermophilic) or salty environments, and **eubacteria** that include the remaining vast majority of bacterial species.

In general, the presence of bacteria in soil is a sign of good agricultural soil.

Bacterial cell wall

The bacterial cell wall is made of murein, a molecule that makes the cell wall strong and rigid. This molecule has long, parallel polysaccharide chains cross-linked with short chains of amino acids at regular intervals. A net-like sac surrounds the cell wall (Fig.B.3) and prevents rupture that would have otherwise been caused by water absorption. The cell wall has minute pores which allow water, ions and small molecules to pass.

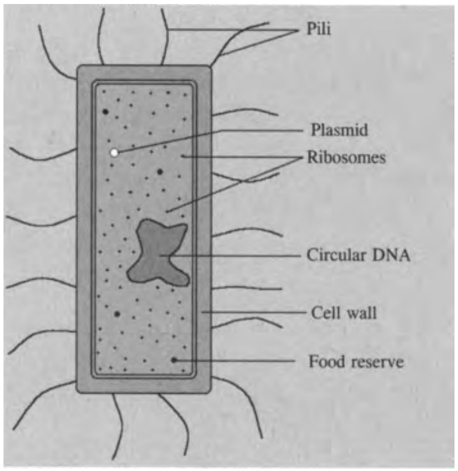


Fig.B.3: Bacterial cell wall contains murein that makes it strong and rigid.

Bacterial synergism

Bacterial **synergism** is the ability of two or more bacteria to bring about such chemical changes as are not possible individually. For example, the oxidation of ammonia to nitrate via nitrite is possible only by a combination of *Nitrosomonas* and *Nitrobacter.*

Bacteriocin

Bacteriocin is the toxin produced by a bacterium with specific inhibitor action. For example, *Cicer* rhizobia have been detected to produce a toxin that plays an important role in inter-strain competitiveness for nodulation in legumes. Tyrothricin produced by *Bacillus brevis* inhibits Gram-positive bacteria and cocci.

Bacteriophage

Bacteriophage is a virus that parasitizes a bacterium and causes the rupture of bacterial cells. The bacteriophage consists of a polyhedral head measuring upto 1000Å units across the material containing DNA, which is enclosed by a wall of protein.

A bacteriophage produces a transmissible dissolution of specific bacterial cells. Rhizophage is a bacteriophage that destroys *Rhizobium* bacteria.

Bacterium

Bacterium is the singular of **bacteria**.

Bacterization

Bacterization is the process of coating legume seeds with a culture of nitrogen-fixing bacteria before sowing. Such a coating becomes necessary when the organisms essential for good growth are either insufficient in number or are ineffective in the given soil conditions. Bacterization stimulates the formation of root nodules and symbiotic nitrogen fixation.

Badlands

The word badlands originates from the arid, semi-arid or dry tropical lands in Dakota, USA. These highly eroded regions are devoid of vegetation and often have narrow ravines and sharp ridges. Here, the total precipitation and its distribution is insufficient to support a protective vegetative cover common in other arid regions with deep alluvium deposits.

Bagasse

Bagasse is the residue left after crushing, and extracting the juice from sugar cane. It has a variety of uses as a fuel, as an animal feed, for making paper, insulating materials, as a medium for bacterial growth and for the manufacture of furfural. The term is also applied to similar residues from other plants like beet, sorghum or sisal. Bagasse is made up of cellulose and contains a high proportion of **hemicellulose**.

Bag muck

Bag muck is another name for artificial fertilizers supplied in bags.

Bag set of fertilizers

Bag set is the agglomeration or lumping of fertilizers when stored in bags, samples of which can be dropped from a height to observe the nature of lumps. (See also Caking tendency, evaluation of).

Bait

An insecticide or rodenticide placed in such a way as to attract the pest is called bait. Arsenic compounds and Bordeaux mixtures are typical insect baits. Most types of baits are highly toxic.

Balanced fertilization: See Balanced fertilizer

Balanced fertilizer

A balanced fertilizer contains all essential elements in the right proportion for the growth of a plant or a crop. (Fig.B.4 and B.5). The application of such additives or

Fig.B.4: A balanced fertilizer being administered through irrigation water.

nutrients to ensure proper crop growth is called **balanced fertilization**. The plants in turn supply minerals essential for the growth and well-being of livestock.

Fig.B.5: Grapevines are supplied with balanced fertilizers through irrigation, using mechanical fertilizer distributors.

Balanced solution

A balanced solution contains salts in the proportions required for maximum plant uptake under the given soil and crop conditions. The solution may be prepared in such a way that any toxicity of a critically required salt is minimized by adjusting the quantity of the salt in that solution. Another benefit of a balanced solution is that one salt does not hamper the uptake of another salt. For example, too much potassium hampers the uptake of magnesium. If a toxicity-causing metal is in excess in the soil, a balanced solution can minimize it. For example, calcium phosphate in the balanced solution precipitates excess aluminum and simultaneously provides the necessary phosphate nutrition.

Thus, a balanced solution attempts to provide adequate nutrition and overcome deficiency, while minimizing toxicity through the constituent salts. The actual constituents of a balanced fertilizer solution, however, vary with soil conditions and crop needs.

Ballast elements

Ballast elements are nutrients that are beneficial, but not essential to plants. These include sodium, silicon, cobalt, lanthanum, cerium, vanadium and aluminum. It may be noted that more than half the elements in the Periodic Table are known to occur in plant tissues, but their specific role in plant growth is still unclear.

Band application of fertilizer

Fertilizers and manures are applied to soils by many methods. Broadcasting, contact placement, fertigation, foliar and aerial application, etc. are some of the methods used. When a fertilizer is applied to the crop, keeping in view the distance and depth from the seed and the quantity required at a specific growth stage of the crop, it is called **fertilizer placement**.

Band application is a method of "placing" fertilizers. When fertilizers are applied to the soil in narrow bands or ribbons on the sides of the plants, as rings around the plants, or at a certain depth during plowing, it is called band application (Fig.B.6). Band application is also called **banding** or **band placement**. Banding may be done prior to, during or after planting. Banding is effective in poor soils where compaction limits the root development and where large surfaces limit contact between the soil and the fertilizer. Banding, which facilitates better nutrient utilization and vegetative growth in the early growth stage, is essential for promoting photosynthesis.

Fig.B.6: Applying fertilizers in bands or rows, manually or mechanically, is a common practice.

No single method of fertilizer application can be considered ideal for all crops. Placement of fertilizers is crucial since it influences, both positively and adversely, seed germination and plant growth. For instance, potassium, inorganic nitrogen and ammoniated phosphates can injure seedlings by salt burn and, therefore, should not be placed too close to the seed. On the other hand, phosphatic fertilizers are usually not only placed close to the seed, but also drilled, sometimes, together with the seed. Shallow-rooted crops and cereals respond favorably to banding or contact placement.

While banding, two factors are important: depth from the seed and the actual placement mode. In a single band placement, fertilizers may be placed to the side of the seed level or below. Here the fertilizer can be dribbled on the opened furrow while plowing, and subsequently covered. The commonly accepted distance and depth of the band from the seed are around 5 cm each. The fertilizer may be administered in a band on one side of the plant row.

Banding can also be carried out on both sides, in which case it is called double band. Double banding requires a cultivator with multiple tines that can be adjusted for distance and depth, depending on the crop need. Both single and double bands also apply to standing crops. Shallow rooted crops also benefit from banding. Such an application of fertilizers on the side or around standing crops is called **side dressing**. Circular band or ring placement (which is a band made in a circular ring away from the plant base) is ideal for fruit trees.

Deep banding is a pre-plant application of nutrient elements 5 to 20 cm below the soil surface. Deep-rooted crops fare better with deep banding of fertilizers. Legumes, which are particularly sensitive to the placement distance, respond well to deep banding below the seed row.

In cold weather, early nutrient supplies by band applications may be inadequate because of (a) slow mineralization of N, P, S, (b) restricted release of nutrients and micronutrients from soil minerals and organic matter, respectively, and (c) reduced diffusion of phosphorus and potassium or limited absorption of nutrients by the plant. The effective nutrient utilization and the early growth enhancement due to band application and fertilizers can benefit the plants in the following ways: (i) Fast-growing young plants are more likely to resist insect and disease attacks. (ii) A fast and early growth of the crop is important in reducing weed competition as it can improve herbicide effectiveness or reduce the number of cultivation practices. (iii) An early crop is generally important, particularly for vegetables where a delay of even 3 to 4 days can affect the price, market and the break-even scenario.

Banding: See Band application of fertilizer

Band placement of fertilizers: See Band application of fertilizer

Banin-Navrot plot

Banin-Navrot plot is a log-log graph of the **biological enrichment factor** (**EF$_B$**) and the **ionic potential (IP)**. Ionic potential is the ratio of the **cation** valence to the cation radii. IP is useful in understanding behavior of an element in the soil solution. The Banin-Navrot plot explains the biological significance of these attributes of an essential element. For instance, elements with IP > 100 nm^{-1} exists as oxyanions, whereas those with < 30 nm^{-1} exist as salruted cations.

EF$_B$ is given by -

$$EF_B = \frac{\text{Element concentration in organisms (mg/kg)}}{\text{Element concentration in crystal rock (mg/kg)}}$$

Banin-Navrot plots for higher plants are remarkably similar to those for animals. They bear close similarity to the Banin-Navrot plots for soil microflora (bacteria and fungi). The biological enrichment factor increases in the following order: hydrolyzed cations << solvated cations < oxyanions forming ions. The solubility and the consequent mobility of the ion are the determining factors for plant nutrient essentiality. Therefore, an insoluble element cannot become an essential or nutrient element.

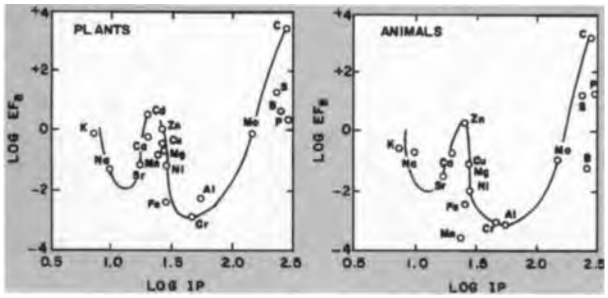


Fig.B.7: Banin-Navrot plots for terrestrial plants and animals. Source: Banin-Navrot, 1985 @Science, USA. As adapted by U. Ashwathnarayan's "Soil Resources and the Environment", 1999. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi. With permission.

Barium chloride method for determination of soil CEC: See Cation exchange capacity

Bark

Bark is a cellulosic outer layer or cortex of trees and other plants. The bark of certain species such as oak and hemlock gives valuable products and is a source of tannic acid. Quercitrin and quillaja are bark products of medicinal importance. Quinine is produced from cinchona tree. Phenolic-rich bark extracts mixed with epichlorohydrin are good adhesive compounds. Cork is an unusual form of bark.

Barrier, moisture

Any substance that is impervious to water or water vapor is a barrier to moisture. The most effective moisture barriers are high polymeric materials like vulcanized rubber, phenolformaldehyde resins, polyvinyl chloride (PVC) and polyethylene, which are widely used in the packaging industry. Some of these are also used in coating fertilizers like urea and ammonium nitrate to make them less water absorbent. The influencing factors for moisture barrier properties in polymeric materials are polarity, crystallinity and degree of cross-linking. Water soluble surfactants and protective colloids increase the susceptibility of a film to water penetration. Pigments and fillers must be completely wetted by the polymer to give good moisture resistance.

Basal application of fertilizer

Basal application of a fertilizer means applying the fertilizer prior to sowing or along with the sowing of a crop. An example is shown in Fig.B.8. The need of resorting to basal application varies depending on the crop and the soil. It is administered either as a single dose or in multiple doses. The basal dose of a fertilizer ensures requisite nutrient supply to the plant during the early

Fig.B.8: Basal dose of fertilizer being broadcast prior to transplanting of rice. Picture reproduced with permission from "Handbook on Fertilizer Usage", 1994. S.Seetharaman, et al (Ed). The Fertilizer Association of India (FAI), New Delhi.

stages of growth. During the later period of growth and at the maturity of the crop, fertilizers are top-dressed as per recommendations.

Basal dressing is another term for basal application. Any amendment done at the beginning of the crop rotation is designed to ensure that the soil has the requisite soil nutrient elements.

Basal dressing: See Basal application of fertilizer

Basalt dust: See Basalt fertilizer

Basalt fertilizer

Basalt, a dark colored igneous rock formed by the solidification of lava, is low in silica and rich in minerals. **Basalt dust**, if used as fertilizer, can provide a range of trace minerals to agricultural systems. Basalt's agronomic value is highlighted from the fact that most of the rich volcanic soils of the world are derived from basalt. Basalt dust is very expensive for land application. In addition, transportation costs add to the total costs. However, if basalt is available nearby and if it can be accessed easily, it proves to be very effective when used with manures.

Base

Base is a large class of chemical compounds with the following properties: (a) bitter taste, (b) soapy touch in solution, (c) ability to turn litmus blue, and (d) ability to react with acids to form salts. Both hydroxides and oxides of metals are included as bases.

Water soluble hydroxides such as sodium, potassium and ammonium hydroxides ionize to liberate hydroxyl ions (OH^-) in large concentration. The hydroxyl ion exhibits the properties described above.

Bases are classified as being strong or weak, like in the case of acids. Examples of two common strong bases are sodium and potassium hydroxides with pH ranging from 7.1 to 14. They cause irritation to the skin, eyes and mucous membranes. Ammonium hydroxide is an example of a weak base.

In modern terminology, a base is any molecular or ionic substance that can combine with a proton to form a new compound. A **Lewis base** is any substance that provides a pair of electrons for a covalent bond with a Lewis acid. Examples of such bases are hydroxyl ions and most anions, metal oxides, and compounds of oxygen, nitrogen and sulphur with non-bonded electron pairs.

Base saturation

Base saturation is an important chemical property of acid soils affecting plant growth and nutrient uptake and is defined as :

$$\text{Base saturation \%} = \frac{\text{Exchangeable Ca,Mg,Na,K}}{\text{Cation exchange capacity at pH 7 or 8.2}} \times 100$$

Base saturation helps to achieve maximum yield by creating an ideal ratio of calcium (Ca), magnesium (Mg) and potassium (K) in the soil. Viewed in terms of chemical properties and reactions, base saturation is synonymous with **acidity index** or **liming index**. The relative dry matter yield with respect to the base saturation is 25% for rice, 60% for wheat, 67% for bean and 53% for cowpea. For corn, the dry matter yield increases with base saturation from 26 to 80% in oxisol soils.

Basic phosphate slag

Basic phosphate slag or **basic slag**, also called **Thomas slag** or **phosphate slag**, is a by-product of steel manufactured in a Thomas converter. Here, oxidation of high phosphorus-containing iron ore is done in the presence of basic calcium oxide (high CaO) liner. A slag forms in the process.

Usually, slag used for phosphate fertilization has 10 to 20% phosphorus pentoxide (P_2O_5). This can be increased by adding phosphate rock to the blast furnace charge. The basic open-hearth slag may contain up to 10 to 12% P_2O_5. It is used in agriculture for **liming** and for providing surplus phosphorus. The slag is a good phosphate fertilizer for acid soils because of its liming effect and micronutrient content. It is usually applied as a finely ground powder, sometimes granulated with potash.

Basic salt

Basic salt is a compound belonging to both the salt and base categories because it contains hydroxide or oxide as well as the usual positive and negative radicals of **normal salts**. Bismuth subnitrate ($BiONO_3$) and basic copper carbonate [$Cu_2(OH)_2CO_3$] are examples of basic salts. Most basic salts, which are insoluble in water, have variable compositions.

Basic slag

Basic slag is another name for **phosphate slag**, a by-product of steel produced from phosphatic iron ores. It contains 6 to 18% phosphorus (as P_2O_5). Indian basic slag is not used as commercial fertilizer because of its poor quality.

Basic stain: See Basophillic cell components

Basin application

Basin application means applying a fertilizer in a circular sloping strip around a tree. Such an application is useful in plantations of coconut and fruit trees like mango (Fig.B.9).

Basin irrigation method

Basin irrigation is a method of irrigating a field that slopes in more than one direction. It involves making ridges of check basins called **dikes** on the land contour to retain water. Basin irrigation is not suitable if the soil is highly permeable, irregularly sloped or affected by temporary flooding.

Basipetal translocation of fungicides

Basipetal translocation of fungicides occurs when the fungicide entering plant tissues is transported downward from the leaves to the roots. When the fungicide is

Fig.B.9: A basin (ring) is made around a tree trunk to facilitate better irrigation and fertilizer application.

transported upward, it is called **acropetal translocation of fungicide**. (See also Fungicides.)

Basophilic cell components

Staining is a technique used for observing various components of a cell or a tissue. The cell or a thin section of a biological tissue is actually immersed in a dye which can be either an acidic or a **basic stain**. The cell components that are receptive to basic stains are basophilic components and those receptive to acidic stains are **acidophilic cell components**.

Batch

A batch refers to a particular lot, say, of a fertilizer, produced in a manufacturing plant as per the standard procedure. The batch that is acceptable must meet the product specifications in each production run.

Batch drying: See Drying

Batch process for measuring adsorption

Batch process is one of the processes used in measuring adsorption. In this process, soil particles are uniformly mixed in a solution and then separated from it by centrifugal or gravitational force. This is followed by a chemical analysis.

Baule unit

A Baule unit is defined as the amount of fertilizer required to achieve at least 50% of the maximum possible yield. It measures the nutrient supplying power of a soil to sustain the crop yield and represents the growth factor of a fertilizer. One Baule of a growth factor is equivalent to one Baule of any other growth factor in terms of its growth promoting ability. Suppose 50% of the maximum yield is obtainable from 1 Baule unit of a nutrient, then a maximum of 75% yield may be associated with 2 Baule units, 87.5% of the maximum yield with 3 Baule units, and so on.

Baumé

Baumé (°**Bé**) is an arbitrary scale of specific gravities devised by the French chemist Antoine Baumé. It is used in the graduation of hydrometers. The relations of specific gravity (at 60/60° F) are as follows : °Bé = 145 - 145/sp.gr., for liquids heavier than water. °Bé = 140/sp.gr. - 130, for liquids lighter than water.

BCF

BCF is short of **bioconcentration factor**.

BC horizon

BC horizon is a transitional soil horizon between B and C horizons. The first letter denotes the principal horizon that the transitional horizon resembles most closely. (See also Soil horizons.)

BC soil

BC soil represents a profile having no horizon of eluviation and the maximum biological activity (i.e., A horizon).

Bean rhizobia

Bean rhizobia are a fast-growing, acid-forming species of *Rhizobium* **bacteria** that form nodules on the roots of legumes like pea (*Phaseolus*). (See also Rhizobia.)

Bedder

Bedder is an implement used to make ridges or narrow beds.

Bedding-drainage system

Bedding-drainage system or **drainage by bed** is a surface drainage system similar to open-W drainage systems. The major difference between the two is that the bedding drainage has a higher crown and narrower drains. The height and the width of the beds depend on the water drainage requirements. The more the water to be disposed, the higher the crown and the narrower the beds. Usually, bed widths are in multiples of the width of the tillage and the planting equipment used and are maintained by plowing a back furrow at the crest of the ridge and working uphill, leaving the final furrows at the drains. (See also Drainage.)

Bedrock

Bedrock is the solid rock underlying loose deposits such as soil or alluvium. It is near the earth surface or at some depth beneath the superficial deposits (Fig.B.10).

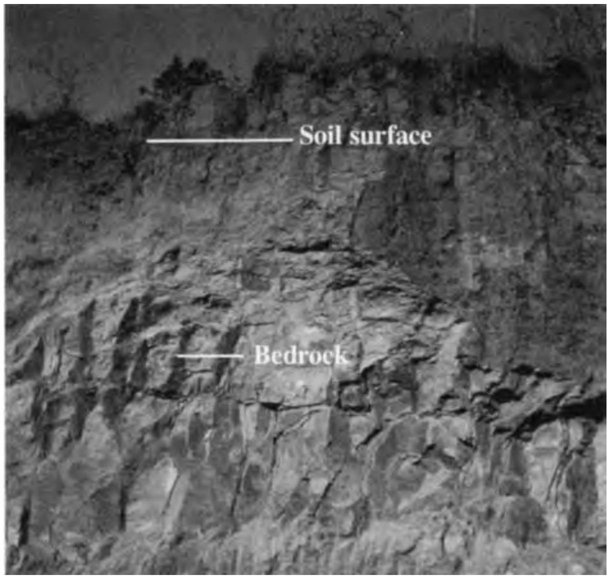


Fig.B.10: Bedrock near the surface soil layer.

BE horizon

BE horizon is one of several transitional soil horizons. A BE horizon lies between B and E horizons, and has more properties of B horizon above it than those of E below it.

Beidellite

Beidellite is a 2:1 type clay mineral with expanding lattice belonging to the silicon rich smectite group. It has a cation exchange capacity (**CEC**) of about 100 meq/100 g and is found in semi-arid region soils.

Beijerinckia

Beijerinckia is a nitrogen-fixing bacterium isolated by Derx in 1950 and named in honor of the scientist Beijerinck. These are aerobic bacteria having the shape of straight or slightly curved rods. The bacterial cells contain poly-β-hydroxybutyrate granules at each end. The bacteria grow well in acid conditions and sometimes develop even at a pH as low as 3.

The genus *Beijerinckia* has four species, namely, *B. fluminensis, B. indica, B. mobilis* and *B. derxii*.

Beneficial cultivation

Beneficial cultivation refers to cultivation that improves land condition and crop yield.

Beneficiation

Beneficiation, also called **ore dressing**, refers to a set of steps (or treatments) that improve ore quality by separating valuable components from the waste material by sieving and floatation. For instance, the phosphorus (as P_2O_5) content in phosphate rock is increased by beneficiation of rock phosphate.

Beneficiation technique of froth floatation

The beneficiation technique of froth floatation is an industrial method for separating ores from unwanted gangue. Here, water and suitable frothing agents are added to the powdered ore. Air is then blown through the mixture to form bubbles. The ore particles are caught in these bubbles, which float on the surface leaving the gangue particles at the bottom.

Froth floatation is generally employed with siliceous ores when the other less expensive methods fail to produce concentrates suitable for chemical processing. (See also Floatation of phosphate rock.)

Bengal isinglass

Different red algae are used for making agar and each alga carries the name of the country or the place where it is used. The alga (red seaweed) *Gracilaria lichenoides* found along the eastern Indian coasts is called Bengal isinglass. The same alga found in Sri Lanka (earlier, Ceylon) is called **Ceylon agar**.

Benor system of training

In an attempt to reach relevant farming information to the actual farmer, Daniel Benor and his colleagues developed, in 1977, an extension management system for the World Bank, called the Training and Visit system, (**T & V system of farming**). This system came to be named after Benor.

The aim of this system was to strengthen the hands of small landholder farmers. It passed proven agricultural practices and technical know-how from national and international research centers through extension officers, subject specialists, village-level extension officers, down to the farmer. The T and V system facilitated a practical link between research centers and farmers' experience.

The training and visit system was successful in irrigation projects but not so in dryland farming. Although it led to increased cash crop production by the farmers, the system was abandoned a decade later, since it was found to be inappropriate in resource-strapped nations, where local conditions and practices made it difficult to follow a strict regimen of inflexible procedures and timetables.

However, the T & V system is credited with creating a methodology for dissemination of farming information. It paved the way for improved systems, which included local parameters and variety. The T & V system was deemed successful in Nigeria, Zimbabwe and many other agricultural economies.

Bentonite

Bentonite, also known as **montmorillonite**, **volcanic clay**, **soap clay** and **amargosite**, is a soft, plastic, light-colored, porous rock consisting largely of colloidal silica. Composed essentially of clay minerals, it swells extensively when wet. Bentonite belongs chiefly to the montmorillonite group and has two varieties: (a) sodium bentonite, with a high swelling capacity in water, and (b) calcium bentonite, with negligible swelling capacity.

Bentonite is used variously as a suspending aid, a gelatinous slurry to extinguish fire, a paint thickener, and as a sealant for earthen pots. Bentonite is also widely used in metallurgy, soap manufacture, and in petroleum refining because of its high decolorizing power and strong adsorbing capacity.

26°Bé product

26 °Bé product is commercial aqueous ammonia supplied at 26 degrees Baumé which is equivalent to 29.4% by weight of ammonia dissolved in water. Since the Baumé reading varies with temperature, it is standardized at some fixed temperature, like at 15°F. (See also Aqua ammonia.)

Bernard calcimeter

Bernard calcimeter is the most commonly known calcimeter for determining the calcium carbonate content of soil. (See also Calcimeter.)

Berti and Cunningham's bioremediation method

Berti and Cunningham's bioremediation method is a method used for the removal of lead ions from contaminated soils. (See also Bioremediation through green plants.)

Bessemer basic slag: See Blast furnace slag

Bessemer process

The Bessemer process, named after the British engineer Henry Bessemer, is used to convert phosphorus and iron ores into slag. In this process, air is blown at 1250°C from the base of a refractory-lined furnace called Bessemer converter. The by-product, **dephosphorated slag** or **basic slag**, is regarded as a good phosphate fertilizer for acid soils. (See also Dephosphorated slag.)

Best management practices

Best management practices (**BMPs**) in agriculture are soil conservation practices. They include such practices as strip-cropping, cover crops, green manure crops, soil testing, liming, and chemical applications to prevent loss of nutrients and pesticides.

BMP also provides water quality benefits. Various consultants and soil conservation agents employ BMP to help farmers develop conservation plants for their farms.

BET equation

The BET equation is named after its inventors Brunauer, Emmett and Teller. It is used to determine the specific surface area of a finely divided substance (like clay) by measuring the volume of a monomolecular layer of an inert gas (like nitrogen), physically adsorbed on the substance at the boiling point of the gas.

The BET equation linearly relates the volume of the adsorbed gas on the surface of a solid to the volume of a monomolecular layer of the gas, and is expressed as:

$$\frac{P}{V\,(1-P)} = \frac{1}{V_m \times C} + \frac{C-1}{V_m \times C} \times P$$

where V is the volume adsorbed, P is the relative pressure, V_m is the volume of the gas required to form a monomolecular layer, and C is a constant. The surface area is obtained from the value of V_m.

With the value of P/V(1−P) calculated from the volume adsorbed on the y-axis and the pressure P on the x-axis, a straight regression line ($y = m\ x + C$) is obtained in which the slope m is equal to $(C-1)/V_m \times C$, and the intercept is $1/V_m \times C$.

BGA

BGA is short for **blue-green algae**. Previously they were thought to be algae, BGA are actually bacteria, called **cyanobacteria**. They fix nitrogen, hence are very useful for crops.

βH

βH is the symbol for **buffer intensity**. The **acid neutralizing capacity** (ANC) of a substance increases with higher pH and the rate of change of ANC with pH (dANC/dpH) is called the buffer intensity. The buffer intensity of organic-rich, temperate zone acid soils ranges between 0.1 and 1.5 mol_c/kg of organic matter, per pH.

B horizon

B horizon is a major soil horizon and is enriched by illuviation of fine or amorphous elements - clay, iron, aluminum oxides and sometimes, humus.

B horizon is also a major mineral horizon in which the structure of the rock has disappeared or is only very slightly visible. It has one or more of the following features: (a) illuvial concentration of clay, iron, aluminum and free or combined humus, (b) residual concentration of sesquioxides from the parent material, and (c) alteration of the material, whereby the clays get formed or the oxides liberated, or both. There are also transition horizons between master horizons and they are designated as AB, BE, BC, etc. The letter B is used for endopedon horizons, indicating colloid accumulation or changes due to weathering in a subsurface horizon. (See also Soil horizons.)

Bidentate ligand

Depending on the number of sites at which one molecule of a ligand coordinates with the central metal atom or ion, ligands have been classified as **monodentate,** bidentate,

polydentate and multidentate ligands. Thus, a bidentate ligand like ethylenediamine or bipyridyl is coordinated to the central metallic atom at two sites. Bidentate ligands may be neutral molecules or anions. (See also Ligand.)

Biennial

A plant is termed biennial when it requires two growing seasons to complete its life cycle. Such plants flower and bear fruits in the second year and then die. Carrot and beetroot are examples of biennial plants (Fig.B.11).

Fig.B.11: Beet root, a biennial crop.

Bioaccumulation

Bioaccumulation refers to the accumulation of organic or inorganic substances caused by an intake rate faster than the excretion rate in an organism over a period of time.

Biochemical oxygen demand

Biochemical oxygen demand (**BOD**) is the amount of oxygen used by micro-organisms to decompose organic waste matter in water.

BOD facilitates measurement of organic pollutants in water and the efficiency of waste treatment plants. A high BOD indicates the presence of a large number of micro-organisms which may cause a high degree of pollution, as in the case of sludge and manure effluents.

BOD is calculated by storing a sample of water containing a known amount of oxygen at 20°C, and then measuring the oxygen content after 5 days. The difference between the two values gives the BOD.

Chemical oxygen demand (**COD**) is a measure of the oxygen-consuming capacity of inorganic and organic matter present in water. It is expressed as the amount of oxygen consumed by a chemical oxidant in a specific test. Water with high BOD or COD contains organic material (such as algae and plant residues) which is undesirable for aquatic life. High BOD waters can lead to poor aeration conditions.

Bioconcentration factor – an environment issue

Bioconcentration is the increased chemical concentration in an organism (through tissue absorption) with respect to its rate of metabolism and excretion. The Environmental Protection Agency defines **bioconcentration factor** or **BCF** as the ratio of chemical concentration in the organism to that in surrounding water.

BCF assumes importance since a higher uptake of chemical compounds causes toxins to move up the food chain. A higher infusion of pesticides, chlorinated compounds and nitrogen fertilizers threatens many species of birds, frogs, fish and other aquatic life. Chemical uptake also takes place in plants which can absorb such contaminants both through the soil and air. An unacceptable and uncontrolled uptake of nutrient chemical in plants can cause its concentrations to go up in meat, milk and other dairy products. Although many methods have been devised to calculate and assess bioconcentrations, (often it is calculated as a function of log$P$), relying on generalized BCFs may not be correct. This is so because a BCF varies greatly with biotic and physical factors like species, season, pH, temperature, salinity, etc.

In the context of plant life, the bioconcentration factor is the ratio of the plant shoot metal concentration to the soil metal concentration. Most of the accumulator plants have a BCF ratio of less than one. In the context of applying the technique of **phytoremediation** to restore lands of chemical excesses, it is estimated that it would take ten years for a crop producing ten tons of biomass per hectare with a BCF greater than twenty to reduce soil metals by half. These figures put the potential environment hazards, via nutrient excesses (NPK and compounds), BTX compounds, chlorinated solvents, etc. in the right perspective.

Biocontrol agent

Any biological agent which is used in the control of insect pests or disease causing plant pathogens is called a biocontrol agent. Such an agent could be an insect or a micro-organism such as a fungus or bacterium.

The following are some examples of biocontrol agents: (i) *Bacillus thuringiensis* (Bt) is used in the control of caterpillars of moths infesting crops like cabbage, tomato, brinjal, cotton, soybean, okra, sunflower, etc. (ii) *Bacillus subtilis* controls the stem rot disease of carnation. (iii) A strain of *Bacillus subtilis* (No.4000), also known as 'Quantum 4000', has been developed to control groundnut diseases. (iv) *Agrobacterium radiobactor* (strain No. 84) is developed to control the soft-rot disease of vegetables, caused by *Agrobacterium tumefacience*.

In fungi, various species of the genera *Trichoderma*, *Paecilomyces*, *Verticillium*, *Nomuraea*, *Metarhizium*, *Beauveria*, etc. are identified as biocontrol agents.

Trichoderma parasitizes disease causing fungi, and controls diseases like wilt and root-rot caused by fungal pathogens. Species like *Trichoderma viride*, *T. harzianum*, *T. hamatum* and *T. virens* are used as biocontrol agents.

Paecilomyces lilacinus is used to control root-knot forming nematodes in all vegetable crops. *Verticillium lecanii* attacks aphids, white fly, scale insects, mites, etc., and is used as a biocontrol agent in fruit crops like grapes, pomogranate, guava and custard apple.

Helicoverpa nuclear polyhydrosis virus (HNPV) is a virus that kills the larvae of Helicoverpa by infecting them. These larvae destroy the crops of sorghum, gram, pigeon pea, cotton, sunflower, maize, tomato, safflower, etc., and can be controlled by the use of HNP virus.

Similarly, *Trichograma* sp. is an example of a biocontrol agent insect which acts against insect pests like bollworm, stem borers and fruit borers in crops such as sugar cane, sorghum, maize, rice, cotton and okra.

Biocontrol of pests – some tested methods

Insect pests have been in existence from time immemorial and farmers had to control them by the means available at their disposal. Before chemical fertilizers became popular, farmers used materials of biological origin for the purpose.

Indian literature mentions many prescriptions for insect pests that are applicable even today. The 11th Century A.D. historic treatise "***Vrikshayurveda***" by Surpala and the 16th Century A.D document "***Vishvavallabha***" by Chakrapani Mishra have recommended several herbs, plant parts and materials of animal origin for controlling insect pests. Out of them 'karanja' (*Pongamia pinnata*), 'nimba' or neem (*Azadirachta indica*), 'shatapushpa' (*Anethum sowa*) and 'vasa' (*Adhatoda vasica*) have insecticidal and antimicrobial properties. According to these books, the plants were mixed with cow urine and ash, and used in several ways for killing or repelling insect pests (for instance, by applying to the affected tree by fumigating). 'Vishvavallabha' also recommends (a) planting of 'shatapushpa' (*Anethum sowa*) and 'kuberakshi' (*Caesapinia crista*) densely between tree rows for controlling insect pests, and (b) planting of 'ajagandha' (*Cleome gynandra*) to repel termites.

In the traditional Sri Lankan agriculture scenario, poisonous plants were once commonly planted for controlling pests. Also, branches, stems and leaves of a poisonous creeper, 'Glory lily' (*Gloriosa superba*), were spread over the field to kill pests on the rice roots. Paddy farmers used these pest repellent plant materials in their fields. A crude paste of neem (*Azadirachta indica*) and mahapatta (*Leea macrophylla Roxb.Ex)* leaves wrapped in cloth, used to be placed at the entry point of water canals. These carried the pesticidal property right through the fields. Farmers in some countries grew trees along the borders of the fields, or kept branches of trees in the area, so that birds such as owls could perch and prey on insects.

Dusting plants with wood ash in the mornings when leaves are wet with dew was a usual ancient practice for repelling insects.

Leaves of 'mahapatta' and neem, soaked in water for several days (for maturation) and then sprayed over bean plants was another traditional method for repelling insects.

Many of these above mentioned non-invasive techniques are still in use in many farming communities in Asia.

Biodegradability

The susceptibility of a substance or an object to being decomposed by bacteria or other living organisms is called biodegradability. Specifically, the rate at which detergents, pesticides and other compounds may be chemically broken down by bacteria and/or natural environmental factors is also known as biodegradability. This process of converting organic substance into simpler compounds like water and carbon dioxide is called **biodegradation**. Branched alkylbenzene sulphonates are much more resistant to such decomposition than are linear alkylbenzene sulphonates in which the long straight alkyl chain is attacked by bacteria. If the branching is at the end of the chain, the molecules are about as biodegradable as normal alkyls. Among the pesticides, the highly toxic organophosphorus types, are more biodegradable than DDT and its derivatives. Additives which can accelerate the biodegradation of polyethylene, polystyrene and other plastics are available. Soluble sugars formed from cellulose or organic acids formed during cellulose fermentation are examples of biodegradation. In the final stage of biodegradation, carbon dioxide (CO_2), and ammonium (NH_4^+) and nitrate (NO_3^-) ions are formed from carbohydrates and proteins, respectively.

Biodegradable polymer coating

Biodegradable polymers like polyurethanes are being developed by incorporating carbon monoxide in polymer chains like polythene, polypropylene and their copolymers, to promote photochemical degradation. Common polymers used as fertilizer coatings decompose very slowly (if at all), while retaining their ability to release nutrients at a controlled rate. This causes soil polymer residue pollution. Coating fertilizers with such biodegradable polymers overcomes this pollution problem. (See also Polythene coated urea.)

Biodegradation : See Biodegradability

Biodiversity

Biodiversity or **biological diversity** refers to the sum total of biota or living organisms including plants, animals, macro- and microfauna with all their individual variations and interactions on earth or in a particular area.

Agricultural biodiversity, sometimes called agrobiodiversity, is a sub-set of general biodiversity and is a fundamental feature of farming systems around the world. Agrobiodiversity includes genetic resources, cultivated and wild plants, livestock or domesticated and wild animals, fish and other aquatic animals, soil organisms, naturally occurring insects, bacteria, fungi, agroecosystems like forest, rangeland, aquatic ecosystems, and wild resources of natural habitats and landscapes useful to agriculture. Agrobiodiversity thus includes not only a wide variety of species but also the various ways in which a farmer can exploit biodiversity for production and management purposes.

Agrobiodiversity provides sustainable production of food and other agricultural products. It emphasizes both strengthening and improving, (sustainability of production, conservation, sustainable use) and enhancement of diversity of all genetic resources for food and agriculture. Agrobiodiversity also supports the conservation, sustainable use and enhancement of biological resources, particularly soil biota, pollinators, predators, etc. which support sustainable production systems. Agrobiodiversity also provides social and ecological services provided by the agro-ecosystems. Soil protection, wildlife protection and air quality are examples.

Biodynamic agriculture

Biodynamic agriculture, **biodynamic farming** or **biodynamics** is an organic farming practice that does not rely on artificial fertilizers. Some natural mineral fertilizers may be necessary during the early phase.

The concept of biodynamic farming was established in 1924 by Dr. Rudalf Steiner, an Australian scientist and philosopher. Biodynamics encompasses certain herbal preparations which have some useful properties and life energy stored in them.

Biodynamic farming, if used properly, can enhance soil structure, nutrient cycles and plant growth. It works on the understanding of life processes as well as mineral processes used in conventional agriculture.

Biodynamic preparations are not fertilizers themselves but they greatly assist the fertilizing process. These can be used in combination with the existing agricultural practices such as composting, manuring, crop rotations and integrated use of livestock.

The preparations include the following: (i) Horn manure (500) is used to increase microflora, nutrient availability, humus formation and the water holding capacity of the soil. (ii) Horn silica (501) enhances the light and warmth assimilation of a plant resulting into better fruit and seed development with improved qualities such as flavor, color, nutritional content, etc. (iii) Compost: Preparations numbered 502 to 507 are collectively known as compost preparations and include 502 (*Achillea millifolium*) 503 (*Chamomilia officinalis*), 504 (*Utrica dioca*), 505 (*Quereus robur*), 506 (*Taraxacum officinale*) and 507 (*Valeriana officinalis*). These preparations are designed to work directly with the dynamic biological processes and cycles which form the basis of soil fertility. The biodynamic method considers weeds and pests as useful indicators of imbalances in soil, plants and animals in a positive way. Pest and disease control is managed by making use of specific products for weed and pest control, made from those very weed and pests themselves.

The biodynamic method of farming has been practiced in Australia for decades to promote soil quality and reduce soil degradation.

Biodynamic farming: See Biodynamic agriculture

Biodynamics: See Biodynamic agriculture

Biofertilizer phosphobacterium

The bacterium *Bacillus megatherium* var. *phosphobacterium* is popularly known as biofertilzer phosphobacterium. It is used for increasing the availability of native soil phosphorus. The best result occurrs on neutral to alkaline soils with a high organic matter content.

Biofertilizers

Biofertilizers or **bioinoculants** contain micro-organisms which are beneficial to agriculture. They supply plants with nutrients, particularly nitrogen and phosphorus. Biofertilizers are environment-friendly organisms which enrich the soil and develop a symbiotic relationship with plants. This relationship is seen among many bacteria, fungi, actinomycetes and cyanobacteria.

Biofertilizers are mainly of two types : nitrogen fixers and phosphate solubilizers. Crops inoculated with **nitrogen fixing bioinoculants** get atmospheric nitrogen. For example, *Rhizobium* fixes ammonia and has a symbiotic relationship with legumes in which the bacterium supplies the required amount of nitrogen (Fig. B.12). After harvest, these bacteria continue to fix nitrogen till the roots die. This fixed nitrogen is useful for subsequent crops.

Biological nitrogen fixers or **diazotrophs** are micro-organisms that fix atmospheric nitrogen and are grouped as (a) free living bacteria *(**Azotobacter** and Azospirillum)*, (b) aquatic **blue-green algae** or **cyanobacteria**, and (c) symbiotic bacteria such as ***Rhizobium*** and *Frankia*. The ***Azolla*** and blue-green algae ***Anabaena*** also associate symbiotically.

After nitrogen, the second most important plant nutrient is phosphorus which exists in poor to medium quantities in Indian soils. A few heterotrophic bacteria and fungi, also called **phosphate solubilizing micro-organisms**, solubilize inorganic phosphorus (Table-B.1).

These phosphate-solubilizing micro-organisms grow on insoluble phosphate sources, such as tri-calcium phosphate, ferric aluminum magnesium phosphate, rock phosphate and **bone meal**, by solubilizing them. The symbiotic relationship of plant roots and fungi, like arbuscular mycorrhizae or vesicular-arbuscular mycorrhizae, mobilize phosphate (PO_4^{3-}) ions.

The slow release character of biofertilizers is their major advantage. Plant nutrition, disease resistance, soil fertility and tolerance to adverse soil or climatic conditions are some other benefits of biofertilizers. They also help counter increased soil salinity and chemical run-off from agricultural fields.

Fig.B.12: A field trial plot of soybean showing a healthy crop in a biofertilizer-treated plot (behind). An untreated (control) plot is seen in the front.

Excessive use of chemical fertilizers and pesticides causes considerable harm, both to the soil and to the environment. It can reduce fertility and make the soil impervious. A high concentration of chemical fertilizers like urea becomes toxic to the site of application, and results in the fertilizers being depleted faster by irrigation or soil bacteria.

The high cost of fossil fuels, the widening gap between the supply and demand of nitrogen fertilizers, and the prevailing low purchasing power in developing countries have caused serious concern for rice production in densely populated rice-growing regions of the developing world. Biofertilizers can augment nitrogen supply to rice and boost the crop yield. The use of biofertilizers, along with chemical fertilizers helps to maintain soil fertility for higher crop production. Biofertilizers are slowly becoming popular in many countries, especially for the supply of nitrogen and phosphorus. However, they cannot completely replace chemical fertilizers which supply N, P, K as well as essential nutrients to plants.

Table-B.1: Micro-organisms involved in phosphate solubilization.

Bacteria	Actinomycetes	Fungi
Achromobacter sp.	*Streptomyces* sp.	*Aspergillus* sp.
Aerobacter aerogenes		*A. awamori*
Alcaligenes spp.		*A. flavus*
Bacillus sp.		*A. fumigatus*
B. circulars		*A. niger*
B. fluorescence		*A. terreus*
B. polymixa		*Candida* sp.
B. pulvifaciens		*Cladosporium* sp.
B. subtilis		*Curvularia lunata*
Brevibacterium spp.		*Fusarium oxysporum*
Erwinia spp.		*Humicola* sp.
Escherichia freundi		*Mortierella* sp.
E. intermedia		*Paecilomyces* sp.
Flavobacterium spp.		*Penicillium digitatum*
Nitrosomonas spp.		*Pythium sp.*
Pseudomonas spp.		*Rhizoctonia* sp.
Pseudomonas striata		*Rhodotorula* sp.
Serratia spp.		*Schwanniomyces occidentalis*
Thiobacillus thiooxidans		*Sclerotium rolfsii*
Xanthomonas spp.		

Biogas

Biogas, a gaseous fuel, is produced by the fermentation of organic matter by methane-forming bacteria (methanogens). Biogas consists of a mixture of **methane**, carbon dioxide and hydrogen.

A mixture of methane and carbon dioxide, or even methane alone, formed in the deep layers of organic material in swamp bottoms or landfills, is sometimes called **swamp gas** or **marsh gas**.

Acetoclastic bacteria form methane exclusively from acetic acid in anaerobic digestion. They grow slowly and have a doubling time of several days, which is the rate-limiting step in biogas production. Bacteria that ferment fatty acids (mainly propionic acid and butyric acid) to acetic acid are called **acetogenic bacteria**.

Animal dung and plant residues are used to produce biogas in a fermenter. The residual **biogas slurry** containing 1.4 to 1.8% nitrogen, 1.1 to 1.7% phosphorus (as P_2O_5) and 0.8 to 1.3% potassium (as K_2O) is used as organic manure. Animal manure used for biogas production does not lose its fertilizer nutrient value.

Biogas is usually made by the decomposition of domestic, industrial and agricultural sewage wastes. Methane, its major component, can be harvested and used as a pollution-free renewable resource and a derived source of domestic energy. Biogas, produced in special biogas digesters, is widely used in China and India (Fig.B.13).

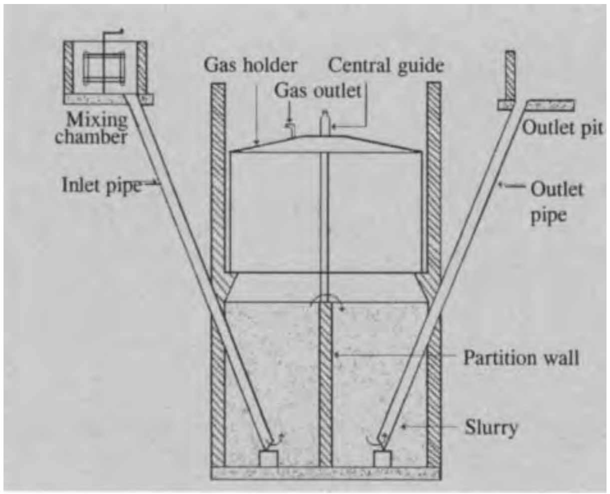


Fig.B.13: A schematic diagram of an Indian biogas plant (digester).

Biogas slurry: See Biogas

Biogenic compost

Biogenic **compost** is compost made from biologically degradable kitchen waste or city tankage which is collected and separated from houses. As this waste forms 30 to 40% by weight of total domestic usable waste, the pollutant concentrations in biogenic compost is lower than compost made from total domestic wastes. (See also Garbage tankage.)

Bioinoculants

Bioinoculants is another term used for **biofertilizers**.

Biological accelerators

An **activator** or **accelerator** is a substance that activates, accelerates or increases the total output of a process. Microbial cultures added to organic material or residues to hasten decomposition during composting are called biological accelerators. Microbial cultures include fungi like *Aspergillus* sp., *Paecilomyces fusisporus*, *Trichurus spiralis*, *Trichoderma viride* and other phosphate solubilizers.

Biological diversity

Biological diversity is commonly known as **biodiversity**.

Biological efficiency

Biological efficiency, also called efficiency ratio, is another name for **physiological efficiency**. It is the amount of dry matter produced per unit of nutrient absorbed or applied. (See also Physiological efficiency; Nutrient recovery.)

Biological enrichment factor

Biological enrichment factor is the ratio of concentration of an element in an organism to that in rock crystal. The significance of the biological enrichment factor is understood by the study of the **Banin-Navrot plot** which plots biological enrichment and ionic potential in a log-log graph. The solubility and mobility of the ions are the determining factors for essentiality of an element as nutrient. (See also Banin-Navrot plot.)

Biological harvesting of salts

Biological harvesting of salts is a method used for determining soil salt depletion via **bioremediation**. The salt uptake of plants is generally insufficient to maintain salt balance and to reduce leaching. Forage crops take up a significant amount of salt; 20 tons of forage crops remove about one ton of salt annually. **Halophytes** can deplete even more salt. (See also Bioremediation through green plants.)

Biological interchange

Biological interchange involves biological activity in which elements interchange between organic and inorganic substances in the soil. It is triggered by biological decomposition of organic compounds and liberation of inorganic materials that are utilized in the synthesis of microbial constituents by two processes, namely, **mineralization** and **immobilization**, which occur continuously in normal soils.

Biologically active substance: See Activated sludge

Biological mineralization

Biological mineralization converts elements occurring in organic compounds to an inorganic form by biological decomposition. Decomposition is very rapid in warm, well-aerated, moist soils and very slow in clay soils and during cool springs. (See also Mineralization.)

Biological nitrogen fixation

When symbiotic and free-living bacteria reduce nitrogen to plant-available ammonia (NH_3), the phenomenon is called biological nitrogen fixation.

Atmospheric nitrogen is fixed by a number of micro-organisms called biological nitrogen fixers. These include **fungi**, **blue-green algae** and **bacteria**. Symbiotic fixation by *Rhizobium* spp. in association with legumes, and the non-symbiotic fixation by *Azotobacter* spp. and *Beijerinckia* spp. are classic examples of biological nitrogen fixers. In temperate and tropical waters, blue-green algae and *Azolla* fern form a symbiotic relationship. A similar relationship is seen in cycads.

Nitrogen fixing micro-organisms reduce atmospheric nitrogen into ammonia with the help of nitrogenase enzymes. Biological nitrogen fixation is a vital source of fixed nitrogen for plant life. It is estimated that around 50 million tons of nitrogen gets biologically fixed every year. (See also Effective nodule for nitrogen fixation.)

Biological yield

Crop production can be measured by the total mass of, or the economically useful parts of the plant. The total yield of the plant material is known as the biological yield. The ratio of the grain yield to the biological yield is the **harvest index**.

Biomass

Biomass is the total mass of all organisms of a species in a given area. For example, it is possible to measure the biomass of trees in the world, or biomass of elephants in parks and zoos. Biomass is also measured in grams of dry mass/square meter (g/m^2).

Renewable and recyclable organic matter formed through the process of photosynthesis is also called biomass. It includes all food and feed products, plants, their residues and by-products, trees and forest products, fresh and saltwater algae and plants. Considerable energy is now being derived from all these sources, such as alcohol, for use as a gasoline additive.

The portion of a cellular mass with microbiological activity is called **active biomass**. For instance, *Rhizobium* biofertilizer requires 10^9 bacterial cells/g of carrier to be completely effective as active biomass of *Rhizobium*. Active biomass increases with growth, and decreases with the starvation of microbes.

By far the most promising component of biomass is wood. Both by direct combustion and by chemical and bacterial conversion, wood can be converted to gaseous and liquid fuels.

Biomeal

Biomeal is organic manure. It comprises *Penicillium* (a fungus) mycelium residue (PMR) in bulk quantity enriched with a biofertilizer and micronutrients to meet soil requirements.

The main input for biomeal production is organic material rich in enzymes, hormones, organic acids and proteins. The soil microbial population is dependent on the soil organic carbon level. The microbial population increases rapidly once biomeal is added making proteins and organic acids available to the plants. The humus present in biomeal enhances the availability of phosphorus in the soil. The whole process helps in achieving a balance in the soil ecosystem.

Thus, biomeal can be considered as a **bio-soil conditioner**. It is highly suitable for the cultivation of crops as it ensures optimum utilization of all essential nutrients like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and molybdenum (Mo). It contains about 20% organic carbon, 3 to 3.6% total nitrogen, 1.3 to 1.45% total phosphorus (as P_2O_5), 2.3 to 3% total potassium (as K_2O), 1.8 to 2.3% calcium (as CaO), 0.7 to 1.1% magnesium (as MgO), 0.25% sulphur, 3% iron, 90 ppm manganese, 380 ppm zinc, and 70 ppm copper.

It also contains biodegrading microflora (like species of *Aspergillus*, *Cladosporium* and *Streptomyces*), plant protecting microflora (like *Trichoderma* spp.), phosphate solubilizing microbes (like species of *Penicillium* and *Bacillus*), and N-fixing microflora (like *Azotobacter* and *Azospirillum*).

Prepared from typical organic waste (like PMR), biomeal decomposes quickly, within the first few weeks of its application to soil, depending on the formation of carbon dioxide. Pre-soaking crop seeds like paddy with a water extract of PMR helps better germination. This also brings about favorable changes in the soil microbial activity, resulting in better availability of nutrients (like N, P and K), higher nutrient uptake and higher crop yield. Besides this, the physical, chemical and biological properties of the soil improve.

Generally, biomeal improves the soil structure, the crop quality and the yield by at least 20 to 30%. Increasing the biomeal dose enhances the microbial population of **fungi**, **actinomycetes** and **bacteria**. It also enhances the level of organic carbon, carbon dioxide evolution and nitrogen in the form of ammonia (NH_3) and nitrate (NO_3^-). Application of biomeal also protects crops from diseases, like damping-off and root rot.

Biomeal, which tolerates a wide range of soil pH (4.5 to 9), judging by carbon dioxide (CO_2) evolution, also works efficiently in salt-affected soils. The chelated micronutrients present in biomeal are available to the crop for a long time in optimum quantity. The recommended dose of biomeal for different crops is between 2 and 5 Mt/ha.

Biomull

Biomull is a compost made from organic kitchen waste and is used as an organic fertilizer. (See also Farmyard manure.)

Biopurification factor

Biopurification factor (**BPF**) is the inherent capacity of a biological system to resist the uptake of toxic elements. BPF of a toxic element E is determined in relation to the nutrient element calcium as:

$$\text{BPF} = \frac{\text{E in food} \times \text{Ca consumed}}{\text{E consumed} \times \text{Ca in food}}$$

Since the BPF is functional, the toxic element should decrease in the food chain while the nutrient element should increase. A toxic element in grass is not automatically transferred to the flesh of the grazing animal at the same level of concentration, but often reduced.

Bioremediation through green plants

Bioremediation or **biotreatment** is the treatment of contaminated land with naturally occurring or genetically modified microbes. They degrade complex organic compounds (like polychlorobenzenes, pesticides and insecticides) which are thus made less harmful or even useful, and which render the soil suitable for cultivation.

Bioremediation is also used to treat contamination of heavy metal and radioactive substances. While the micro-organisms cannot destroy or degrade complex organic compounds, they can make them less mobile.

Unlike organic compounds, metals cannot be degraded and therefore, bioremediation through metal-accumulating plants and crops (called **phytoremediation**) has emerged as an inexpensive and environment-friendly alternative to disposing metals in the sea or storing them in concrete containers. Although still not commercially viable (despite considerable research), phytoremediation is definitely an emerging clean-up technology.

A number of subsets of phytoremediation has been proposed to utilize the plant potential to remediate the soil and the water contaminated with a variety of metal compounds. One such method is the **phytoextraction**, which uses higher plants to remove metals from the polluted soil. At maturity, the metal-enriched, above-ground portion of the plant is harvested and a fraction of the metal contamination removed. **Metal hyper-accumulator plants** have been known since the nineteenth century.

Berti and Cunningham's bioremediation method is used for removing lead ions from contaminated soils. According to the United States Environment Protection Act (USEPA), the hazardous waste material treatment follows the toxicity characteristic leaching procedure which works on a set of guidelines (lead, for instance, with a critical value of 5 mg/liter, is acceptable).

Two approaches were attempted to bring down the soil toxicity of a sample dump from 30 mg lead/liter to 5 mg/liter: (a) use of lead accumulator plants, like common ragweed *(Ambrosia artemisifolia)*, hemp dogbane *(Apocynum cannabinum)*, musk or nodding thistle *(Cardus nutans)*, and Asiatic dayflower *(Commelina communis)*, which exhibited concentrations of 400 to 1250 mg lead (Pb)/kg of shoots, and (b) the use of soil amendments like lime, fertilizers, biosolids and industrial by-products to promote plant growth which enhanced metal intake, and prevented migration of metals, reducing soil erosion and downward flow of soil water.

More efficient soil remediation methods are being tried by employing breeding or bioengineering techniques on plants which can absorb, translocate, and tolerate lead, while producing sufficient **biomass**.

The success of phytoextraction depends on the extent of soil contamination, metal availability for root uptake, and the ability of plants to intercept, absorb, and accumulate metals in the shoots. It also depends on the interactions of soils, metals and plants. The metal adsorptions to soil solids, and/or precipitation as insoluble compounds adversely affect the potential for phytoextraction of several major metal contaminants, including lead. The addition of chelates has been shown to stimulate the release of metals in soil solution and enhance the potential for root uptake.

Identification of metal hyper-accumulator plants has significantly increased the interest in phytoextraction. Today there is information about hyper-accumulators capable of accumulating metals in their shoot at levels 100-fold greater than those in the shoots of non-accumulator plants. Plants are known to concentrate upto 100 ppm cadmium, 1000 ppm of cobalt, chromium, copper and lead, 10,000 ppm of zinc and nickel, and 14,500 ppm of arsenic.

The sodium chloride uptake by plants is insufficient to maintain salt balance and reduce leaching requirement. Forage crops, however, are able to take up a significant quantity of salt. An average forage crop yielding 20 tons/hectare with 5% salt content can deplete one ton of salt per year. Certain halophytes and bushes also deplete higher amounts of sodium chloride. The biological harvesting of salt depends on the degree of salt tolerance of the crop. (See also Phytoremediation.)

Biosequence

Biosequence is a sequence of soils, the properties of which are functionally related to differences in organisms, leading to a soil-forming factor. (See also Soil sequence.)

Bio-soil conditioner: See Biomeal

Biosuper

Biosuper is the biological form of a superphosphate fertilizer containing nutrient elements and rock phosphate. When inoculated with S-oxidizing bacteria (thiobacilli), the bacteria convert sulphur to sulphuric acid and the acid solubilizes rock phosphate. Biosuper is commonly used in Australia and New Zealand.

Biota

Biota is plant and animal life, that is, the flora and fauna of an area or region. The activity of living plants and animals influences soil formation and its development. Micro-organisms decomposing organic matter and burrowing animals mixing up soil are the examples of the activity of biota.

Biotechnology: See Agricultural biotechnology

Biotic factors

Biotic factors are the living components of soil and refer to organisms that influence the soil formation process. All aspects of climate, geology and atmosphere affect biotic environments. Biotic factors include soil micro-organisms like **bacteria**, **actinomycetes**, **fungi** and **nematodes**. These micro-organisms carry out a range of harmful as well as beneficial activities in the plant rhizosphere. The most beneficial common biotic activities are nitrogen fixation, secretion of growth substances, increasing the micronutrient activity and breaking down organic matter.

Biotic factors can also be unsuitable and these prove to be a hindrance to plant growth and crop yields. Biochemical interference and **allelopathy** exhibited by some plants which involve plant exudates in soil or air hinder plant growth and suppress crop growth.

Human interference can disrupt the biotic environment which, in turn, leads to harmful effects. For example, heavy chemical fertilization may encourage the growth of insect and weed population. It also facilitates greater vegetative growth, which calls for greater chemical inputs. To reduce the effects of pests, proper rotation and integrated pest management strategies are commonly recommended.

Abiotic means inanimate, non-living or having a non-biological nature such as rainfall, minerals, heat or wind.

Biotite

Biotite is a widely distributed and important rock-forming mineral of the mica group. The general term designates all ferro-magnesium micas, also called **black mica** or **magnesium-iron mica**. This black and plate-like mineral is found in some igneous rocks, such as granite. It is tetrahedral mica with aluminum substituted for silicon in the tetrahedral sheet, and ferrous (Fe^{2+}) or magnesium (Mg^{2+}) ions in the octahedral sheet. Since the charge is localized in the tetrahedral sheet, anhydrous potassium ions are retained in the inter layer to give a unit cell formula:

$$K\,(Mg,Fe^{3+})_3\,(Al,Fe^{3+})\,Si_3\,O_{10}\,(OH)_2$$

Biotite is useful in the potassium-argon method of age determination. Potassium release occurs more easily with biotite than with **muscovite**. Biotite is used as the source of soil potassium. It is more easily weathered to chlorite than muscovite and, therefore, is less common in sediments. Although commercially unimportant under hydrothermal conditions, biotite transforms to vermiculite which expands on heating and has widespread application as light-weight concrete, plaster aggregate, insulation, plant growing medium and lubricant.

Biotreatment

Biotreatment, also called **bioremediation**, is a method of treating contaminated land using genetically modified microbes or metal-accumulating plants to make the land suitable for cultivation. Types of soil bioremediation methods include land farming, composting, land spreading and biopiles. Types of water bioremediation include natural attenuation and engineered wetlands. (See also Bioremediation through green plants.)

Bioturbation

Bioturbation is the process of reworking or rearranging soil layers by soil organisms leading to soil mixing. Bioturbation is usually caused by burrowing, gallerying, digging or creeping by soil organisms.

Bird repellents

Bird repellents protect human beings, domestic animals, plants and other products from bird attacks. A repellent does not mix or blend with another substance because of its physico-chemical nature and is chiefly based on consideration of taste, which varies widely with the type of bird.

BIS

BIS is short for Bureau of Indian Standards which maintains standards for Indian goods. It was previously called Indian Standards Institution (ISI). The bureau is the custodian of all standards in India, similar to **DIN** in Germany.

Bisect

Bisect is a profile of plants and soil, showing roots and shoots in their normal positions and indicating their vertical and lateral distributions.

Bituminous coal

Bituminous coal is the most abundant rank of **coal**. It has 14 to 30% water and has high heating value (15 to 16 MJ/kg). Destructive distillation of bituminous coal yields coke, coal and ammonia. The ammonia produced in the process is recovered as ammonium sulphate. Coal grades vary between lignite and bituminous and are called **sub-bituminous coals**.

Biuret

Biuret is a compound formed from urea when the temperature during the manufacture of urea goes above 140 to 170°C.

$$2NH_2CONH_2 \longrightarrow NH_2CONHCONH_2 + H_2O$$

A biuret concentration of more than 2% in urea is harmful to plants as it affects the metabolism of proteins.

Black alkali soil

Black alkali soils are made of a mixture of alkali salts and organic matter. Alkali salts are mainly sodium carbonate or sulphate. These soils have black or brown incrustations on the surface. Their pH is higher than 8.8 and the **exchangeable sodium** represents at least 15% of the **cation exchange capacity** (**CEC**), affecting the growth of most plants. (See also Saline alkali soils.)

Black clay soil

Black clay soils, also called **cracking clay**, belong to the **vertisols** order and are found in hot and dry climates. Tropical black clays of North Africa, regur of India and tirs of the Mediterranean are all examples of black clay soil. Black clay soil is alkaline in reaction, soft when wet, and it develops large cracks on drying. With up to 60% clay, black clay soils (Fig.B.14) have a low carbon content, characteristic high moisture retention property and cation exchange capacity (CEC).

Black earth

Black earth is the general term for dark clays of the tropics, including **chernozem**. It is alkaline in reaction, becomes soft when wet and develops large cracks upon drying.

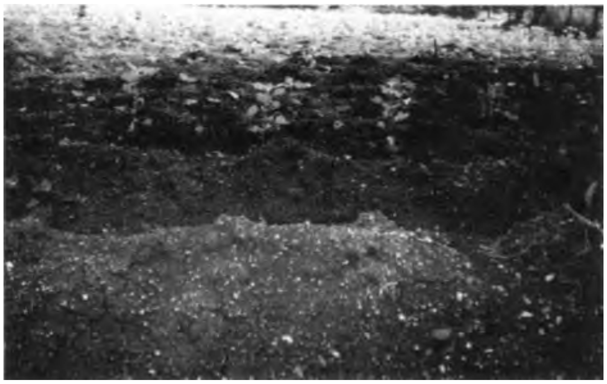


Fig.B.14: Black clay soil, also called black cotton soil, has high clay content and is harder to cultivate than light soils.

Black forest rendzinas

Black forest rendzinas are a humus rich class of **rendzinas**. (See also Rendzinas.)

Black heart

Black heart refers to calcium deficiency in celery and peanut plants, the deficiency being caused by inadequate supply of calcium.

Black land

Black lands are open country acid soil lands. These are dark in appearance, covered with heather and located on high grounds. The term black land is also used for the **humus rich fen land soils** found in low-lying areas with slightly acidic to alkaline peat soils. Such low-lying areas in eastern England have been drained to produce fertile lands called **fens**.

Black layer

Black layer is the abscission layer formed in the basal region of the placental tissue of carpel (for example, corn) at physiological maturity. Black layer restricts translocation of carbohydrates to the mature seed. The appearance of black layer coincides with the cut-off of radioactive assimilate translocation to developing kernels in sorghum.

Black mica

Black mica is another term for **biotite**, a rock forming mineral of the mica group. This black, plate-like mineral which designates all ferro-magnesium micas, is found in some igneous rocks like granite. In this mica, aluminum is substituted for silicon in the tetrahedral sheet, and ferrous (Fe^{2+}) or magnesium (Mg^{2+}) ions in the octahedral sheet.

Black peat

Black peat is another term for **upland moor peat**. (See also Peat.)

Black soils

Black soils, **black earth** or **chernozems** are soils with dark colored surface horizons, developed from loose carbonate materials with high content of fine particles. **Wiesenboden** and **solonetz** are also black soils. In Australia, some authors use the word black soil for **self-mulching black clays**.

Black tourmaline

Black tourmaline is a common **tourmaline** mineral (borosilicate). It is rich in iron and is found in igneous and metamorphic rocks. (See also Tourmaline.)

Blast furnace slag

Blast furnace slag, a by-product in the manufacture of pig iron from ores, contains a significant amount of phosphorus. This phosphorus is removed by adding lime or calcium carbonate to the converter. The phosphorus oxide formed combines with calcium oxide and silica to form a slag on top of the molten iron. The slag is then removed, cooled and powdered and is used for **liming** acid soils. Depending on the process of steel manufacture, the slag is called **Bessemer basic slag** or **open-hearth basic slag**. (See also Liming materials.)

Bleicherde

Bleicherde is the light colored A_2 horizon of podzol soils caused by leaching. (See also Podzoluvisols.)

Blended fertilizer

Blended or **mixed fertilizer** is a compound fertilizer made by dry blending several fertilizer materials of the same particle size range with no chemical reaction among them. Blended fertilizers have at least two of the essential plant nutrients, N, K and P. (See also Bulk blended fertilizer.)

Block serpentine

Block serpentine or **dead-end serpentine** is a modification of a **serpentine irrigation scheme**. Serpentine irrigation increases the percolation of water in clayey soils by maximizing stream flow, minimizing erosion and water run-off, and increasing the water-soil contact time by longer furrows. This arrangement keeps a large soil area in contact with water as flow occurs in only half of it. (See also Irrigation of clayey soil.)

Blood meal

Blood meal, an organic manure created from blood, is a rich source of nitrogen. This high-grade nitrogen-containing organic manure, when added to soil, undergoes mineralization similar to low grade manures, but releases a higher proportion of nitrogen. The release of nitrogen depends on a host of factors, such as soil pH, moisture, temperature, duration of manure application and the rate of its mineralization.

The process of converting blood into blood meal has received considerable attention since 1970. The conventional method of drying blood is laborious and time consuming. Hence, chemicals like alum, aluminum sulphate, lime, etc., are used for reducing the time and giving a good quality product. Depending on the chemicals used, the total time required for preparing blood meal varies from 7 to 11 days, the percentage recovery from 13 to 24%; the manurial value of nitrogen from 8.1 to 13.9% and the pH value from 3.2 to 11.7.

Among calcium carriers, superphosphate gives the highest recovery of blood meal with the least level of nitrogen and the highest level of phosphate, whereas calcium hydroxide gives the highest level of nitrogen and a high degree of recovery. The use of alum results in a higher recovery of blood meal, whereas aluminum sulphate gives a slightly higher percentage of nitrogen and phosphorus (as P_2O_5) in the blood meal.

The nitrogen released by a nitrogen containing manure is fully or partly utilized by the first crop and the unutilized nitrogen serves as a nutrient for the next crop grown in the same soil. The nitrogen uptake by the first and the succeeding crop represents the degree of nitrifiability of the added manure and of the utility to the succeeding crop in terms of the time factor.

Among all organic manures, blood meal has the highest nitrogen content (12 to 15%). It is quickly nitrified when added to soil. While the blood meal prepared by adding calcium hydroxide shows inferior performance when applied to previous crops, it helps to enhance the yield of the succeeding wheat crop. Blood meal prepared by adding superphosphate has shown the best performance with the first crop but it lacked in residual effect.

Blossom end rot of tomato, pimiento peppers

Blossom-end rot is a **calcium deficiency** disease which affects pimiento peppers and tomatoes.

Blue-green algae

Blue-green algae, the older name for **cyanobacteria**, is a heterogeneous group of photosynthetic nitrogen fixing organisms (Fig.B.15). It contains chlorophyll-a, and is used as a biofertilizer for wetland rice. The color of the algae is due to the presence of the photosynthetic pigment phycocyanin. (See also Cyanobacteria.)

Bluff podzol

Bluff podzol is a poorly drained soil with depressions which are characterized by the presence of a bleached E horizon and a fine-textured B horizon. Also called **prairie podzol** or **swamp podzol**, such soils are present in many parts of the world, like the Canadian prairie. (See also Podzoluvisols.)

BMP

BMP is short for **best management practices** used in crop production.

BOD

BOD, short for **biochemical oxygen demand**, is the total amount of oxygen consumed by micro-organisms in the process of decomposing organic matter in water.

Bog

Bog is a type of **wetland** characterized by spongy, poorly drained, peaty soil. Bogs are divided into three classes: (a) boreal regions found in cool areas dominated by sphagnum and heather, (b) **fens**, dominated by grasses, sedges, reeds, and (c) tropical tree bogs, with the peat composed almost entirely of tree remains.

Bogs are formed in depressions created by glacial ice and in small lakes in glaciated regions. Colonization by sphagnum and subsequent poor drainage contribute to a process that eventually fills the body of water with vegetation. At the stage when surface vegetation is still floating and not coherent, the bog is called a **quaking bog** because of its surface instability. Peat bogs are not

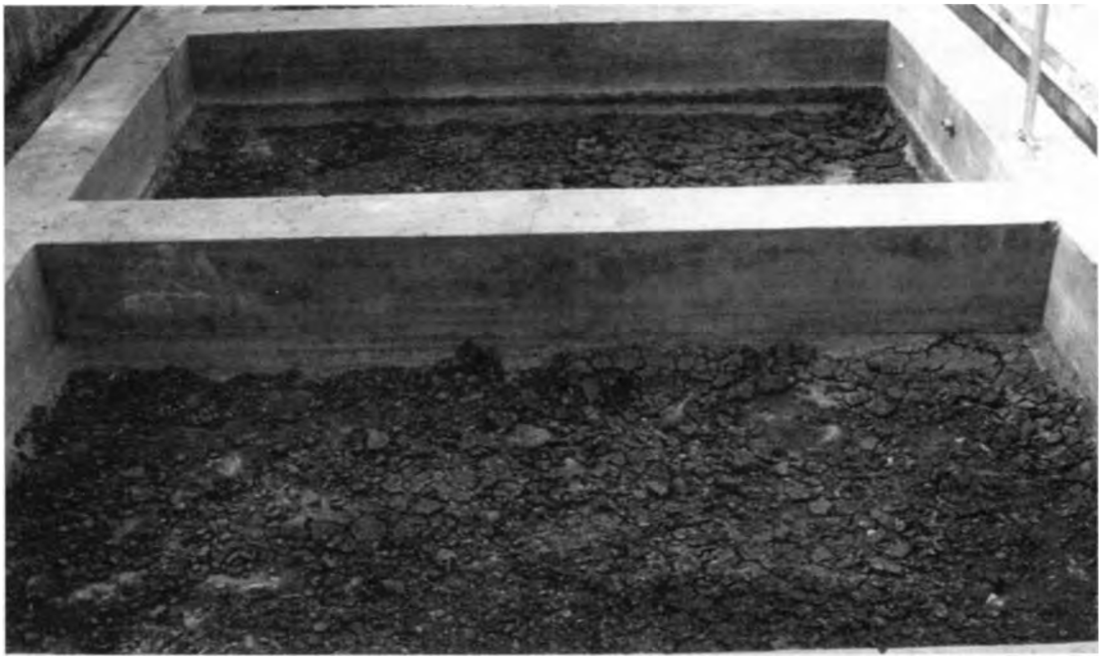


Fig.B.15: Dried flakes of blue-green algae in a pond.

generally found in lowland tropical areas because high temperatures facilitate the rapid decomposition of organic matter. Tropical peat bogs may develop, however, in areas of high rainfall and with very low mineral content groundwater. The peat from such bogs is composed of the remains of seed plants as well as sphagnum.

Bog iron

Bog iron or **bog iron ore** is an impure, porous form of limonite ferruginous deposit developed in soft, wet and swampy land (**bog**) by the oxidation of algae, bacteria, etc. and by iron-carrying solutions.

Bog iron ore: See Bog iron

Bond albedo

Bond albedo is defined as the fraction of total incident solar energy that a plant reflects back into space. Bond albedo and normal albedo or normal reflectance determine the energy balance of the plant.

Bone ash

Bone ash is obtained by burning bones. It contains about 30 to 40% phosphorus (as P_2O_5) and hence, is used as a fertilizer.

Bone flour meal

Bone flour meal is the soft mixture obtained by boiling a mixture of bone, calcium phosphate and nitrogenous organic matter in water. It can also be produced by steaming under pressure to remove nitrogenous glue. Bone flour meal contains around 2% nitrogen and 50 to 55% phosphate. This chalk-like bone powder is available to plants quickly as fertilizer material. (See also Bone meal.)

Bone meal

Bones, bone meal and other bone products are the earliest phosphatic materials used as fertilizers. Bone meal is produced and marketed in many forms: raw, steamed, untreated, and crushed.

Raw bone meal is prepared by grinding raw bones. It contains 20 to 28% phosphorus pentoxide (7 to 12% P) and 4 to 6% nitrogen. The powder is effective as manure only if the particles are smaller than 2.5 mm.

Raw bones have fatty substances stuck to them, which slow down the decomposition of the bone meal. When bones are treated with steam to remove the fat before grinding, the resultant bone meal is called **steamed bone meal** or **bone flour meal** which contains only 2% nitrogen as against 4 to 6% in untreated bones. Steaming makes the bones friable and amenable to fine grinding for soil applications and increases the citrate-soluble phosphorus content.

Bone meal contains 20 to 28% water-insoluble phosphorus (as P_2O_5), and about 50% citrate-soluble phosphorus (as P_2O_5). Similar to superphosphate, bone meal is effective in acidic soils for wheat and rice. Burning bones gives **bone ash** which contains 30 to 40% readily available phosphorus.

Bone phosphate of lime (**BPL**) in a phosphate ore is the content of tri-calcium phosphate, $Ca_3(PO_4)_2$. In commercial trading, the phosphorus content of phosphate rock is calculated as the weight percentage of tri-calcium phosphate and is expressed as bone phosphate of lime or the **total phosphate of lime** (**TPL**).

For phosphate rock to be acceptable commercially as a substance with sufficiently high percentage of phosphorus, it must contain 30 to 40% phosphorus (as P_2O_5) and 66 to 87% BPL.

When ground bones are treated with sulphuric acid, **bone superphosphate** is formed. It contains 1 to 2% nitrogen and 16% phosphorus (as P_2O_5). **Bone tankage** is a concentrated organic manure with animal carcasses, containing 7 to 20% phosphorus (as P_2O_5) and 3 to 10% nitrogen.

Bone phosphate of lime

Bone phosphate of lime is a measure of the phosphate content, expressed as tricalcium phosphate $Ca_3(PO_4)_2$ in phosphate materials. (See also Bone meal.)

Bone superphosphate

Bone superphosphate is the resultant material of bone solubilized by treatment with sulphuric acid. It has the same agronomic value as superphosphate. It is also known as **dissolved bone**. In Europe, it is called **vitriolated bone**. It contains 1 to 2% nitrogen and 16% phosphorus (as P_2O_5).

Bone tankage

Bone tankage is a concentrated organic manure with animal carcasses, containing 3 to 10% nitrogen and 7 to 20% phosphorus (as P_2O_5).

Boot leaf: See Flag leaf

Boralfs

Boralfs is a suborder of **alfisols** formed in cold regions. The latter is either a frigid or cryic but not a perigilic soil temperature regime. The regions are not saturated with water long enough for the cultivation of most plants. The great groups belonging to boralfs are cryoboralfs, eutroboralfs, fragiboralfs, glassoboralfs, natriboralfs and paleboralfs.

Borate

Borate is a salt of boric acid (H_3BO_3). There are two known types of borates - orthoborate and metaborate which are used as fertilizers. Besides these, polyborates, boric acid, calcium polyborate (colemanite), sodium tetraborate, solubor and complex borosilicate (**boron frits**) are also used as fertilizers to reduce **boron deficiency**. Borate minerals like kernite and tincal are the main sources of borax.

Borax, a source of boron, is the salt of boric acid, sodium hydroxide and sodium carbonate. Borax, otherwise called disodium tetraborate decahydrate

($Na_2B_4O_7{\cdot}10H_2O$) is a water-soluble white compound. It occurs as a mineral in some alkaline salt deposits. The main sources of borax are borate minerals, **kernite** ($Na_2B_4O_7{\cdot}4H_2O$), **rasorite** and **tincal** ($Na_2B_4O_7{\cdot}10H_2O$) which are purified by recrystallization. On treatment with an acid, borax gives boric acid which is absorbed as boron by plants. Borax contains 10.5 to 11.4% boron or 36.5% boric oxide (B_2O_3).

Borax is a supplier of micronutrient boron for plants and is applied as such or as a **foliar spray**. Solubor is preferred to borax for its greater solubility and because it causes minimum changes in the crystallization temperature.

Borax is a very important substance in other industries too. It is used as a metallurgical flux in glass and ceramic industries, a buffer, a mild alkaline antiseptic and a source of boron compounds.

Borax: See Borate

Bordeaux mixture

Bordeaux mixture is a copper **fungicide** invented by Millardet of France in 1882. It is a mixture of copper sulphate and lime (either quick lime or **hydrated lime**), and is available commercially.

Bordeaux mixture is used for the control of numerous plant diseases such as downy and powdery mildews of grapes, scab or fire blight of apple, early and late blight of potato and various leaf spot diseases.

Besides its fungicidal nature, Bordeaux mixture is also used to control bacterial diseases like citrus canker, caused by *Xanthomonas citri*. Bordeux mixture is most effective when used fresh. When stored, it loses its fungicidal property. However, the stability of the mixture can be increased by adding sugar or jaggery at a rate of 0.1 g/liter of water.

A range of formulations has been tried for the preparation of Bordeaux mixture. Of these, the one used often is 4-4-50, representing the respective percentage of copper sulphate, lime and water. For preparing this mixture, solutions of copper sulphate and lime are prepared separately with sufficient quantities of water. They are then simultaneously added to a third container and the mixture is agitated vigorously. The containers should preferably be wooden or earthen or of materials that do not react with copper sulphate.

The advantages of using Bordeaux mixture are that it (a) is cost effective, (b) has natural adhesiveness or tenacity, (c) controls a wide variety of diseases, and (d) is safe to handle. The disadvantages include its (a) **phytotoxicity** on crops, especially on fruits like apple and peach, (b) corrosive action on metallic containers or equipment, and (c) tendency to delay ripening of the fruit.

Border irrigation method: See Border strip method of irrigation

Border strip method of irrigation

Border strip method of irrigation or **border irrigation method** divides land into border strips and delivers water to each strip from a head at the upper end. There are significant levels of percolation and run-off losses. Border irrigation works well when the soil is inclined in the direction of the water flow. (See also Irrigation methods.)

Boric acid

Boric acid (H_3BO_3) is one of the boron-containing nutrients added to fertilizers. It contains around 17% boron. A solution of boric acid and water is used as a foliar spray to overcome boron deficiency. (See also Boron.)

Boron

Boron (B) is a non-metal occupying the first period and Group 13 (formerly, III B) of the Periodic Table (Fig.B.16). Boron is essential for the growth of new cells. Its concentration in monocots and dicots varies between 6 to 18 ppm and 20 to 60 ppm, respectively. In most crops, the concentration of boron in mature leaf tissue is over 20 ppm.

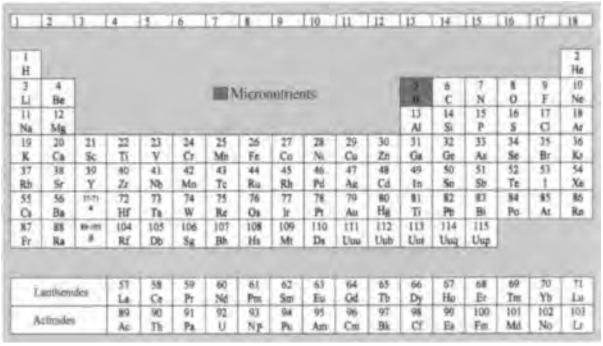


Fig.B.16: Position of boron in the Periodic Table.

Boron is one of the seven micronutrients needed by plants. It exists in soils as a (a) primary rock and mineral, (b) mass combined in soil organic matter or adsorbed on colloidal clay and hydrous oxide surfaces, and (c) borate ion in solution. It occurs as borosilicate to the extent of 20 to 200 ppm in most semi-precious minerals that contain 3 to 4% boron.

Borosilicate contains varying amounts of iron (Fe), aluminum (Al), manganese (Mn), calcium (Ca), lithium (Li) and sodium (Na). As boron is resistant to weathering, its release from the mineral is slow and, therefore, it cannot meet the need of prolonged and heavy cropping.

Though boron is essential for plants, its requirements and tolerances vary widely from plant to plant. It is required during (a) active cell division, (b) pollen germination, flower formation, fruit and root development, material transportation and cation absorption, (c) new cell development in meristematic tissue, (d) synthesis of amino acids and proteins, (e) nodule formation in legumes, (f) translocation of sugars,

(g) polymerization of phenolic compounds, and (h) regulation of carbohydrate metabolism. Although boron is required for the growth of agricultural crops, it is not necessary for algae, diatoms, animals, fungi and microorganisms.

Fruits, vegetables, and field crops may suffer from **boron deficiency**. The first visual symptom is cessation of terminal bud growth, followed by the death of young leaves. Boron deficiency restricts flowering and fruit development, and the symptoms are (a) thickened, wilted or curled leaves, (b) thickened, cracked or water-soaked condition of petioles and stems, and (c) discoloration, cracking or rotting of fruits, tubers or roots. The breakdown of internal root tissues gives rise to darkened areas, referred to as **black** or **brown heart**.

The total boron content in soil varies from region to region and soil to soil. In Indian soils, for instance, the total boron content ranges between 4 and 630 mg/kg soil, while the available boron varies from traces to 68 mg/kg soil. Irrigation of arid and semi-arid soils with boron-rich water causes toxicity in plants, which can be reduced with the addition of organic matter.

Boron is available in soils as an organic fraction and is released on decomposition to be partly absorbed by plants and partly lost during leaching. In soil solution, boron is present as a non-ionized molecule (H_3BO_3) which is absorbed by plant roots and distributed with the transpiration stream. The soil texture, pH and the moisture affect the movement of boron in soils. Coarse-textured sandy soils are low in boron and crops in such soils require additional boron in the form of borax, whereas crops in fine-structured sandy soils do not respond to the added boron. Fine-textured soils retain added boron for longer periods than coarse-textured soils. Clays retain boron more effectively than sands. Plant uptake of boron from clayey soils is larger than that from sandy soils.

The soil pH influences the availability of boron; the higher the pH, the lower the boron uptake and the greater the deficiency. Generally, for the same type of crop, the application rate of a fertilizer containing water-soluble boron is lesser for coarse soils than for fine-textured sandy soils. Apple, alfalfa, asparagus, beet, celery, sunflower are some of the crops requiring high levels of boron (more than 0.5 ppm), whereas carrots, cotton, lettuce, peanuts, peach, sweet potato, tobacco and tomato need only 0.10 to 0.15 ppm of boron. The requirement of barley, beans, citrus, corn, forage grasses, soybeans and strawberry is lower than 0.1 ppm of the available soil boron.

Interaction of boron with nutrients plays a vital role in the efficiency of the use of boron. For instance, boron is particularly effective with phosphorus, potassium and micronutrients, whereas its efficiency suffers with sodium, calcium and magnesium. For a good crop, it is essential to have a correct calcium to boron ratio.

Boron compounds that are used to overcome **boron deficiency** are borax, boric acid, borosilicate glass or frits, calcium borate (Colemanite) and magnesium borate (Boracite). All boron materials used as fertilizers are stable chemicals and create no storage problem. The various methods by which boron is applied to plants are by drilling, broadcasting and spraying.

The presence of boron in a fertilizer has to be clearly stated on the bag.

Borax ($Na_2B_4O_7 \cdot 10H_2O$) is the most popular boron-containing fertilizer. For most crops, 15 to 20 kg borax/ha is applied at the time of sowing or transplanting. As boron is readily leached out from the soil and the initial uptake of the plant is large, it is applied as a fused glass to reduce its solubility.

Solubor, a commercial product, is a highly concentrated and completely soluble source of boron (20%) like borax. It is preferred to borax and is applied as spray or dust directly to the foliage of fruit trees, vegetables and other crops. **Colemanite**, a naturally occurring calcium borate ($Ca_2B_6O_{11} \cdot 5H_2O$), is less soluble and is also superior to borax.

Boron frits or **borosilicate glass** containing up to 6% boron provide boron traces to plants. Borosilicate glass, due to its slow solubility, makes boron available for a longer time than borax. The finely ground form is more effective than the coarse variety.

A dilute solution of boric acid and water is sprayed to be absorbed by the leaves.

Boronated single superphosphate

Boronated single superphosphate is a superphosphate containing 0.18% borax and is used as a fertilizer. (See also Superphosphate.)

Boron deficiency

Boron deficiency, which is the most widespread micronutrient deficiency in agricultural plants in countries like India, sets in when the boron content in soil comes down to 5 to 25 mg/ha.

Boron is found mostly in the topsoil. Dry weather reduces moisture in the topsoil and the boron uptake by the plant, causing boron deficiency. High rainfall areas also witness the leaching out of borosilicate from the soil which leads to boron deficiency.

Aluminum hydroxide adsorbs large amounts of soluble boron, making the soil acidic and causing boron deficiency.

Soils containing a high proportion of organic matter are less deficient in boron. But when the deficiency does occur, it causes stunting of both the root growth and flower formation, as well as a reduction in the number of flowers and their retention time. Pollen germination and pollen tube growth are also markedly reduced.

Boron deficiency is manifested in the twisting and distortion of the upper leaves of plants. This generally leads to (a) death of the terminal bud, (b) development of brown or reddish-yellow coloration of leaf tips and margins followed by their premature death, (c) occurrence of brittle stems and petioles, (d) internal browning or blackening of fruit and roots, and (e) leaves with pale yellow spots, as in lucerne grass.

In various crops, boron deficiency also shows up as marginal tip burn and the yellowing or death of the areas between the veins. In sugar beets, boron deficiency is reflected in small and deformed leaves and **heart rot**. The deficiency also causes the cracking of bark, gummosis, malformation of flowers and fruits (Fig.B.17) and injury to the vascular zone (cambium and phloem). Some examples of boron deficiency are cracked celery stems, top sickness of tobacco, internal cork of apple, hollow heart of groundnut, hollow stem of cauliflower and brown spot of sweet potato.

Fig.B.17: Mummification of berries in grapes, a symptom of boron deficiency. (Courtesy: Institute of Micronutrient Technology, Pune, India)

Boron deficiency also leads to stem-end russet of tomato, death of the growing tips of alfalfa (with a new growth occurring from a new shoot at the lower axillary bud) corky internal tissues and discoloration of leaves of cabbage, beet, turnip and cauliflower. Boron deficiency in grapevines in San Joaquin Valley, California, was found to drastically reduce the fruit set. The symptoms of boron deficiency resemble those caused by an infestation of leaf hopper insects.

Boron deficiency can be rectified by the application of borax, the latter being mined in the USA, Sri Lanka, India and Tibet. Borax contains 14% boron in the fertilization schedule. The low solubility of **boron frits** minimizes leaching losses when used for soil application. Top dressing of boron is a desirable amendment.

Boron frits

Boron frits, a source of boron in a matrix of glass, make the nutrient available over a longer period. An example of a fertilizer impregnated frit is a glass frit applied at the rate of 45 kg/ha, containing the following percentages: iron (Fe) 3.9, manganese (Mn) 9.7, copper (Cu) 2.0, zinc (Zn) 4.0, boron (B) 2.8 and molybdenum (Mo) 0.13. (See also Frits; Boron.)

Boron toxicity

The critical level of boron toxicity varies from 80 to 800 mg/kg, depending on the plant and its varying degrees of tolerance. Excess boron is toxic and should be avoided. Severe toxicity in the soil also affects germination.

The most prominent symptoms of boron toxicity are the yellowing of the leaf tip or leaflets followed by browning and scorching or gradual necrosis of the tips and leaf margins. This renders the plants stunted and bushy, with a few thinly branched leaves supporting small, curled-up and discolored leaflets. Older leaves develop brown spots which make the leaf appear dried up and brittle. (See also Boron.)

Borosilicate frits

Borosilicate frits are a source of boron. These are melted glass particles containing measured amounts of minor nutrients. Impregnated, granulated or powdered glass is usually mixed with N, P and K fertilizers to make application more efficient.

Borosilicate glass

Borosilicate glass is formed by fusing borax with silicate glass and is used as a nutrient for crops like alfalfa and apple. The boron content of borosilicate glass varies from 3 to 6% and its advantage lies in the slow availability of boron due to its low solubility in water. The availability of boron is directly related to the size of the borosilicate glass particles; the finer the particles, the greater the surface area and, therefore, the greater the boron availability.

Borosilicates are substances in which borate (BO_3^-) and silicate (SiO_4^{4-}) ions are linked to form networks with a wide range of structures. The addition of boron to the silicate network enables glass to be fused at temperatures lower than pure silica. This glass has a low coefficient of expansion and a high softening point.

Borosilicate also contains varying amounts of iron, aluminum, manganese, calcium, lithium and sodium. (See also Boron.)

Borosilicates: See Borosilicate glass

Bottle test

Bottle test is usually carried out to test the chemical compatibility of ingredients in a blend of fertilizer. A small amount of freshly blended material is kept in a glass bottle tightly closed and observed periodically for any wetting of the sides, caking, disintegration, or gas formation due to chemical reactions between ingredients in the blends. (See also Compatibility.)

Bottom lands

Bottom lands are lands created by rivers, streams or floods. They have deposits of alluvial materials like clay, silt and sand and are used for cultivation.

Bound water

Water molecules that are tightly held by various chemical groups in a larger molecule or by colloids are known as bound water. Carboxyl, hydroxyl or amino groups are involved in holding water molecules and hydrogen bonding is the factor. Proteins tend to bind water in this way, and it means, water will remain unfrozen even at temperatures as low as minus 40°C. This water is not absorbed by plant roots.

Boy's land

Boy's land is a colloquial term for light soil. Boy's land has a high sand content. It is easy to cultivate unlike **heavy land**, (also sometimes called **man's land**) which has high clay content.

BPF

BPF is short for **biopurification factor**.

BPL

BPL is short for **bone phosphate of lime**.

Brace roots

The adventitious roots in corn, arising from the internodes, are called brace roots or **anchor roots** because they anchor the plant and hold it in an upright position.

Brachy soil

Brachy soil has coarse and angular fragments with fine soil filling the inter-spaces.

Bracts

Bracts or **floral leaves** are modified leaves with a flower or inflorescence in its axil. Bracts are often brightly colored and may be mistaken for the petals of flowers. The showy flowers of *Poinsettia* and *Bougainvillea* are composed of bracts. The true flowers are comparatively inconspicuous.

Bradyrhizobium japonicum

Bradyrhizobium japonicum is a slow-growing, nitrogen-fixing strain of bacteria that inoculates soybean to form root nodules for fixing atmospheric nitrogen.

Bradyrhizobium spp.

Bradyrhizobium spp. are slow-growing strains of nitrogen fixing bacteria inoculating *Lotus, Vigna* and *Cicers* types of legumes.

Brak soil

Brak soil, found in South Africa, is **alkaline soil** formed owing to extreme temperature changes.

Brand

Brand or brand name refers to a design or a trademark, or a specific designation used by companies or manufacturers for a particular product. In the fertilizer industry, a brand name is a specific designation applied to an individual fertilizer (Fig.B.18). The grade of the fertilizer has to be included with its brand name and similarly displayed by the manufacturer on sacks and in printed literature.

Fig.B.18: Willase and Wilspar are two brand names for soil conditioners and organic manures, respectively. (Courtesy: Institute of Micronutrient Technology, Pune, India).

Braunification

Braunification is a process in which the soil acquires a brownish color because of the presence of iron oxide released from iron in primary minerals.

Bray-1 test

Bray-1 test is a method of estimating phosphorus, (similar to Olsen's test).

Bray and Kurtz P_1 method for phosphorus estimation

The Bray and Kurtz P_1 method for phosphorus estimation uses a soil extracting solution [containing 0.025N hydrochloric acid (HCl) and 0.03N ammonium fluoride (NH_4F)] for estimating the available phosphorus. The method is generally used for acidic soils.

When 0.1N HCl replaces 0.025N HCl, the method is called the **Bray and Kurtz P_2 method**. The primary phosphorus mineral is aluminum phosphate or calcium phosphate. The fluoride complexes aluminum ion (Al^{3+}) in solution, which results in a decrease in the aluminum ion concentration in solution. Aluminum phosphate dissolves to buffer or refurbish aluminum in solution and releases phosphorus, which is then measured. This represents the capacity of the soil to supply available phosphorus to the plant. The hydrochloric acid in the extractant also dissolves calcium-phosphorus (Ca-P) minerals present in the slightly acidic soil.

Bray and Kurtz P_2 method for phosphorus estimation: See Bray and Kurtz P_1 method for phosphorus estimation

Bray's modified Mitscherlich equation for plant growth and nutrient supply

E. A. Mitscherlich developed a relationship between the growth of plants and the supply of plant nutrients. This was further modified by R Bray. According to him, the soil nutrient mobility decreases as the amount of that nutrient needed in the soil to produce a maximum yield increases to a constant value. This increase to a constant value is from a value determined by the magnitude of the yield and the optimum percentage composition of the crop. The magnitude of the constant value is independent of the crop yield, provided that the pattern of planting as well as the fertility rate are constant, and the soil and seasonal conditions are similar.

Bray modified the **Mitscherlich equation for plant growth and nutrient supply** in the following way:

$$\frac{dy}{dx} = (A-y)\,C$$

to

$$\log(A-Y) = \log A - C_1 b - C(x)$$

where A is the maximum possible yield obtained after supplying all growth factors, Y the actual yield, x the growth factor, C_1 the constant, b the amount of immobile but available form of nutrients like phosphorus and potassium, and C the efficiency factor for x which is the added fertilizer form of the nutrient b. Bray showed that the values of C_1 and C are specific and constant over a wide area, regardless of the yield and the season.

Bray's nutrient mobility concept: See Bray's modified Mitscherlich equation for plant growth and nutrient supply

Breccia

Breccia is a coarse-grained elastic rock composed of angular and large broken fragments, cemented together in a finer grained matrix of any composition, origin or mode of accumulation. The consolidated form is equivalent to rubble. The rock can be formed by sedimentation or by igneous activity and diastrophism.

Brimstone

Brimstone is coarsely ground sulphur which is used to increase the acidity of soil and correct sulphur deficiency in plants. (See also Agricultural sulphur.)

British imperial gallon

British imperial gallon is the volume occupied by exactly 10 pounds of water having a density of 0.998859 g per cubic centimeter. One gallon = 4.54609 liters.

Broad-base terrace

Soil erosion can be controlled by reducing the gradient of a slope and erecting such barriers as brush dams, terraces, contour cultivation and contour strip cropping. Reshaping the slope steepness to reduce run-off is called terracing and a broad-base terrace is one such type.

The cross-section of a broad-base terrace is shown in Fig.B.19.

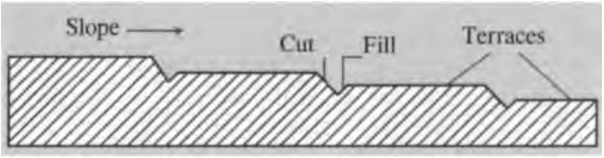


Fig.B.19: A cross-section of a broad-base terrace.

Broad-base terraces have the entire surface area planted to slow down eroding water and to control run-off (Fig.B.20).

Fig.B.20: Terraces made on slopes are cultivated to reduce soil erosion by run-off water.

Broadcast application: See Broadcasting

Broadcasting

Broadcasting, or **broadcast application**, is a method of applying fertilizer by throwing it over the soil either manually or by a mechanical spreader at the time of sowing (Fig.B.21). Broadcasting is also done as top-dressing which means broadcasting the fertilizer on a standing crop (Fig.B.22).

Fig.B.21: Broadcast spreader. Courtesy: Port Agric Ltd. www.portagric.co.uk With permission from Mr. Colin Port, Port Agric Ltd., U.K.

Broadcasting has many advantages: (i) Large quantities of fertilizer can be applied without injuring the plant. (ii) The distribution of nutrients throughout the plow layer encourages deeper rooting and improved exploration of the soil for water and nutrients. (iii) Labor involved in applying the fertilizer is saved.

Fig.B.22: Manual broadcasting of fertilizer in a standing crop.

(iv) Nutrients can be made available to plants at all times. Broadcasting is particularly advantageous when a maintenance fertilizer is to be applied to no-till cropping systems and to forage crops.

Broadcasting is done when water-insoluble or citrate-soluble **phosphatic fertilizers** are to be applied to acidic soils. Nitrogenous fertilizers (such as ammonium sulphate and ammonium sulphate-nitrate) can be broadcast at the time of sowing. For potassium-deficient soils, however, potash fertilizers (muriate of potash, potassium sulphate) are broadcast at planting time to help maintain and grow the crop. In the case of corn, a row application of P and K fertilizers is preferred to broadcasting, if levels of soil P and K are low. However, healthy soil P and K levels call for broadcasting.

Top-dressing of nitrogenous fertilizers (such as sodium nitrate, calcium ammonium nitrate, ammonium nitrate sulphate and ammonium sulphate) supplies nitrogen to plants that are closely spaced. For instance, wheat and rice are top-dressed with nitrogen just prior to the boot stage when the developing seed can be felt in the stalk by fingers. When the land is excessively wet or flooded, fertilizers can be **aerially sprayed**. Side-dressing and top-dressing of crops other than rice are most widely used in areas of high rainfall and coarse sandy soils.

The application of phosphorus and potassium is particularly effective in pre-plant applications.

Alfalfa, which needs nutrients to be applied before sowing, also benefits greatly if the established stands are top dressed. Many forage crops, sorghum and silage crops benefit from top dressed nitrogen and phosphorus in well drained soil conditions.

Phosphatic and potash fertilizers are top-dressed only on pasturelands. **Top dressing** by aircraft or helicopters is particularly beneficial on hilly terrain. An aircraft or helicopter is used when (a) very small quantities of fertilizers are needed over large areas, as in the case of micronutrients, (b) high quality materials are to be applied, (c) fertilizer application is to be combined with insect control or some other air operation, and (d) labor and time are to be saved.

In New Zealand, nearly 38.4 million hectares are top-dressed aerially. The aircrafts are also used for the application of superphosphate. In the USA, a substantial acreage of paddy is sown and top-dressed every year. Care must be taken, however, to see that the top-dressing of fertilizers on wet leaves does not scorch them. If the fertilizer is spread uniformly, accurately and at the right time, the crop are benefitted maximally. Inadequate supply of fertilizers on low-fertility soils result in the loss of yield.

Where soil phosphorus levels are healthy in a corn-soybean rotation system, phosphorus fertilizers can be broadcast and also incorporated into the soil prior to planting.

However, broadcasting distributes fertilizers unevenly and stimulates undesirable weed growth. Water-soluble fertilizers like superphosphate get fixed by broadcasting. Broadcasting urea on dry soil leads to nitrogen loss by volatilization.

Broadfield den process

The Broadfield den process is a manufacturing process (batch process) for **normal superphosphate**.

Broad leaf weeds

Weeds are plant pests that grow where they are not wanted, for instance, often on a cultivated land where they compete with crop plants for nutrients. They can be classified based on their leaf forms, such as broad leaf weeds or narrow leaf weeds.

Bronzing

Bronzing is the golden yellow coloration of the plant tissue that occurs due to nutrient deficiency. Bronzing causes a reduction in the formation of the green pigment (chlorophyll), giving a distinctive yellowish to whitish appearance. Sometimes, phosphorus deficiency causes bronzing on the lower side of leaves.

Bronzing of leaves with tiny brown spots is a typical symptom seen in rice crops, when excess iron is present in the soil. (See also Iron.)

Brown calcareous soils

Brown calcareous soil is related to **brown soils** in morphology. A major difference between the two is the presence of active calcium carbonate throughout the profile of brown calcareous soils. The top horizon is characterized by a mull less thick and less humus-bearing than in **rendzina**. This soil can have a calcareous incrustation. It can also have vertic features. (See also Calcareous soil.)

Brown coal

Brown coal, also known as **lignite**, is a soft, brown, material with a high moisture content. In the process of coalification, the proportion of carbon rises relative to oxygen, and volatile substances and water are driven out. The various stages in this process are referred to as the ranks of **coal**. Brown coal and **bituminous coal** are examples of ranks.

Brown coal is a low rank coal with 35 to 40% water and, therefore, a low heat content. Drying, crushing and pelletizing lignite with an asphaltic binder for direct use as fuel has been successfully demonstrated. Lignite can also be used as a source of hydrogen for ammonia synthesis.

Brown earth

Brown earth is the neutral soil found in temperate climates. Its profile is quite homogeneous, with good structure, permeability and aeration. There is no horizon of accumulation but these soils have a distinct cambic **B horizon**. (See also Brown soil.)

Brown forest

Brown forest is an old name, used in the USA, for inceptisols. **Inceptisols** is one of the 12 soil orders in **soil taxonomy**. (See also Soil taxonomy.)

Brown heart, Escarole

Brown heart is a disease caused in escarole crop, due to calcium deficiency. (See also Calcium.)

Brown rendzinas

Rendzinas are distinguished as humus-rich **black forest rendzinas** and **white rendzinas** with a high content of calcium carbonate. Brown rendzinas, which are less rich in carbonates and have a thinner **B horizon**, retain the features of **rendzinas**. (See also Rendzinas.)

Brown rice

Brown rice is rice with its hull removed, but the bran and embryo retained. (See also Paddy).

Brown soil

An acidic soil is called **brown earth** or brown soil. It is characterized by little or no leaching of clay and iron and is a mull with a B or Bt horizon.

Brown soil is very poor in organic matter and is colored brown by iron oxides which arise from the weathering of the parent rock. The profile is always decalcified, at least in the upper horizons.

Brown soil occurs in frigid, temperate and tropical zones, and typically has a pH higher than 5.5. The soil is characterized by the mull type organic constituent of soil (humus) with high biological activity. Brown soil is sometimes also of the modder type at the extremes of the class. The carbon to nitrogen ratio (C:N) of the surface horizon is always less than 14.

Brown earth is a major type of British soil. It generally has a dry brown surface and lighter subsoil. Brown earth is an agriculturally desirable, well-drained land found in the south and midlands of England, where the rainfall is relatively moderate and the climate mild. There is no horizon of accumulation but it is a distinct cambic **B horizon**. The profile is quite homogeneous with a good structure, permeability and aeration.

There are several types of brown earth, such as eutrophic, oligotrophic and ferric.

Brunaur-Emmett-Teller adsorption equation

Brunaur-Emmett-Teller (BET) adsorption equation, also known as **BET equation** is used to determine the specific surface area of finely divided substances such as clay minerals.

The specific surface area is computed by measuring the volume of an inert gas physically adsorbed on the substance as a monomolecular layer, at the boiling point of the gas. (See also Specific surface area; BET equation.)

BSA

BSA is short for British Standards Association which is the custodian of the British standards. (See also Sieving.)

Bt cotton

Bt cotton is the name of a biotechnologically modified cotton plant. Biotechnologically modified plants are also known as **transgenic plants**. The modification entails transfer of a gene from a beneficial bacterium, called *Bacillus thuringiensis* (Bt) to the cotton plant, resulting in disease-resistance traits in the new cultivar.

Cotton is susceptible to a host of pathogens. It needs more pesticides than perhaps any other crop in the world. Pesticides, however, become ineffective after the pests develop resistance. At this stage additional amounts and varieties of pesticides become necessary, setting off a vicious cycle: the more the pesticides, the more the number of resistant pests, the greater the environmental damage and the greater the health hazard to farm workers.

One of the major threats to cotton cultivation comes from the Cotton bollworm (*Helicoverpa armigera*) which attacks cotton plants and affects the yield. The success of Bt cotton lies in countering bollworm attack. *Bacillus thuringiensis* (Bt) contains a gene named Cry 1 Ac. This gene produces a protein, called delta endotoxin, which has insecticidal properties. The gene is transferred to the cotton plant cells in culture. From the cells grow cotton plants with the newly introduced gene in each of their cells. The resulting cotton plants are resistant to the cotton bollworm and other sucking pests.

The cultivation of Bt cotton plants is considered a safe and effective way to achieve good cotton yields. It saves a considerable amount of pesticides from being used and thus avoids contamination of soil and water, which would otherwise have occurred by persistent use. Bt cotton is thus seen to be a healthier alternative to conventional pest management measures applied for cotton cultivation. Thus, it is seen as an effective way to manage pests and conserve the environment.

International authorities like USDA, EPA and FDA have approved use of Bt cotton after a number of field tests.

In India, a company called Mahyco Seeds Ltd. developed three varieties of cotton hybrids with Bt cotton in the year 2002. With the approval of the concerned authorities, hybrid varieties of Bt cotton are cultivated in the country. Compared to conventional pest management methods, the pest population during Bt cotton cultivation was observed to be less. While the seeds are expensive, they are seen to give high yields with a significantly lower use of pesticides. During 2002 to 2005, the yield increased from 309 kg/ha to 460 kg/ha. The good cotton yield has given a boost to the Indian textile industry, both domestically and for exports.

Bubbler irrigation

Bubbler irrigation is a simple modification of drip irrigation used on gently sloping lands. The method uses low water pressure and open, standing outlet tubes (Fig.B.23) which control the water flow by their elevation, by a valve, or both. (See also Micro-irrigation.)

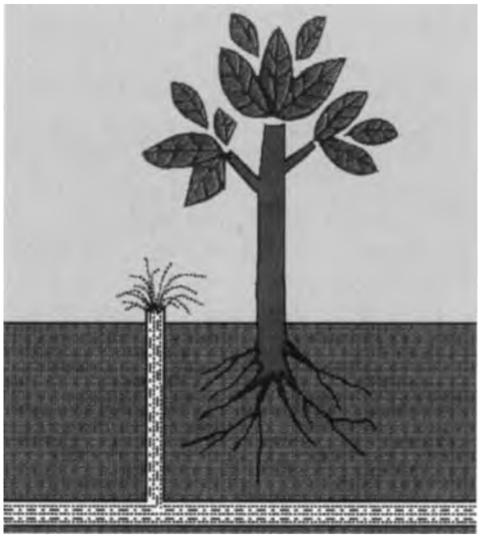


Fig.B.23: Bubbler irrigation system.

Buffer

A buffer or a **buffer solution** is a solution that resists change in its pH value brought about by the addition of an acid or a base. It consists of mixtures of either weak acids and their salts or weak bases and their salts. Buffers are important in living organisms because they guard against sudden changes in pH.

In biochemistry, the main buffer systems are phosphate (H_3PO_4 / HPO_4^{2-}) and bicarbonate (H_2CO_3 / HCO_3^-). The capacity of a solution to resist alteration in its pH value is its **buffering capacity**.

Buffers have either reserve acidity or reserve alkalinity. For example, a buffer of ammonium acetate or acetic acid exists largely in the form of the ammonium ion (NH_4^+) and acetate ion (CH_3COO^-). When an acid is added to this solution, the hydrogen ions (H^+) furnished by the acid combine with the acetate ions to form feebly dissociated acetic acid.

$$CH_3COO^- + H^+ \longrightarrow CH_3COOH \text{ (feebly dissociated)}$$

As most of the added hydrogen (H^+) ions are taken up by the acetate ions to form acetic acid which is itself slightly dissociated, the hydrogen ion concentration (and the pH) of the acetic acid or ammonium acetate solution changes only slightly.

When a base is added to acetic acid or ammonium acetate solution, hydroxyl ions (OH^-) furnished by the base will be taken by NH_4^+ ions to form feebly dissociated ammonium hydroxide (NH_4OH) and there is little change in the OH^- ion concentration and the pH.

$$NH_4^+ + OH^- \longrightarrow NH_4OH$$

The pH of a buffer solution is calculated by the mass law equation:

$$pH = Pk + \log \frac{C_B}{C_A}$$

where Pk is the negative logarithm of the apparent ionization constant of the buffer acid and C_A and C_B are the concentrations of the buffer base (C_B) and its conjugate acid (C_A). Acetic acid and sodium acetate, and ammonium hydroxide and ammonium chloride are examples of buffers.

In laboratories, buffers are used to prepare solutions of a known stable pH. Natural buffers - H_2CO_3/HCO_3^- and $H_2PO_4^-$ /H_3PO_4 occur in living organisms, where the biochemical reactions are sensitive to changes in pH.

Buffering capacity of soil

The buffering capacity of a soil is a measure of its ability to resist a change in pH. To exhibit buffering, the soil must either remove the hydrogen ions (H^+) of the added acids or neutralize the hydroxyl ions (OH^-) of the added bases.

$$\text{Ca-clay} + 2\text{HCl} \longrightarrow \text{H-clay} + \text{CaCl}_2$$

H-clay being weakly ionized, the pH falls only slightly.

The buffering capacity of a soil is its ability to re-supply an ion to the solution and involves all solid components or those adsorbed to cation or anion exchange sites in the soil system. For example, when **liming** neutralizes the hydrogen (H^+) ions in a solution, the hydrogen ions held on the exchange site would desorb from the exchange sites. The solution pH is thus buffered until significant quantities of the exchangeable acids are neutralized. Similarly, when plant roots absorb potassium ions (K^+), the exchangeable potassium ion is desorbed to re-supply solution potassium ion.

Soil buffering capacity is the ratio of the concentrations of the absorbed (ΔQ) ions to the solution (ΔZ) ions. This ratio increases with increasing **cation exchange capacity** (CEC), organic matter, and other solid constituents in the soil.

$$\text{Buffering capacity} = \frac{\Delta Q}{\Delta Z}$$

Since CEC increases with increasing clay content, a fine-textured soil exhibits a higher buffering capacity than a coarse-textured soil.

Buffering capacity is a very important soil property, which strongly influences nutrient availability and fertilizer management.

Buffer intensity

The rate of change of the acid neutralizing capacity with the pH of soil is called buffer intensity. It varies from 0.1 to 1.5 mole/kg of organic matter per pH in organic soils.

Buffer solution

Buffer solution is a solution that resists change in its pH value brought about by the addition of an acid or a base. It generally consists of mixtures of either weak acids and their salts, or weak bases and their salts. (See also Buffer.)

Builders' lime

Builders' lime is another name for calcium hydroxide. It is a white powder with a neutralizing value or CCE (calcium carbonate equivalent) of 136% and is made by hydrating calcium oxide (CaO). It cannot mix with soil because of water absorption.

Bulb vegetables: See Horticulture

Bulk blended fertilizer

A bulk blended fertilizer is generally defined as a **compound fertilizer** produced by mixing two or more fertilizers to yield specific ratios and grades. The process of producing a compound fertilizer by dry mixing two or more fertilizers with similar granular sizes in large quantities is called bulk blending. The granules of the constituents granules do not react chemically with one another. Individual granules in a bulk blended fertilizer may not have the same ratios and contents of the plant food. The bulk blending process for producing NPK fertilizers in batches is shown in Fig.B.24.

In Australia, a bulk blend of fertilizers is considered to be a mixture of two or more compounds and straight

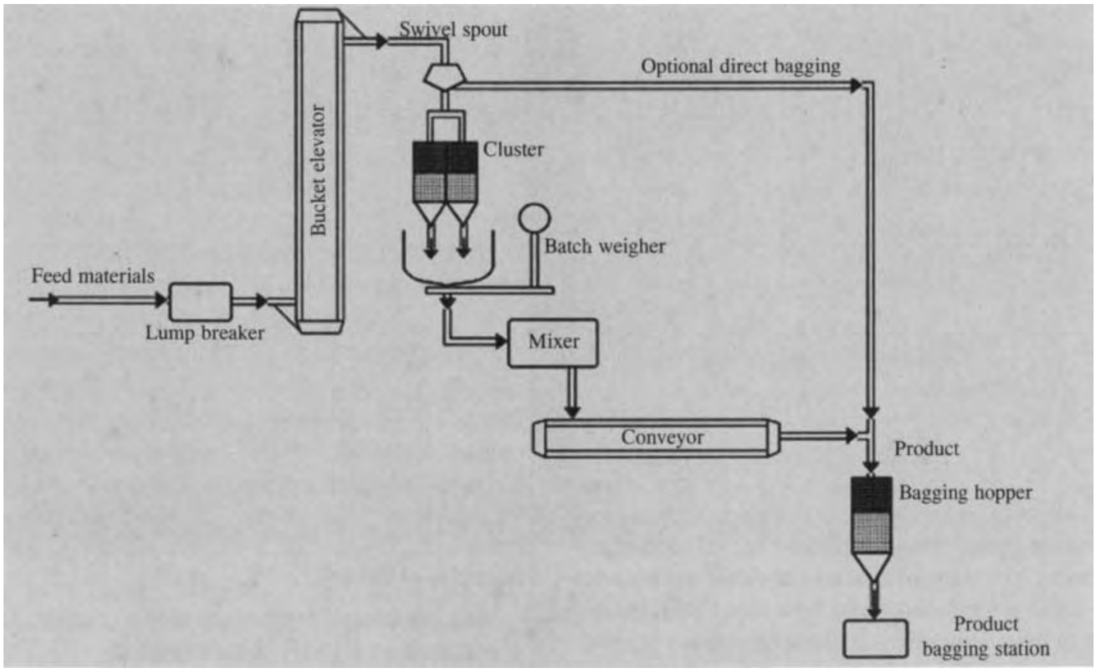


Fig.B.24: Flow chart of bulk blending process of 'batch type' NPK fertilizer. Source: "Fertilizer Manual", 1998. UNIDO, IFDC and Kluwer Academic Publishers, The Netherlands. With permisson.

fertilizers, preferably in the form of pellets or granules. These are also called **blended fertilizers**.

Bulk fertilizers are supplied to the purchaser generally in a non-packed form for use or for repacking.

Bulk density of fertilizer

The bulk density of a fertilizer is the mass per unit volume (including the voids between the particles) of the fertilizer. Knowledge of bulk density is of interest in package sizing, in calibrating volumetric feeders or applicators and in determining the storage capacity of bins and transport vehicles.

The bulk density of a fertilizer is determined by weighing a container of known volume, filling it to capacity with the sample to give the volume and then dividing the measured weight of the filled sample by the volume.

There are two types of bulk density, namely, loose pour and tapped. **Loose pour bulk density**, also known as the **apparent bulk density**, is the mass per unit volume of a substance after it has been tipped freely into the container under clearly specified conditions (Fig. B.25). It gives the minimum density (meaning, the greatest volume) expected. The values of loose bulk density are commonly used to avoid equipments and containers from being under-sized.

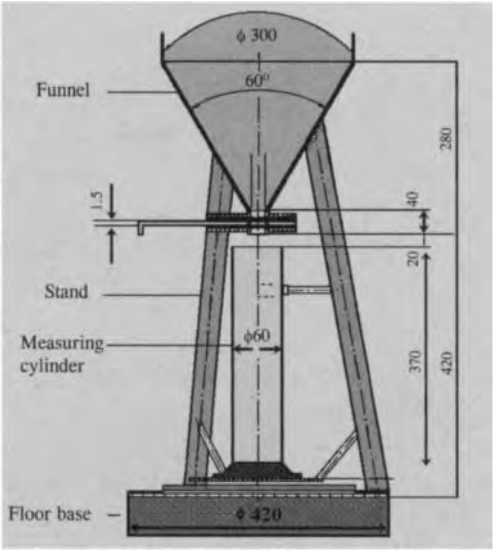


Fig.B.25: Loose pour bulk density apparatus. The dimensions (approximate) are in millimeters.

Tapped bulk density, also called **tapped pour bulk density**, is the mass per unit volume of a substance tipped into a container and then compacted under clearly specified conditions (Fig.B.26). It represents the maximum density (meaning, the smallest volume) expected. Generally, the tapped bulk density of prilled and granular fertilizers is 6 to 12% higher than their loose pour bulk density.

The bulk density values of fertilizers generally range from 750 to 1500 kg/m^3 and are measured using a metal box of the height, length and breadth of 30.48 cm each, or of 0.0283 m^3 volume.

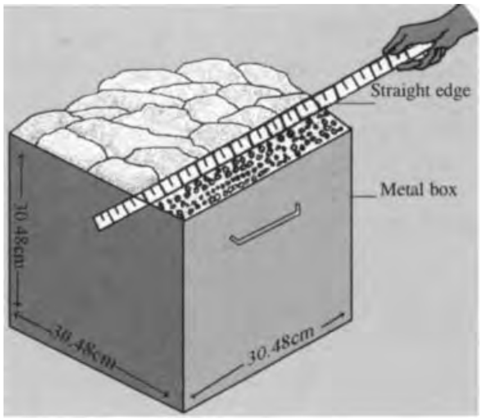


Fig.B.26: Measuring bulk density of a fertilizer in a metal box of 0.0283 m^3 size.

The **apparent density** is the mass per unit volume of a fertilizer, excluding voids between the particles. It is not measured often, but is of interest in particle segregation studies and development of granulation processes. It is determined by submerging a known weight of granules in mercury and measuring the volume of mercury that gets displaced (Fig.B.27). The apparent density values of fertilizer granules range from 1.22 to 2.65 g/cm^3.

There is another type of density, designated as **true density**. It is the mass per unit volume of the material and excludes voids between the particles as well as pores within the particles. This density is of interest in process control and the design of process equipment. An air-comparison pycnometer is used to determine true density. The pycnometer has two sample chambers of equal size. One is flooded with a measured volume of air, while the other is filled with a weighed amount of the ground test sample and then flooded with a measured volume of air. The difference in air volumes is equivalent to the sample volume. Based on the sample weight and the volume, the true density is calculated. True density varies with temperature and pressure.

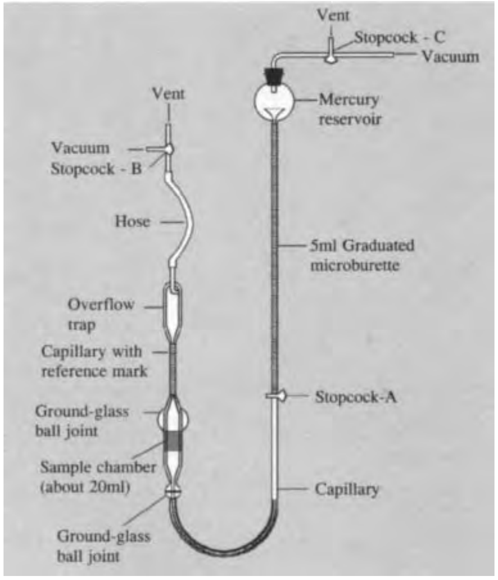


Fig.B.27: An apparatus for determining apparent density of fertilizer granules.

Bulk density of soil

The bulk density of soil is the mass per unit volume of soil, including its pore space. It is used along with particle density to calculate the **porosity of soil**. (See also Soil porosity.)

Bulk fertilizer

A bulk fertilizer is generally a solid or a liquid commercial fertilizer, which is delivered to the purchaser in a non-packaged form without a label.

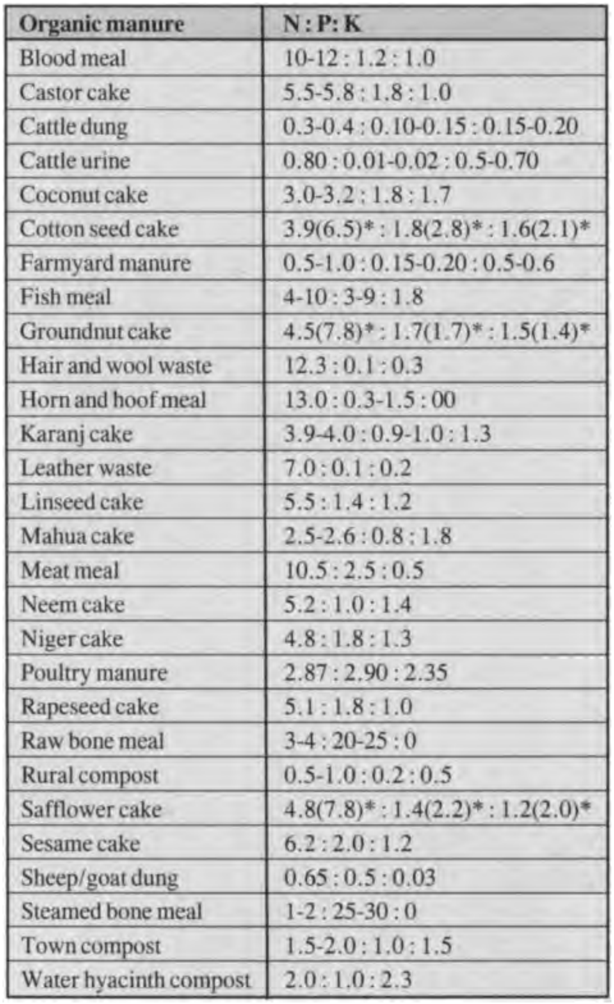
Also known as **bulk-spread fertilizer**, it can be spread over a large acreage of land.

Bulk-spread fertilizer: See Bulk fertilizer

Bulky organic manure

Farmyard manure (FYM), farm compost, **sludge**, **green manure** and other organic matter are collectively called bulky organic manures, their bulk not being in proportion to their nutrient content. These manures supply plant nutrients in small quantities and organic matter in large quantities.

Table-B.2: Common bulky organic manures and their nutrient contents.



Organic manure	N : P: K
Blood meal	10-12 : 1.2 : 1.0
Castor cake	5.5-5.8 : 1.8 : 1.0
Cattle dung	0.3-0.4 : 0.10-0.15 : 0.15-0.20
Cattle urine	0.80 : 0.01-0.02 : 0.5-0.70
Coconut cake	3.0-3.2 : 1.8 : 1.7
Cotton seed cake	3.9(6.5)* : 1.8(2.8)* : 1.6(2.1)*
Farmyard manure	0.5-1.0 : 0.15-0.20 : 0.5-0.6
Fish meal	4-10 : 3-9 : 1.8
Groundnut cake	4.5(7.8)* : 1.7(1.7)* : 1.5(1.4)*
Hair and wool waste	12.3 : 0.1 : 0.3
Horn and hoof meal	13.0 : 0.3-1.5 : 00
Karanj cake	3.9-4.0 : 0.9-1.0 : 1.3
Leather waste	7.0 : 0.1 : 0.2
Linseed cake	5.5 : 1.4 : 1.2
Mahua cake	2.5-2.6 : 0.8 : 1.8
Meat meal	10.5 : 2.5 : 0.5
Neem cake	5.2 : 1.0 : 1.4
Niger cake	4.8 : 1.8 : 1.3
Poultry manure	2.87 : 2.90 : 2.35
Rapeseed cake	5.1 : 1.8 : 1.0
Raw bone meal	3-4 : 20-25 : 0
Rural compost	0.5-1.0 : 0.2 : 0.5
Safflower cake	4.8(7.8)* : 1.4(2.2)* : 1.2(2.0)*
Sesame cake	6.2 : 2.0 : 1.2
Sheep/goat dung	0.65 : 0.5 : 0.03
Steamed bone meal	1-2 : 25-30 : 0
Town compost	1.5-2.0 : 1.0 : 1.5
Water hyacinth compost	2.0 : 1.0 : 2.3

* For decorticated material

Bulky organic manures have a three-fold effect on the soil: (i) As these manures contain plant nutrients, they have a beneficial effect on plant growth. Besides major plant nutrients, they also contain traces of micronutrients. But because they contain small quantities of plant nutrients, they need to be applied in large quantities. (ii) They increase the organic matter content, improve the physical properties of the soil, temporarily increase the humus content of the soil, improve the water holding capacity of sandy soils and the drainage of clayey soils. (iii) They provide food for soil micro-organisms, increasing their activity to help convert unavailable plant nutrients into available forms.

Table-B.2 lists some common bulky organic manures and their associated substances, along with the values of their average nutrient content.

Buminafos

Buminafos is a compound used as a **defoliant** or harvesting aid in potato and cotton. (See also Defoliants.)

Bureau of Indian Standards: See BIS

Burger cylinder

A burger cylinder is a metallic cylinder with a sharp edge, which is pushed into soil for extracting a known volume of soil without affecting the soil structure. The soil sample is then tested for water content, porosity and bulk density.

Burkeite

Burkeite is a naturally occurring ore, containing sodium sulphate and sodium carbonate. It is treated with potassium chloride to make potassium sulphate. (See also Potassium sulphate.)

Burned lime

Burned lime is another name for calcium oxide. It is also known as **unslaked lime** or **quicklime**.

Burned lime is a white powder with a neutralizing value or calcium carbonate equivalent (CCE) of 179%, compared to 100% for calcium carbonate ($CaCO_3$). Calcium oxide (CaO) or calcium hydroxide [$Ca(OH)_2$] used while liming gives quick results.

Burning technique in farming

Burning technique consists of the simultaneous removal of vegetation as well as the arable soil surface layer by burning them and spreading the ashes over the soil. This makes mineral elements directly available to plants. In the rice-growing areas in India, this kind of burning is called **rabbing** (Fig.B.28).

Bury

Bury is the indoor storage of potato and other root crops. (See also Clamp.)

Fig.B.28: Stubbles and residues of the crops are burnt in the fields, mainly to supply ash and mineral elements.

Bushel weight

Bushel is a formerly used standard measure for cereal grain weight. It was based on the Winchester bushel, a cylinder kept in the town hall of Winchester, England.

The weight of grain, when the cylinder was filled to the brim, was known as bushel weight. The weight of seeds varied with the amount of moisture and the quality of seeds. To overcome this difficulty, a hectoliter (the SI equivalent) is now used, which is equivalent to 2.5 bushel. (See also Yield.)

Bush fallow

Bush fallow is the shifting of cultivation at intervals to allow for some restocking of organic matter. This practice involves burning natural vegetation and cultivating the soil till its fertility is exhausted and then abandoning the site to move on to a new site. It also involves returning to an earlier abandoned area that has re-grown the natural plant cover, and beginning the cycle again.

During fallowing, nutrients extracted from lower soil horizons by plants are returned to the surface through the accumulation of organic matter. This undisturbed vegetative cover reduces the amount of water that passes beyond the root zone, thus minimizing leaching losses. The amount and type of fresh organic material added to the soil depend on the type of vegetation involved and how quickly it establishes itself. The amount of plant residue added annually to the soil varies with the climate and local conditions.

The fallow period necessary for restoring about 75% of the organic matter is as follows: 3 to 6 years for rain forest, 9 to 20 years for humid tropical land and 9 to 22 years for semi-arid tropical savannah, for every year of cultivation.

Bush fallowing is still practiced by farming communities in the tropics. (See also Shifting cultivation.)

Butters

Butters constitute one of many familiar **landforms**. The mass of **parent material** has a distinct shape with characteristic particle sizes. Its mineral or organic masses are known as landforms.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

C

C_3 and C_4 plants

Plants are classified as C_3 and C_4 groups according to the pathway of carbon dioxide fixation. Plants with a 3-carbon compound (like phosphoglyceric acid) as the first product of carbon dioxide (CO_2) fixation are called C_3 plants; those with a 4-carbon compound (like oxaloacetic acid) are C_4 plants.

C_4 plants exhibit high (a) photosynthetic efficiency, (b) water utilization efficiency, (c) leaf chlorophyll content, and (d) response to light intensity as well as to high carbon dioxide and oxygen concentrations. They have lower ratios for photorespiration and transpiration than C_3 plants.

The optimum temperature range for photosynthesis is 10 to 25°C for C_3 plants, and 30 to 45°C for C_4 plants. The C_4 plants are thus adapted to habitats with high temperature, high light intensity and limited water availability.

Rice, wheat, oats, barley, bamboo, cotton and soybean are important crops in the C_3 group whereas sugar cane, maize, sorghum, pearl millet, tropical grasses, etc. fall under the C_4 group.

Cablegation

Cablegation is a method of **irrigation** which is done through cables or pipes equipped with gates that open or close.

Caking of fertilizer

Caking of fertilizer refers to the undesirable formation of hard lumps or a coherent mass that usually occurs during extended storage under pressure and in humid environments (Fig.C.1).

Fig.C.1: Flowability of a fertilizer in a free particulate state and its non-flowability, when caking occurs.

The allowable storage time for a fertilizer from the time of its production to its field application can vary from a few days to several years. During storage the fertilizer should remain in a free flowing particulate form and any caking should be readily reversible to the original free particulate condition.

There are no universally accepted standards for caking. Generally, when a fertilizer is applied by machines, they can handle upto 15% material in small lumps. Manually, however, a higher percentage of lumps of medium hardness can be managed.

Fertilizer caking is caused by the formation of contact points among the particles. Different types of contact points are (a) phase contacts, (b) adhesive contacts, or (c) surface diffusion. **Phase contacts** are crystal bridges formed at the contact points between the particles. They cause the most troublesome type of caking which occurs during storage and are the result of continuing internal chemical reactions, dissolution or recrystallization due to heat.

Adhesive contacts (capillary adhesions) are formed between the surfaces coming into contact as a result of molecular attraction, known as **van der Waals forces**. This type of contact is influenced mostly by the plasticity of the particles and the pressure exerted on the fertilizer material when it is stacked in bags or piled in bulk (usually referred to as **bag set** or **pile set**). In this type of caking the fertilizer easily reverts to a free particulate form.

Surface diffusion is a result of water-salt complexes, consisting of pairs of hydrated ions transported within the adsorbed phase and then forming contacts with the adjacent granules. The diffusion mechanism of caking in fertilizers is greatly influenced by the degree of porosity in the structure of particles.

The factors that influence caking can be internal (related to the physico-chemical constitution of the fertilizer) or external, such as environmental conditions to which the fertilizer is subjected during handling and storage. (See also Agglomeration.)

Caking tendency, evaluation of

Excessive caking can cause problems in the removal of material from storage bins, rail wagons, trucks, shiploads and during bagging operations.

The tendency of a fertilizer to cake can be assessed in relative terms by storage tests in large or small bags, or by accelerated storage, as described below.

(i) **Large bag storage test**: This involves storing the fertilizer in a standard-sized bag for a period of 1 to 12 months, depending on the approximate period it is likely to be stored. The material is evaluated at certain intervals (e.g., after 1, 3, 6 and 12 months). The storage temperature may vary, depending on the actual storage conditions of the fertilizer. After storage, the test samples are evaluated for **bag set** by dropping the samples from a predetermined height and observing whether and how they break. The caking tendency of the fertilizer is determined by measuring the percentage of lumps formed during storage and their hardness.

Drawbacks of the large bag storage test are that it needs a large quantity of test material, and test area, and considerable labor. In addition, the test takes a long time (1 to 12 months) to complete and the measure of caking can sometimes be unreliable because actual storage conditions are difficult to simulate.

(ii) **Small bag storage test**: To simulate actual storage conditions, 1800 cm^3 of the material is sealed in a moisture-resistant bag and stored under a predetermined pressure for a period of 1 to 2 months. The caking tendency is then determined by measuring the hardness and percentage of lumps formed during storage. The small-bag storage test also takes a long time to complete and is not always reliable.

(iii) **Accelerated caking test**: Unlike in the large-bag and small-bag storage tests, the sample in this test is subjected to increased temperature, pressure and/or humidity, to speed up caking. Moreover, the test duration is shortened. But this method too is not fully reliable and at best can be used as a 'screening method' for relative evaluation of different anti-caking agents.

Calcareous

The term calcareous is used to describe a substance containing calcium carbonate or calcium in the form of chalk. Calcareous substances give effervescence with a 10% hydrochloric acid solution. (See also Calcareous soil.)

Calcareous soil

Calcareous substances contain mostly calcium carbonate or other calcium salts. A soil that contains more than 2% calcium carbonate (often along with magnesium carbonate) and produces vigorous effervescence when treated with 0.1N hydrochloric acid, is termed calcareous soil. Calcareous soil is classified depending on the calcium carbonate content as slightly calcareous, moderately calcareous and highly calcareous.

Brown calcareous soils are well-drained soils with a medium to heavy texture. They are slightly acidic in the surface layers and calcareous underneath and are developed over limestone or calcareous sandstone.

Calcic horizon

Calcic refers to anything containing calcium or lime. Calcic horizon is a diagnostic mineral horizon with secondary carbonates, mainly calcium carbonate and with or without accumulation of magnesium carbonate. This horizon can be either in the **C horizon** or in the **A horizon**, and sometimes even in the epipedon or the surface layer (like mollic epipedon).

Calcic horizon is commonly found in **aridisols**. It is more than 15 cm thick and contains at least 15% calcium carbonate ($CaCO_3$) equivalent (which is at least 5% carbonates more than that in the C horizon). Translocation of the carbonates to the **C horizon** or in the mollic epipedons is evident from the lime-filled cracks and stalagmites on the underside of rocks and stones.

A calcic horizon is evident in the accumulation of soft, powdery lime in the top 125 cm of soil. The following can be calcic: **vertisols**, **gypsisols**, **gleysols** and **luvisols**.

A horizon enriched with secondary carbonates but which is indurated or hardened is called **petrocalcic horizon**.

Calcicole plant

Calcicole plants are plants that grow best in calcareous soils. Such plants grow primarily on chalk, limestone, and calcium-rich soils. Examples of calcicolous forest species are *Pinus nigra* var *austriaca, Fraxinus excelsior, Ulmus campestris, Acer campestre* (called **field maple** or **hedge maple** in Europe) and *Viburnum lantana*. (See also Calcifuge plant.)

Calcic peat

Calcic peat is a type of peat categorized on the basis of its environment.

Calcification

Calcification is the process that leads to the accumulation of calcium carbonate in some horizon of the soil, especially in the **B** and **C horizons**, as happens in some **aridisols**.

The general reaction controlling the movement of carbonate is:

$$CaCO_3 + H_2O + CO_2 \underset{1}{\overset{2}{\rightleftharpoons}} Ca(HCO_3)_2$$

When carbon dioxide (CO_2) and water are eliminated from the above system, the reaction proceeds in direction 1 with the precipitation of calcium carbonate; if CO_2 and water are present, the reaction proceeds in direction 2 with the formation of soluble bicarbonate and is called **decalcification** or **decarbonation**.

Calcifuge plant

Calcifuge plants are plants that do not adapt to calcareous soil. Heather (*Calluna vulgaris*) is an example of a calcifuge plant as it cannot tolerate excess calcium. Coffee is another example of a calcifuge plant.

A calcifuge plant is extremely sensitive to manganese deficiency as manganous ion (Mn^{++}) becomes unavailable in an alkaline medium. Calcifuge plants also include some conifers.

A calcifuge plant can also be defined as a plant that thrives on an acidic soil or soils poor in calcium carbonate. Such plants are also called siliceous plants.

Calcimeter

Calcimeter is a device used to determine the calcium carbonate in all types of air-dried soil samples. The apparatus works on the principle that a soil sample (250 to 500 mg) placed in contact with hydrochloric acid (HCl) causes carbon dioxide (CO_2) emission.

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2\uparrow$$

The volume of CO_2 thus formed is compared to that released from the same quantity of pure calcium carbonate (224 ml from 1 g of calcium carbonate). The most commonly known calcimeter for this analysis is the **Bernard calcimeter** (Fig.C.2) or automatic calcimeter.

Calcination

Calcination refers to a process of heating a solid to a temperature below its melting point to bring about a state

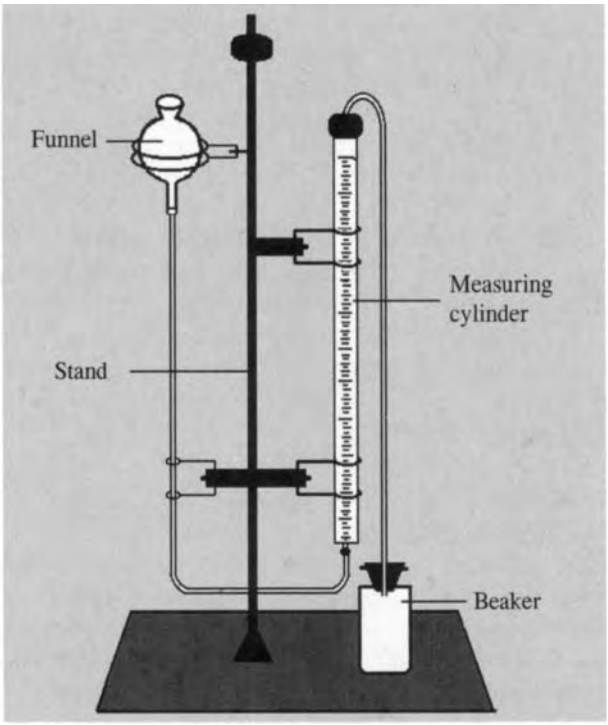


Fig.C.2: Diagrammatic representation of a Bernard calcimeter.

of thermal decomposition or phase transition without melting. The reactions involved are (a) thermal dissociation including destructive distillation, (b) polymorphic phase transition, and (c) thermal crystallization, that is, devitrification of glass.

Calcined phosphate

Calcined phosphate is a fertilizer made by heat-treating phosphate rocks.

Two types of calcined phosphate are known. In the first, the rock phosphate is heated directly up to 780 to 835°C in a kiln, which dissociates calcium carbonate (thermally), removes organic matter and improves the quality of the final product. Calcium oxide and magnesium oxide, produced by calcination of the carbonates, are removed by slaking with water. Calcined phosphate thus formed is used for the manufacture of food grade phosphoric acid.

In the second type of calcined phosphate, the ground rock phosphate is mixed with a small quantity of sodium carbonate (or sulphate) and of the wet process acid. It is calcined at about 1350°C in an oil-fired rotary kiln. The product is free of fluorine and contains 38 to 42% phosphorus pentoxide (P_2O_5), of which more than 90% is soluble in neutral citrate. Fluorine is recovered as sodium hydrogen fluoride. This type of calcined phosphate is mainly used as an animal feed supplement and as an effective fertilizer in finely ground form for acid soils. The Tennessee Valley Authority (TVA) follows the fusion process for defluorination of lower grade phosphate rocks.

Hydrated aluminum phosphate minerals after calcination at a controlled temperature, are useful for direct application. The **calcining** is done in a rotary kiln (or in a fluidized bed calciner) to remove the combined water, thereby destroying the crystalline material and improving the reactivity of the product.

At present, two aluminum phosphate ores are used for direct application after calcining. One of these, which occurs in Senegal, contains 29% phosphorus pentoxide on a dry weight basis and has over 34% phosphorus pentoxide after calcination. After **calcination**, the ore is ground so that about 95% of it passes through a 100 mesh sieve, and is used for direct application under the trade name **phosphal**. About 75% of the phosphorus pentoxide in this ore is soluble in alkaline ammonium citrate.

The other ore occurs in Christmas Island in the Indian Ocean. This ore is '**C-grade**', composed mostly of aluminum and iron phosphates. It contains 25% P_2O_5 on a dry weight basis which, after calcination, increases to 29 to 33%.

Calcination is carried out in a fluidised bed reactor within a temperature range of 400 to 600°C, after which the product is ground (to 0.15 mm size) for use. About 70% of the P_2O_5 in the fertilizer thus formed is soluble in alkaline ammonium citrate.

Major disadvantages of using calcined phosphates as a fertilizer are the (a) absence of water-soluble phosphorus, (b) high-energy requirements which lead to high manufacturing cost, and (c) low profit margins as the products can neither be ammoniated nor be used for the manufacture of NPK fertilizer.

Some important fertilizer materials in the calcined phosphate group are (a) **defluorinated phosphate rock** or **coronet phosphate**, (b) **rhenania phosphate**, (c) phosphate rock-magnesium silicate glass, and (d) **basic** or **Thomas slag**.

Calcining

Calcining involves the heating of a solid to a temperature below its melting point, which brings about a thermal decomposition of the solid or the phase transition but not melting. Calcining is often resorted to in the beneficiation of ores. (See also Calcined phosphate.)

Calciphyte

Calciphytes are plants that require or tolerate large amounts of calcium in the soil. (See also Calcicole plant.)

Calcite

Calcite or crystalline calcium carbonate ($CaCO_3$), is used for liming acidic soils. It is a dominant source of calcium in both arid and semi-arid soils.

Calcite crystallizes as a colorless or white crystalline material in a rhombohedral system with a hardness of 3 on the Mho scale. It exhibits the double refraction property, which is apparent in **icelandspar**, the transparent variety of calcite.

Calcite is very slightly soluble in water and is a major constituent of limestone, marbles and carbonates. It gives brisk effervescence with hydrochloric acid (HCl) and is sometimes used for bonding materials. The depth to which free $CaCO_3$ leaches out is a measure of the depth of true leaching and the thickness of the solum.

Calcite is the main source of **quicklime** and **hydrated lime** or **slaked lime**. It is widely used as a metallurgical flux to scavenge siliceous impurities by forming a slag in smelting furnaces. It provides the essential calcium oxide component in common glasses and cement.

Calcite limestone

Calcite limestone is crystalline calcium carbonate mined by the open-pit method. It is used to neutralize soil acidity. (See also Calcium carbonate.)

Calcium

Calcium (Ca), an element essential for the growth of living organisms, is a soft grey metallic element belonging to Group 2 (formerly II A) of the Periodic Table (Fig.C.3). It is an important constituent of bones and teeth in animals and is present in blood. It is required for muscle contraction and other metabolic processes. In plants, it is a constituent of the middle lamella and is essential for plant cell elongation, cell division and various anabolic and catabolic processes.

Calcium is an essential secondary plant nutrient. It is absorbed by plant roots as calcium ions and supplied to the root surface by mass flow and root interception. In cells, calcium levels are micromolar, whereas externally they are millimolar, facilitating a major role in metabolic control. Calcium levels directly control many enzyme reactions and enhance the uptake of nitrate, thus becoming interrelated with nitrogen metabolism.

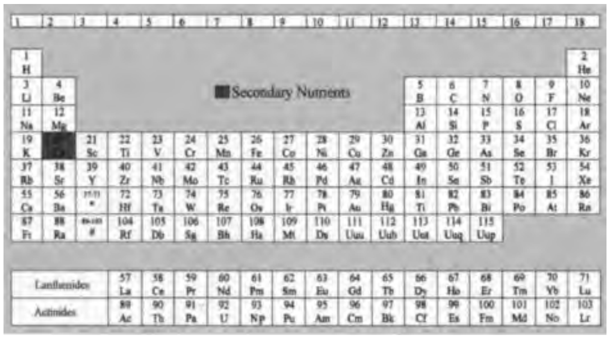


Fig.C.3: Position of calcium, a secondary plant nutrient element, in the Periodic Table.

Calcium also facilitates the uptake of potassium ions preferentially over sodium ions. Therefore, an optimum ratio of potassium to calcium is important for a favorable water balance in plants.

Calcium is generally an immobile element in plants.

Calcium concentration usually averages to about 33 ppm in the soil solution. A level of 15 ppm is adequate for a high corn yield. A higher concentration or excess of calcium in soil can cause deficiency of potassium and some micronutrients, particularly zinc. Crops like alfalfa, cabbage, potato and sugar beet, need higher amounts of calcium.

Calcium content varies widely in soil. Plagioclase mineral anorthite is the most important primary source of calcium. The availability of calcium from soil to plants is determined by many factors, such as the total calcium content, soil pH, **cation exchange capacity** (CEC), calcium percentage saturation, type of soil colloid, ratio of calcium to other cations in solution, etc. Highly acidic soils impede the uptake of calcium ions. As the calcium percentage saturation decreases relative to the total CEC, the amount of calcium ions absorbed by the plant decreases.

Many crops respond to calcium applications when the exchangeable calcium ion saturation falls below 25%. The 2:1 clays (meaning, a lattice with 2 silica sheets for 1 alumina sheet) require a higher calcium ion saturation than 1:1 clays (a lattice with 1 silica sheet for 1 alumina sheet). An increased aluminum ion concentration in the soil solution reduces calcium uptake by crops such as corn, cotton, soybean and wheat. The calcium supply for most crops is considered adequate when the soil calcium to cation ratio is between 0.10 and 0.15. Ammonium, potassium, magnesium, manganese and aluminum ions suppress the calcium ion uptake by plants, whereas nitrate ions enhance it.

Calcium deficiency leads to a decrease in the development of terminal shoot buds and apical root tips, thereby inhibiting plant growth. Calcium deficiency also causes distortion of new leaves; in maize, for instance, the deficiency prevents the emergence and unfolding of new leaves and renders the tips of the existing leaves almost colorless. A sticky gelatinous material causes the leaves to adhere to one another.

Calcium deficiency is rare in fruits (excepting apples which show pitting of flesh and skin) and vegetables; however, it is seen as a disorder in the storage tissues. Some vegetable crop disorders caused by inadequate calcium content are summarized in Table-C.1.

Table-C.1: Effect of calcium deficiency on some cultivated crops.

Vegetable crop	Effect of inadequate calcium content
Bean	Necrosis of hypocotyl
Brussels sprouts	Internal browning
Cabbage	Internal tip burn
Carrot	Cavity spot
Cauliflower	Leaf tip burn
Celery	Black heart
Cotton	Crinkle leaf
Escarole	Brown heart
Lettuce	Tip burn
Peanut	Black heart
Pimiento peppers	Blossom-end rot
Tomato	Blossom-end rot

The quantity of calcium lost by leaching is 75 to 200 kg/ha/yr. This loss is greater than that of sodium ions as the quantity of calcium present in a solution is higher and is in an exchangeable form.

Calcium is also lost or neutralized from the soil by other routes. These are (a) rapid neutralization by acid-forming fertilizers (ammonium), (b) slow neutralization by acid formed by carbon dioxide in water due to decomposition of organic matter, (c) erosion, leaving more acidic subsoil to be limed, (d) slow removal of harvested or grazed crops, and (e) slow neutralization by acidic rain.

Calcium is added to plants as a component of other nutrients, particularly phosphorus, as in superphosphates. Primary sources of liming materials are calcium carbonate and magnesium carbonate. Gypsum is used for supplementing calcium as a nutrient without correcting soil acidity. Synthetic chelates, such as ethylenediaminetetraacetic acid (EDTA) complexes of calcium containing 3 to 5% calcium, are used as fertilizers both for soil and foliar applications.

The uptake of calcium is progressively reduced by the presence of ammonium, magnesium, potassium and sodium ions, in that order. The foliar calcium to magnesium ratio of 2:1 and potassium to calcium ratio of 4:1 are considered optimum for plant growth. Phosphorus favors calcium uptake under acidic conditions. A pH increase after excessive liming results in deficiencies of iron, manganese, boron or zinc, leading to subsequent chlorosis. Calcium and boron exhibit a synergistic effect in reducing plant disorders.

Calcium ammonium nitrate

Calcium ammonium nitrate (CAN) is a nitrogenous fertilizer produced by treating ammonium nitrate solution with powdered limestone. It is a white to grey chalky powder, with the color depending on the limestone used in the manufacturing process. Made with dolomitic limestone, the fertilizer contains 20% nitrogen, 6% calcium and 4% magnesium. If the quantity of limestone is smaller than that of used ammonium nitrate, the nitrogen content can go up to 28%. CAN is preferred to ammonium nitrate in acid soils. The most common grade of CAN contains about 21% nitrogen, corresponding to 60% ammonium nitrate.

Several methods are employed for manufacturing calcium ammonium nitrate. A concentrated ammonium nitrate solution is mixed with powdered limestone to obtain calcium ammonium nitrate granules. These are cooled, dried and coated with a suitable material.

$$2NH_4NO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + 2NH_3 + CO_2 + H_2O$$

Other calcium compounds used for manufacturing CAN are ground calcite or dolomitic limestone, chalk, marl or precipitated calcium carbonate. The mixing is done quickly to avoid decomposition of ammonium nitrate. The granules contain 25% nitrogen, half of which is in a nitrate form and the rest in an ammoniacal form. The fertilizer is water-soluble and useful to many crops and soils; the nitrogen available to plants is relatively resistant to leaching because of its ammoniacal form.

Technologies of both prilling and granulation can be used for producing CAN. The prilled form is conditioned with china clay, kieselghur or calcined Fuller's earth in amounts ranging from 1 to 3% to improve the product characteristics during storage. To improve the product hardness, some manufacturers use pug mill to add ammonium sulphate equivalent to 0.3 to 0.5% of the sulphate (SO_4^{2-}).

Calcium ammonium nitrate is widely used as a fertilizer in Europe and the USA. It supplies nitrogen and calcium to all crops and soils. As CAN is not acid-forming, it is good for acid soils. However, it is hygroscopic and difficult to handle because it absorbs moisture from the air and becomes sticky. Therefore, once a bag is opened, its content has to be used the same day.

CAN is marketed under different trade names, like **Ammonium nitrate limestone** (**ANL**), **Cal-nitro**, **Nitro-chalk**, **Nitrammoniacal**, etc. (See also Ammonium nitrate.)

Calcium ammonium nitrate production processes

Calcium ammonium nitrate (CAN) is used when ammonium nitrate is not acceptable. CAN contains around 27% nitrogen, corresponding to about 75% ammonium nitrate.

CAN is produced by mixing quickly concentrated ammonium nitrate solution with ground or powdered calcitic or dolomitic limestone, marl or the precipitated calcium carbonate obtained during nitro phosphate production.

Both prilling and granulation technologies are used to produce CAN.

In prilling, ammonium nitrate solution is premixed with ground limestone just before prilling. Prill towers of 30 to 50 m height (depending on the ammonium nitrate concentration and cooling technique used) are employed. 1 to 3% China clay, kieselghur or calcined fuller's earth is used to condition the prilled CAN. The mean particle size of CAN formed is 2 to 2.5 mm. To obtain larger particles of CAN, Hoechst and AZF have developed technologies based on a combination of prilling and granulation.

In the granulation process, the methods used are (a) cold spherodizer, (b) fluid bed, (c) pug mill, and (d) drum.

Pan granulation is difficult to handle as the pan is very sensitive to such factors as heat and material balance. The product obtained is also irregular in shape. The other processes need additives and their melt concentrations are also different. For example, a spherodizer needs ammonium sulphate or magnesium sulphate while a fluid bed requires magnesium nitrate. In the pug mill process, 0.3 to 0.5% sulphate as ammonium sulphate is added to improve hardness. The melt concentrations by weight of ammonium nitrate for these processes are as follows: fluid bed 98 to 99%, pug mill 94.5 to 95.5% and drum 93.5 to 94.5%.

In pug mill granulation, ammonium nitrate melt and lime are proportioned in a controlled ratio to the pug mill. The undersized and crushed oversized dust is recycled. The fresh, damp granules pass to a drying drum and the granules are screened in a hot condition. The cooler off-gas is used for drying. The drying air is dedusted in dry cyclones and dedusting is done by scrubbing. The cooled product is coated before storage or bagging.

Calcium borate

The calcium salt of boric acid is called calcium borate. Colemanite is a source of calcium borate, ($Ca_2B_6O_{11}\cdot 5H_2O$), from which boron is extracted. It can also be added to overcome **boron deficiency**. (See also Boron; Colemanite.)

Calcium carbonate

Calcium carbonate ($CaCO_3$) is a naturally occurring white solid that is sparingly soluble in water. It is most commonly used to neutralize soil acidity to the required level in a process called **liming**.

The major sources of calcium carbonate are calcitic limestone, dolomitic limestone, marl, chalk and **marble**. Calcium carbonate is made by passing carbon dioxide (CO_2) into limewater. Pure calcium carbonate is assumed to have a 100% neutralizing value. The values of other **liming materials** are measured against the neutralizing value of pure calcium carbonate. Calcium carbonate, on heating, decomposes to give calcium oxide (quick lime) and carbon dioxide.

Limestone, which consists mainly of calcium carbonate, is called **calcitic limestone** or **high calcium limestone**. Limestone containing more than 10% magnesium carbonate is called **dolomitic limestone** or **dolomite**. These forms contain about 12% magnesium. **Agricultural dolomitic limestone** is a fine, grey to white powder of a double carbonate of calcium and magnesium with 12.8% magnesium and 17% calcium. The double carbonate is much less soluble in water than the individual carbonates.

Calcium carbonate equivalent

Calcium carbonate equivalent is an index of the neutralizing value of liming materials, taking pure calcium carbonate as 100. It is calculated as the molecular weight of calcium carbonate divided by the molecular weight of the neutralizing material, multiplied by 100. For example, the calcium carbonate equivalent of slaked lime is 136 and that of dolomite, 109. (See also Neutralizing value; Neutralization.)

Calcium carbonate-fluorapatite

The sedimentary deposits of rock phosphate contain varieties of carbonate-fluorapatite that are collectively called **francolite**. It is an apatite which is a widely occurring mineral of pale green to purple color. It consists of calcium phosphate with some fluorine, chlorine and other elements. Chemical analysis and X-ray diffraction (XRD) show that the contents of calcium carbonate-fluorapatite are calcium, sodium, magnesium, phosphorus, carbonate and fluorine. Studies indicate that francolite shows the replacement of calcium ions (Ca^{2+}) by sodium (Na^+) and magnesium ions (Mg^{2+}) in a systematic, although limited way. Most importantly, carbonate substitutes phosphate in a 1:1 ratio. The maximum amount of substitution is 6 to 7% carbonate (CO_3^{2-}). The incorporation of carbonate in a francolite structure increases the content of fluorine.

Calcium cyanamide

Calcium cyanamide ($CaCN_2$) is a dark colored, granulated material containing around 21% nitrogen. Its dark color is due to the presence of calcium carbide.

Calcium cyanamide is produced by heating a mixture of limestone with coal in a nitrogen atmosphere. Generally, the process is carried out in three steps. In the first step, calcium carbonate (limestone) is decomposed at about 1100°C.

$$CaCO_3 \xrightarrow[1100^\circ C]{\Delta} CaO + CO_2$$

In the second step, calcium oxide (CaO) and coke (or coal) are heated in an electric furnace to produce calcium carbide.

$$CaO + 3C \longrightarrow CaC_2 + CO$$

The final step involves heating the powdered calcium carbide at about 1100°C with pure nitrogen (produced by liquefaction of air and fractional distillation) to produce calcium cyanamide.

$$CaC_2 + N_2 \xrightarrow[1100^\circ C]{} CaCN_2 + C$$

The fertilizer-grade calcium cyanamide contains 21% nitrogen, 11% calcium, 11% free carbon, 5% oil, 2 to 4% water and oxides of aluminum, iron and silicon. In the presence of moisture and air, **calcium dicyandiamide** (a poisonous compound) is formed. It distinctly leaves alkalinity in the soil equivalent to 1.3 kg calcium carbonate ($CaCO_3$) per 0.45 kg of nitrogen applied. At pH 7 or below, calcium dicyandiamide is converted into urea and lime within one week of its being in the soil.

When dry, calcium cyanamide is dusty but it is generally used as granules. It is poisonous, irritating to the skin and used as a pesticide, fertilizer and defoliant in cotton. It is as good a fertilizer as sodium nitrate or ammonium sulphate, but not as fast acting.

Calcium cyanamide is an excellent weed killer, especially for tobacco plants, when applied 2 to 3 weeks before sowing. It is also used for producing melamine, urea and certain cyanide salts.

Calcium deficiency

Calcium deficiency is caused by the non-availability of calcium, a secondary nutrient to plants. The deficiency is seen first on the growing tips and on young leaves. **Chlorosis** generally occurs along the margins of younger leaves which become necrotic, as seen in Fig.C.4. (See also Calcium.)

Fig.C.4: Calcium deficiency causes chlorosis of bud leaves, die-back of tips and margins and death of terminal bud.

Calcium dicyandiamide: See Calcium cyanamide

Calcium dihydrogen phosphate

Apatite treated with sulphuric acid gets converted to mono calcium dihydrogen phosphate [$Ca(H_2PO_4)_2$] which is called superphosphate.

$$Ca_5F(PO_4)_3 + 7H_3PO_4 \rightleftharpoons 5Ca(H_2PO_4)_2 + HF$$

Calcium dihydrogen phosphate is more water-soluble than apatite. (See also Superphosphate.)

Calcium excess

Calcium excess in plants exhibits magnesium deficiency symptoms. When the excess is large, potassium deficiency also occurs. (See also Calcium.)

Calcium hydroxide

Calcium hydroxide, [$Ca(OH)_2$], also called **slaked lime** or **hydrated lime**, is a white solid that dissolves sparingly in water. It is manufactured by adding water to calcium oxide, a process that emits heat and is known as **slaking**.

Calcium hydroxide is a cheap alkali, used for neutralizing the acidity of acid soils and in the manufacture of mortar, white wash, bleaching powder and glass. It is an excellent absorbent for carbon dioxide to produce insoluble calcium carbonate and has a neutralizing value of 179%, compared to 100% of pure calcium carbonate.

Calcium metaphosphate

Calcium metaphosphate [$Ca(PO_3)_2$] is available as vitreous flakes. It is formed by treating phosphorus rock with gaseous phosphorus pentoxide (P_2O_5). Calcium metaphosphate is also obtained by burning elemental phosphorus with calcium oxide at high temperatures in the presence of oxygen. The molten product is tapped out of the furnace, solidified on a water-cooled steel drum, crushed and passed through a 10-mesh screen to obtain 1.6 mm size material.

Pure calcium metaphosphate contains about 72% phosphorus pentoxide and is not water soluble. However, it hydrolyzes slowly, forming water-soluble compounds. More than 98% of phosphorus pentoxide (P_2O_5) in calcium metaphosphate is soluble in neutral ammonium citrate.

The major drawbacks of calcium metaphosphate as a fertilizer are its (a) dependence on elemental phosphorus, and (b) agronomic effect, caused by the rate of its hydrolysis in the soil, which is too slow for short duration crops ($<$90 days).

Calcium nitrate

Calcium nitrate [$Ca(NO_3)_2$], also known as **lime nitrate**, **nitrocalcite**, **lime saltpeter** and **Norwegian saltpeter**, was the first chemical nitrogenous fertilizer to be marketed. It is produced as small white crystals by neutralizing calcium carbonate with nitric acid, as per the following reaction:

$$CaCO_3 + 2HNO_3 \longrightarrow Ca(NO_3)_2 + H_2O + CO_2$$

Calcium nitrate fertilizer absorbs considerable amount of water, which makes it somewhat difficult to handle. It contains 15% nitrogen and 21% calcium. In a prilled form, it becomes suitable for bulk mixing and the powdered form is useful in sprays.

Calcium nitrate controls the blossom-end rot of tomatoes and is used in Europe as a major source of nitrogen.

Calcium nitrate used on saline soils displaces sodium with calcium. In addition, calcium nitrate is a non-acid forming fertilizer and improves physical properties of acidic and exhausted soils. However, its advantage as a fertilizer is offset by its extreme hygroscopic nature. This calls for its production in air-conditioned plants and the use of sealed moisture proof bags.

Calcium nitrate, in addition to its usage as a fertilizer, finds application in explosives, pyrotechnics, and inorganic chemical operations.

Calcium nitrate production processes

Calcium nitrate is produced in large quantities in Egypt, The Netherlands, Norway, Portugal and Ukraine at plants with a daily capacity of 150 to 1200 tons. Two principal methods are known for its production, which are as follows: (i) Neutralization of 50 to 56% nitric acid by ground limestone and addition of ammonia to the filtered solution to make its pH about 4. This gives calcium nitrate in solution which is evaporated to get a concentration of about 79 to 82%. (ii) The other process starts with calcium nitrate tetrahydrate, a by-product in the nitro phosphate process. The crystals obtained are melted by plant waste heat to get a 70% solution.

The finishing operations are carried out by granulation in a pug mill, drum granulator or pan granulator. Because of effluent problems associated with prilling plants, the trend is to switch over to granulated products. The granulation technology used for calcium nitrate is the same as that used for calcium ammonium nitrate except that cooling is done prior to screening and crushing. For field application, calcium nitrate is coated with stearyl amine (15%) in paraffin oil. It is, however, not coated when applications are for drip irrigation or greenhouse.

Calcium nitrate in vapor and air from the production plants is scrubbed with water to keep the limit of 10 to 30 mg/Nm^3 of dust in the exhaust.

Calcium nitrate urea

Calcium nitrate urea, also called **calurea** in Germany, is a trade name for a white crystalline fertilizer material containing mainly calcium nitrate and urea. It is crystallized from an aqueous solution as calcium nitrate with four urea molecules. It contains 34% nitrogen and is used as a fertilizer.

Calcium oxide

Calcium oxide (CaO) is a white powder with a neutralizing value or **calcium carbonate equivalent (CCE)** of 179%, compared to 100% for calcium carbonate ($CaCO_3$). For quick results, either calcium oxide or calcium hydroxide [$Ca(OH)_2$] is used. Calcium oxide is also known as **lime, unslaked lime, burned lime** or **quicklime**. Roasting $CaCO_3$ in a furnace makes calcium oxide. A complete mixing of calcium oxide with soil is difficult because it cakes due to absorption of water.

Calcium phosphate

Calcium phosphate [$Ca_3(PO_4)_2$] is a white insoluble powder and is the main constituent of bones. Calcium phosphate occurs naturally as rock phosphate in the mineral apatite $Ca_5(PO_4)_3$, which contains OH^-, F^- and Cl^- ions to a small extent.

Calcium ions and hydrogen phosphate ions react in the presence of an alkali to produce calcium phosphate.

$$HPO_4^{2-} + OH^- \longrightarrow PO_4^{3-} + H_2O$$

$$3Ca^{2+} + 2PO_4^{3-} \longrightarrow Ca_3(PO_4)_2$$

Calcium phosphate is used extensively as a fertilizer. Dicalcium phosphate is a common constituent of nitrophosphate fertilizers and of compound fertilizers formed by ammoniation of superphosphates. **Calcining** of phosphate rock, sodium carbonate and silica in a rotary kiln at 1250°C gives **rhenania**, or calcium sodium phosphate.

Calcium polyborate

Calcium polyborates are salts of polyboric acid such as tetraboric acid with calcium. Calcium metaborate consists of calcium ions (Ca^{2+}) and metaborate ions $[(BO_2)_n]^{n-}$. The metaborate ion is made up of triangular BO_3 units which are joined together through oxygen atoms in a way that forms endless flat linear zig-zag chains, as shown in Fig.C.5.

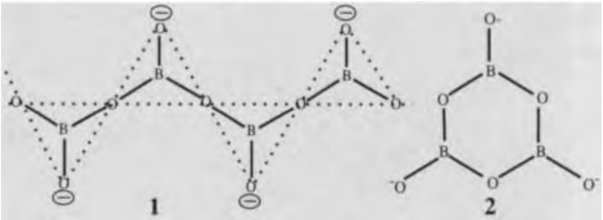


Fig.C.5: (1) Linear $[(BO_2)_n]^{n-}$ ion found in calcium metaborate and (2) cyclic structure of $[(BO_2)_3]^{3-}$.

Calcium sodium phosphate

Calcium sodium phosphate ($CaNaPO_4$) is another name for **rhenania**. It is produced by **calcination** of a mixture of phosphate rock, sodium carbonate and silica at 1250°C.

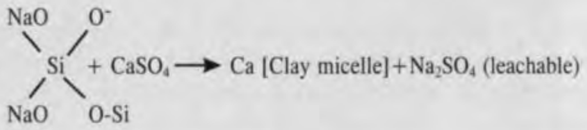
Calcium sulphate

Calcium sulphate ($CaSO_4$) is a white solid that occurs naturally as a mineral anhydrite. It is found more commonly as dihydrate, called **gypsum** ($CaSO_4 \cdot 2H_2O$). When heated, gypsum loses water at 128°C to give a hemihydrate ($2CaSO_4 \cdot H_2O$), also known as **plaster of Paris**.

Calcium sulphate is sparingly soluble in water and makes water permanently hard. $CaSO_4$ is used in the manufacture of certain paints, ceramics and paper. Its naturally occurring form is used in sulphuric acid manufacture.

Gypsum is the cheapest and the most useful material in reclamation of sodic soils. Calcium, solubilized from gypsum, replaces sodium, leaving behind the water-soluble sodium sulphate, which is leached out as a result of the following reactions in the soil:

$$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3 + Na_2SO_4 \text{ (leachable)}$$



$$(NaO)_2Si(O^-)(O\text{-}Si) + CaSO_4 \longrightarrow Ca\text{ [Clay micelle]} + Na_2SO_4 \text{ (leachable)}$$

Since both reactions are reversible, adequate leaching arrangements have to be made to remove sodium sulphate.

The application of about 40 t/ha of gypsum in Nevada (USA) was seen to increase water infiltration and the depth of water penetration substantially. These two measures increased hay yield up to 2.3 t/ha per year.

Gypsum requirement (GR) is the amount of gypsum necessary to be added to reclaim soil and is calculated using the formula:

$$\text{Gypsum requirement (GR)} = \frac{\text{Metric tons of gypsum needed to reclaim the soil}}{\text{Hectares of soil to some fixed depth (30 cm)}}$$

The gypsum requirement is equivalent to (Na_x) x 4.50 metric tons of gypsum per hectare for a 30 cm fixed depth, where Na_x is the milliequivalent of exchangeable sodium to be replaced by calcium from the added gypsum.

Calibration curve

Calibration curve depicts the relationship between two measurements as a graph, as in the colorimetric estimation of iron in soil. It is made by plotting the intensity of light absorbed at a particular wavelength against the corresponding concentration of, say, iron. The unknown sample absorption is interpolated to get the concentration. (See also Standard curve).

Caliche

Caliche is a mineral deposit of gravel, sand and nitrates (such as Chile saltpeter). Mined in Chile, caliche contains nitrates of sodium (8 to 20%), potassium, magnesium and salts like borate, sulphates and chlorides.

The sodium nitrate fertilizer is extracted from caliche. One ton of sodium nitrate (of 99% purity) is extracted from 10 tons of caliche. Calcium carbonate gets deposited within the soil and forms a layer of **caliche horizon**. Sometimes, because of erosion, the top soil gets washed away and caliche is exposed on the surface of the soil. (See also Sodium nitrate).

Caliche horizon: See Caliche

Calmonite

Calmonite is a mixture of ammonium nitrate and limestone, made in Germany.

Cal-nitro

Cal-nitro is a trade name of calcium ammonium nitrate fertilizer, which is marketed in Europe and the USA. (See also Calcium ammonium nitrate).

Calurea

Calurea is a dry, white, crystalline, nitrogenous fertilizer. Also called calcium nitrate urea, it contains 34% nitrogen and 10% calcium. It can be spread uniformly by a suitable farm distributor. When mixed with superphosphate to adjust the nitrogen content, its physical quality deteriorates.

Calvin cycle process

Calvin cycle is one of the two principal reactions by which carbon dioxide is reduced to a carbohydrate in a metabolic pathway during photosynthesis by marine unicellular **algae**. The second principal reaction is the **light dependent process**, during which sunlight is absorbed by the photosynthetic green pigment chlorophyll, and this energy is used to bring about the photolysis of water. The electrons and protons produced by the photolysis of water are used to reduce NADP (nicotinamide adenine dinucleotide phosphate).

The ATP (adenosinetriphosphate) and NADPH produced during the light reaction provide energy and reducing power respectively for the succeeding dark reaction. Calvin cycle takes place in the absence of light.

Cambic horizon

Cambic horizon is a subsurface **soil horizon**, with the texture finer than that of loamy fine sand. In this horizon, materials are altered or lost but not accumulated. The absence of fine stratification in this horizon is the proof of an altered structure. Other characteristics of this horizon are the appearance of grey color, mottling on wetting, redistribution of carbonate and yellowish or reddish color in the underlying horizons.

Cambic horizon contains more than 3% weather-prone materials, as indicated by the cation exchange capacity (CEC) (which is higher than 16 milliequivalents per 100 g of clay).

Cambisol

Cambisol is one of the twenty-four major soil types which changes color, structure and consistency owing to weathering *in situ*. Cambisol is described in the FAO-UNESCO soil map of the world.

Cambisol is a group of soils having a **cambic horizon** occasionally associated with ochric, umbric, calcic or gypsic horizons. It has mollic overlying subsoil with a base saturation which can be determined by 1M ammonium acetate at pH 7, randomly distributed within 100 cm from the soil surface.

Cambisol soils have one of the two characteristic horizons within a specified depth from the soil surface, namely (a) an andic or natric horizon between 25 and 100 cm, and (b) a plinthic, petroplinthic or salic horizon between 50 and 100 cm in the absence of loamy sand or coarser textures to a depth of at least 100 cm.

Calcaric, chromic, dystric, eutric, ferralic, gelic, gleyic, humic or vertic horizons can also be found in cambisols.

Cambium

Cambium is a plant tissue. It is a thin layer of cells that divide to give daughter cells. Cambium is found between the bark and the wood of a stem, and also within the roots.

Cambium is responsible for secondary growth in perennial plants. This growth is brought about by producing new layers of phloem (food conducting tissues) and xylem (wood). Based on temperature and moisture, the cambium produces large wood elements in the spring and minute ones in the summer, thus forming the annual rings in a tree.

There are two types of cambium, namely **vascular cambium** which gives rise to secondary xylem and phloem, and **cork cambium** which gives rise to secondary cortex and cork tissues.

CAN

CAN is short for **calcium ammonium nitrate**.

Capacity factor

The capacity factor of a soil represents the total amount of nutrients which can be transferred with the soil solution, either when the soil solution is depleted by a crop or by leaching. The ability of the soil to supply nutrients to plant roots as well as the plant's ability to absorb and utilize these nutrients determine the availability of nutrients to the plant. In other words, it is the reserve nutrient that moves into the soil solution during the course of plant growth.

Numerous solution-culture experiments have shown a close relationship between the nutrient concentration in the solution and the rate of nutrient uptake by the plant. In a low concentration range (say, lower than 0.05 mmol/liter nitrate, ammonia, potassium and phosphates) the relationship between the nutrient concentration in the growing medium and the nutrient uptake by the plant is linear and is given as:

$$U = 2\pi ra \cdot C_r$$

where U is the uptake of a 1mm long root segment, r is the radius of the root, a is the absorbing power of the root and C_r is the concentration of the ion at the root surface. Two critical chemical properties of the soil that determine the concentration of nutrients in the soil solution, are its pH and redox potential.

Chemical methods currently used to identify the capacity factor are based on the extraction of a readily exchangeable or soluble nutrient. However, the mechanism of supplying nutrients to the soil solution is still not fully understood.

Capacity factor of nutrient

Capacity factor of a nutrient is a measure of the amount of the nutrient available in the solid phase. When plants withdraw nutrients from the soil solution, the solid phase (reserve) goes into solution to replenish the loss. Chemical methods currently used for determining the capacity factor involve the extraction of the readily exchangeable or soluble nutrient.

Capacity of agricultural machines

The capacity of an agricultural machine indicates the limit of its capability. Two types of capacity are commonly used – the **field capacity of a machine** and the **throughput capacity**. Field capacity evaluates the productivity of machines (like plows, cultivators and drills) used for working the soil. Throughput capacity describes the productivity of machines that handle or process a product, such as grain augers, balers, forage harvesters and combines.

Another concept relating to both types of capacity is the difference between **theoretical field capacity** and actual productivity. Theoretical field capacity is defined as:

$$\text{Theoretical field capacity} = \frac{S \times W}{8.25}$$

where S is the speed of travel (m/h) and W is the width of machine (m).

The lost capacity represents the loss of revenues or resources. It is caused by lost time, idle time and under utilization of the machine.

Capillarity

Capillarity is the tendency of a liquid in a capillary tube or absorbent material to rise or fall due to surface tension. This phenomenon is at work when fine pores in the soil act as capillaries for water.

Capillarity is largely responsible for the transport of water against gravity and is, therefore, very important to plants. The size of capillary vessels in fruits and vegetables limits their rate of drying.

The phenomenon of a liquid rising up in a narrow tube or drop-bubble-film formation due to a high intermolecular attraction within the liquid is called **capillary action**. Water rises through the minute capillary spaces between soil particles and through soil pores.

Capillary action: See Capillarity

Capillary adhesion

Capillary adhesion refers to caking due to molecular attraction caused by van der Waals forces. During the storage of fertilizers in bulk or in bags, caking is caused due to contact among particles under pressure. (See also Caking.)

Capillary fringe

Capillary fringe is the zone comprising the horizons of the subsoil, saturated or semi-saturated, above the free surface of ground water, in a porous medium, and in continuity with it. The pressure of water in this zone is less than the atmospheric pressure. Because of the irregularity of the capillary fringe, its upper boundry is defined only by convention. If water is saline, the capillary fringe contributes to salinization of the soil and can be harmful to some crops, such as citrus or sugar cane.(See also Ground water.)

Capillary moisture: See Capillary water

Capillary pores

Capillary pores are the finest pores in the soil occupied by water. The water in capillary pores is known as **capillary water** and it moves through the soil pores because of the water potential gradient.

Capillary spaces: See Capillary water

Capillary water

Capillary water is the water held in capillary spaces by adhesion and surface tension as a continuous film around soil particles. The small spaces between soil particles are called **capillary spaces**. When the force that holds capillary water exceeds the 'pull' or the 'push' of a 60 cm column of water, the water does not drain away easily. Capillary water moves through the pores from wet to dry areas under hydrostatic gradient. It is, in effect, a **permanent soil solution** which contains dissolved solutes such as plant nutrients.

Water that moves up after the soil is drained is called **capillary moisture**. This water stays as a film around the soil particles and in the finer pore spaces by adhesion and surface tension. (See also Soil water.)

Capping

The coating over the top of free or embedded grains is known as capping in micromorphology. The form and the thickness of the coatings vary.

Heavy rains followed by hot and dry conditions create a crust on the soil particles which blocks the pores in the soil. This crust is also called capping.

Capsule

A capsule in the biological context is a generic term used for a variety of purposes, such as (a) a gelatinous envelope around the cell walls of certain bacteria (Fig.C.6), (b) a connective tissue envelope for organs in the animal body (e.g., liver or spleen), (c) a type of hard, dry, dehiscent fruit, opening in various ways to release its seeds (e.g., cotton, okra or poppy), (d) a thin metal envelope in an incubator, containing a liquid (e.g., ether) that expands and contracts and also maintains an even temperature in the incubator, and (e) a soluble gelatinous case containing a dose of medicine administered orally.

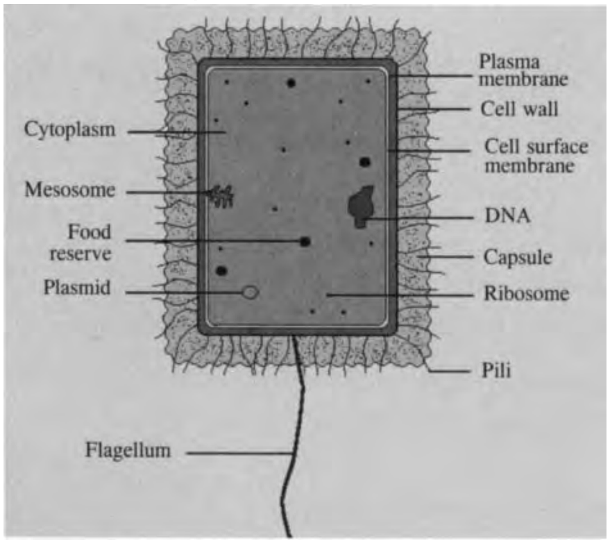


Fig.C.6: A bacterial cell and its parts. Some bacteria produce a slimy secretion called capsule which provides additional protection to them.

Carbamide

Carbamide is another name for urea. (See also Amide fertilizer.)

Carbamide phosphoric acid

Acid-forming fertilizers with urea may help in reducing the soil pH and the evolution of ammonia during urea hydrolysis. Urea phosphate is one such compound, and is formed by the action of urea with orthophosphoric acid. The common grade is 17-44-0. Urea combined with diammonium hydrogen phosphate [$(NH_4)_2HPO_4$] gives a solid fertilizer 28-28-0.

Carbamidine

Carbamidine is another name for guanidine. It is a crystalline basic compound related to urea. It forms a number of salts which are used as fertilizers. Guanidine phosphate is an example.

Carbohydrates

Carbohydrates like glucose, fructose, cane sugar, starch and cellulose were earlier considered to be hydrates of carbon, $C_x(H_2O)_y$. However, some carbohydrates cannot be represented as hydrates of carbon. The term 'carbohydrates' now includes all polyhydroxy-aldehydes and ketones along with substances they yield on hydrolysis. In short, compounds containing carbon, hydrogen and oxygen with a general formula of $(CH_2O)_n$ are called carbohydrates.

Plants produce carbohydrates by photosynthesis and are classified into **monosaccharides**, **oligosaccharides** and **polysaccharides**.

Monosaccharides are non-hydrolysable sugars, such as glucose (Fig.C.7) and fructose, which are soluble in water and sweet in taste. These are the building blocks of various carbohydrate molecules. Monosaccharides which contain an aldehyde group are called **aldoses**, whereas those containing a ketone group are called **ketoses**.

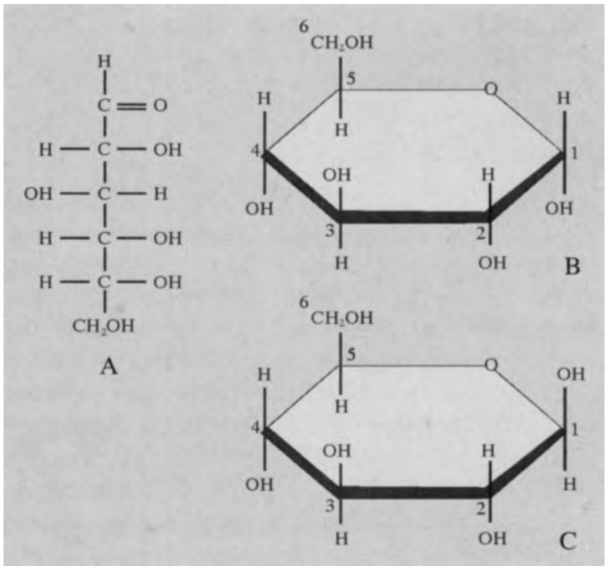


Fig.C.7: Structure of glucose, a monosaccharide. A- open chain; B and C- ring forms of α glucose and β glucose, respectively.

Oligosaccharides are low-molecular-weight condensation polymers of monosaccharides and may be further classified as disaccharides (two monosaccharide units) and trisaccharides (three monosaccharide units). Sucrose and maltose are examples of disaccharides (Fig.C.8).

Non-sugars like starch, dextrin and cellulose, which on hydrolysis yield a large number of monosaccharide

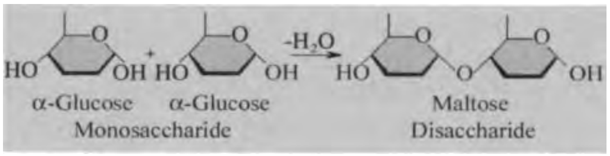


Fig.C.8: Formation of maltose, a disaccharide from glucose molecules (monosaccharides).

molecules, are called polysaccharides (Fig.C.9). They are amorphous, tasteless, non-reducing, mostly insoluble in water and are further classified as homo-polysaccharides and hetero-polysaccharides. Their molecular weight is usually very high and many of them (like starch or glycogen) have molecular weights of several million.

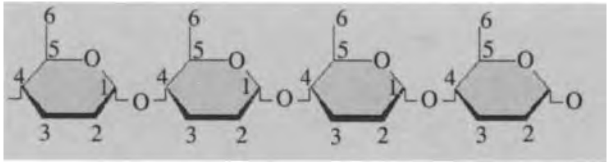


Fig.C.9: Structure of amylose, a polysaccharide.

Carbohydrates perform many vital roles in living organisms. Sugars, especially glucose and its derivatives, are essential intermediates in the conversion of food into energy. Starch and other polysaccharides serve as energy stores in plants, particularly in seeds, tubers, bulbs, leaves, etc., and are a major energy source for animals and including humans. Cellulose, lignin, etc. form supporting cell walls and woody tissues of plants. Chitin is a structural polysaccharide found in the body shells of many invertebrate animals. Carbohydrates also occur in the surface coat of animal cells and in bacterial cell walls. Carbohydrates are an important natural source of ethyl alcohol that is now used extensively in gasohol.

Carbon

Carbon (C) is found in every living being as it forms the major constituent of living cells. As an essential element for plants and animals, carbon is derived from atmospheric carbon dioxide assimilated by plants and photoautotrophic microbes during photosynthesis. Carbon occurs in nature both in an elemental form and as compounds. For example, coal contains elemental carbon which, upon heating in the absence of air, loses the volatile substances, and gives **coke**. Both coal and coke are amorphous (non-crystalline) forms of carbon.

The two crystalline forms of carbon are diamond and graphite. These are called the two allotropes of carbon. Allotropes are two or more forms of an element that exist in different physical forms, and differ in the bonding or molecular structure of their fundamental units. Carbon is found in a combined state in all living organisms, as well as in fossil fuels such as methane and petroleum. It also occurs in large amounts in carbonates such as limestone.

Carbon, a non-metallic element, is found at the head of Group 14 (formerly IV) in the Periodic Table (Fig.C.10). It is unique in the variety and complexity of compounds it forms, which is due to the ability of carbon atoms to bond to one another in long chains, rings and combinations of rings and chains. Carbon in combination with H, O, N, S and other elements produces such a variety of compounds, that a separate branch of chemistry called **organic chemistry**, came into being around carbon compounds.

Elemental carbon is a fairly inert substance. It is insoluble in water, dilute acids and bases, and organic solvents.

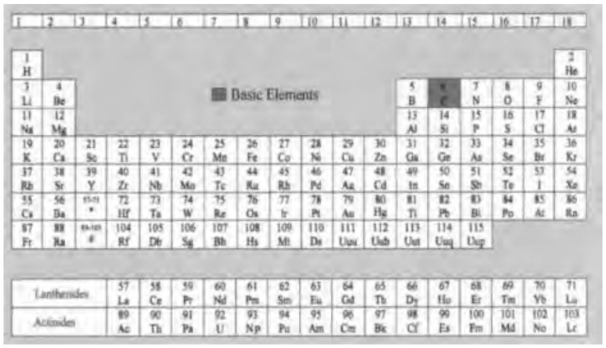


Fig.C.10: Position of carbon, a basic plant nutrient element, in the Periodic Table.

Each carbon atom has four valence electrons and these tend to share with other atoms in the formation of four covalent bonds. Carbon forms two oxides - carbon monoxide (CO) and carbon dioxide (CO_2) - which are formed when carbon or carbon-containing compounds are burned in insufficient or in excess air, respectively.

$$2C + O_2 \longrightarrow 2CO \text{ (restricted air supply)}$$
$$C + O_2 \longrightarrow CO_2 \text{ (abundant air supply)}$$

The free element has many uses, ranging from ornamental applications as diamond in jewelry to the black-colored pigment of carbon black in automobile tires and printing inks. Graphite, another form of carbon, is used for high temperature crucibles, arc lights, dry-cell electrodes, lead pencils and as a lubricant.

Charcoal, an amorphous form of carbon, is used as an absorbent for gases and as a decolorizing agent in its activated form.

Carbonation

Carbonation represents a chemical weathering process which combines the action of acidity and the formation of soluble bicarbonates, and is thus a kind of weathering by acids. Carbon dioxide dissolves in water to produce carbonic acid which acidifies the water and increases its solvent action. When limestone dissolves in water, the reaction of calcite (the main mineral in limestone) with carbonic acid to form soluble calcium bicarbonate is an example of carbonation.

$$H_2O + CO_2 \longrightarrow H_2CO_3$$
$$CaCO_3 + H_2CO_3 \longrightarrow Ca(HCO_3)_2$$

In the process, the potassium, magnesium and calcium found in many rocks (parent material) are released. Many other organic and inorganic acids are present in vegetated areas, and these contribute to weathering. (See also Weathering.)

Carbon cycle

Carbon cycle refers to the circulation of carbon atoms between living organisms and the atmosphere. Carbon dioxide is assimilated during photosynthesis by plants to produce carbohydrates and other complex carbon compounds. These in turn, are consumed by animals. Animals and plants break down these carbon compounds during respiration and release carbon dioxide back to the atmosphere. Carbon dioxide is also released from the decaying remains of plants and animals by the action of micro-organisms in the soil.

Thus, carbon undergoes a sequence of transformation, first used by a set of organisms, subsequently liberated in its original state, only to be reused by another set of organisms (Fig.C.11).

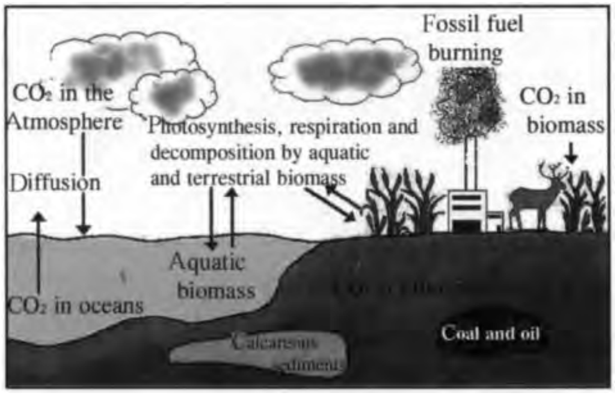


Fig.C.11: The carbon cycle.

Organic matter of the soil arises from the debris of green plants, animal residues and excreta deposited on the soil surface, which is mixed to a variable extent with the mineral component. This matter is colonized by a variety of soil organisms, most importantly micro-organisms that derive energy for their growth from oxidative decomposition of complex organic molecules. These micro-organisms convert the organic compounds to simple inorganic forms by a process known as **mineralization**. For example, organically combined N, P and S appear as ammonium (NH_4^+), dihydrogen phosphate ($H_2PO_4^-$) and sulphate (SO_4^{2-}) ions and about half the carbon is released as carbon dioxide (CO_2). Mineralization, especially that involving the release of CO_2, is vital for the growth of succeeding generations of green plants.

The proportion of remaining substrates used by micro-organisms (and incorporated into their cell substance or microbial biomass) and other essential elements such as N, P, S, etc. varies. These elements are largely unavailable for plant growth until they die and decay and the process is called **immobilization**.

The residues of organisms, together with the more recalcitrant parts of the original substrate, accumulate in the soil. Various interrelated processes of synthesis and decomposition by which carbon is circulated through the biosphere (comprising soil, micro-organisms, plants, animals and air collectively) constitute the carbon cycle.

For the past 100 years or so, the CO_2 emissions have increased from the combustion of fossil fuels and respiration by organisms. They have also increased the sequestration of carbon in living and dead organisms on land and in water. This has led to a steady rise of CO_2 concentration in the atmosphere. The rise, which according to one estimate, is currently occurring at an annual rate of 0.4%, leading to an enhanced **greenhouse effect**.

The amount of carbon in the form of soil organic matter is very large (1500×10^9 tons of carbon) and any change in the dynamic equilibrium of soil, vegetation and atmosphere significantly affects the net addition of CO_2 to the atmosphere. This makes the study of soil organic matter, its composition, accumulation and decomposition very important.

Carbon dioxide

Carbon dioxide (CO_2) is a compound of two oxygen atoms covalently bonded to a carbon atom. It is a colorless, odorless, tasteless gas, soluble in water, ethanol and acetone, and is 15 times heavier than air.

Carbon dioxide occurs in the earth's atmosphere at an average of 0.04% by volume. The volume keeps changing, as it is consumed by plants during **photosynthesis** and replenished during respiration and combustion of biomass. CO_2 is a major source of carbon for plants.

Carbon dioxide is readily prepared in a laboratory by the action of dilute acids on carbonates. It is also obtained as a by-product from the manufacture of lime and from fermentation processes. Chemically, CO_2 is not reactive and does not support combustion. It gives carbonic acid on dissolution in water.

Carbon dioxide is one of the key materials for urea production. Liquid carbon dioxide is produced at high pressures and has a small liquid range. Solid carbon dioxide (known as **dry ice**), produced by subjecting gaseous carbon dioxide to pressure and temperature, is used in refrigeration, carbonated drinks and fire extinguishers. It is also a constituent of medical treatment, as it promotes exhalation.

The level of carbon dioxide in the atmosphere has increased by 12% in the last 100 years, mainly due to the burning of fossil fuels and the destruction of rain forests. The increased level of carbon dioxide is the main cause for an average increase of 0.5°C in the mean global temperature through the **greenhouse effect**. Environmentalists urge that measures be taken to prevent any further increase in atmospheric carbon dioxide, and the subsequent **global warming** and melting of ice caps.

In **calcareous soils**, the partial pressure of carbon dioxide in the soil air influences its pH; it is 8.5 when free calcium carbonate in the soil is in equilibrium with atmospheric carbon dioxide. An increase in carbon dioxide in the soil air decreases the pH to around 7.3.

Applications of carbon dioxide include its use as (a) a refrigerant in either solid or liquid form, (b) an inert medium, (c) a chemical reactant, (d) a neutralizing agent for alkalis, (e) a pressurizing agent, and (f) an ingredient in the manufacture of aerated water.

Carbonitric process

Carbonitric process is undertaken for the removal of calcium ions or salts from nitrophosphate solution by adding ammonia and carbon dioxide. It is a commercially unsuccessful process.

Carbonitric process for nitrophosphate fertilizers

During the carbonitric process, calcium ion or salt is removed from nitrophosphate by passing carbon dioxide and ammonia in a solution of phosphate rock and nitric acid. The final product contains dicalcium phosphate and ammonium nitrate with small quantities of calcium carbonate.

Nitrophosphate is made by reacting phosphate rock with nitric acid and the process is known as the **Odda process**. Calcium ion is a non-nutrient as compared to N, P and K, and hence acts as a diluent. Hence, it is desirable to remove this calcium from solution. This is carried out in the Odda process by cooling the solution to remove the calcium nitrate that crystallizes out. Calcium ions can also be removed by precipitating them as calcium sulphate by adding ammonium sulphate to the solution. (See also PEC process for nitrophosphate fertilizers.)

Carbonization

Carbonization is a fossilization process during which an organism becomes a film of carbon, generally on the bedding surface of a sedimentary rock. Many leaf fossils are formed in this way.

Carbon/nitrogen ratio

Carbon/nitrogen (C/N) ratio is the ratio of organic carbon to nitrogen in organic materials or soils. Micro-organisms that decompose organic matter need nitrogen in some form along with other nutrients; hence, the C/N ratio in decomposing organic material and soil is important. This ratio indicates the likelihood of nitrogen shortage and any competition that might occur between micro-organisms and higher plants for the available nitrogen.

The nitrogen content of **humus** or stable soil organic matter ranges from 5.0 to 5.5%, whereas the carbon content ranges from 50 to 58%, giving a C/N ratio between 9 and 12. Whether nitrogen is mineralized or immobilized depends on the C/N ratio of the organic matter being decomposed by soil micro-organisms. A C/N ratio of approximately 20:1 is the dividing line between **immobilization** and **mineralization**. If this ratio in the fresh material is greater than 30:1, nitrogen immobilization occurs. For ratios between 20 and 30, there may be neither immobilization nor the release of mineral nitrogen. Organic material with a C/N ratio of less than 20 releases mineral nitrogen.

The nitrogen content of the residue being added to the soil can be used to predict whether nitrogen is immobilized or mineralized. A nitrogen content of 1.5 to 1.7% is sufficient to minimize immobilization of the soil nitrogen under aerobic conditions. In submerged soils and under anaerobic conditions, the amount of nitrogen required for decomposition of crop residues is about 0.5%. A severe nitrogen deficiency, which often follows the addition of residues with high C/N ratios to the field just before planting, is a result of this competition for nitrogen.

The C/N ratio of soils tends to be fairly constant, the median being between 10:1 and 12:1. The temperature and precipitation influence the C/N ratio in soil organic matter. Rainfall being constant, the C/N ratio is lower in warmer than in cooler agro-ecological regions. Similarly, when annual temperatures average about the same, the C/N ratios tend to be lower in the drier regions.

Since the C/N ratio of soil tends to be constant, the C/N ratio of added organic residues to the soil assumes considerable importance. When a residue having a high C/N ratio (such as wheat or paddy straw) is added to soil, the resultant increased microbial activity causes a sudden increase in the production of carbon dioxide (CO_2) with a concomitant depression in soil nitrates. This does not happen when leguminous crop residues having low C/N ratios (20:1 to 30:1) are added to the soil.

Available information on tillage effects on soil organic matter and nitrogen availability leads to the conclusion that all tillages lead to a decrease in the C/N ratio of soil compared to native sod. Tillage increases the oxygen content of the soil air and exposes protected organic matter to microbial action. Thus, the more a soil is tilled the greater the loss of its organic matter.

CARNIT process for ammonium nitrate production: See Ammonium nitrate production processes

Carotenes

Carotenes are reddish yellow pigments which occur in all leaves, carrots and butter and give them their distinct colors. Carotenes are unsaturated hydrocarbons ($C_{40}H_{56}$) that belong to a class of **carotenoid** pigments. They are precursors of vitamin A and occur in certain plastids. Examples are ß-carotene and lycopene which give color to carrot and ripe tomatoes respectively.

Carotenoids

Carotenoids are a large class of pigments usually located in the thylakoid membranes of the grana in chloroplasts, in the form of carotenoprotein complexes.

The general structure of carotenoids is that of aliphatic and aliphatic-alicyclic polyenes with a few aromatic-polyenes. They are widely distributed in plants and act as photosynthetic pigments in cells that lack chlorophyll. They have the same basic structure as vitamin A, and are converted into vitamin A in animal livers. More than 300 carotenoids are known and this number is on the rise.

There are several biochemical functions in which carotenoids play a role, apart from their well-known role as photosynthetic pigments. Carotenoids act as blue light harvesting pigments, protect biological systems from photodynamic damage and are safe food colorants.

Carpel

Carpel is the female reproductive organ of a flower, comprising a stigma, style and ovary (Fig.C.12). It develops into a fruit after receiving pollen grains and fertilization. Flowers may have a single carpel, a condition termed **monocarpellary** (as in orange), or many separate carpels called **apocarpous** (as in michelia).

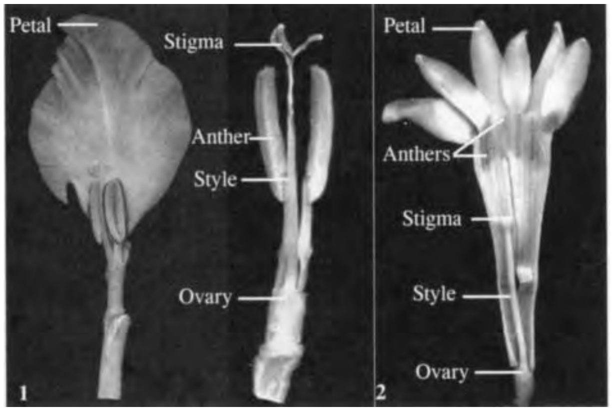


Fig.C.12: Carpels of the flowers of 1. Gladiolus and 2. Tuberose.

Carrageenans

Carrageenans are naturally occurring hydrophilic colloids found in various species of red seaweeds. They perform a role similar to cellulose in terrestrial plants.

Carrageenans are a highly sulphated galactan. Due to this they are a strongly anionic polymer which makes them useful commercially. They are commercially extracted for their use as water soluble gums.

Carrageenans may be compared with furcellaran extracted from agars (furcellarans have a smaller proportion of half-ester sulphate). Agars, in contrast, are commonly considered non-ionic.

Carrier-based inoculant

Mixing a liquid **inoculant** with **carriers** such as peat, lignite or charcoal makes a carrier-based inoculant. The carrier added to inoculum facilitates field application.

Carrier proteins

Carrier proteins are proteins bound to a non-protein group and act as carrier molecules in transporting electrons through the electron transport chain. They can undergo oxidation-reduction easily, thus allowing electrons to flow through the system. There are four types of carriers: flavoproteins, cytochromes, iron-sulphur proteins and coenzymes.

Carriers

Carriers are proteins that mediate the transport of molecules across membranes or that carry out oxidation/reduction reactions in the membrane. Besides the protein components, redox carriers may also have other moieties, such as heme and metals.

Carrier is also a term used for animals, insects or any other living organisms that possess or 'carry' germs of a disease but not its symptoms, and are able to pass on the infection to other plants or animals. In the context of biofertilizers, non-living base materials such as lignite (Fig.C.13), peat, charcoal, sawdust, etc., which carry bacterial inoculum, are called carriers.

Carriers also refer to neutral molecules like those used to support a catalyst in a large scale reaction system, or a gas used to convey a volatilized mixture for analysis by gas chromatography.

Carrier theory of ion transport

According to the carrier theory, a carrier is present on a membrane which combines with the ions on the outer surface of plasmalemma and forms a complex. The complex so formed can travel through the membrane,

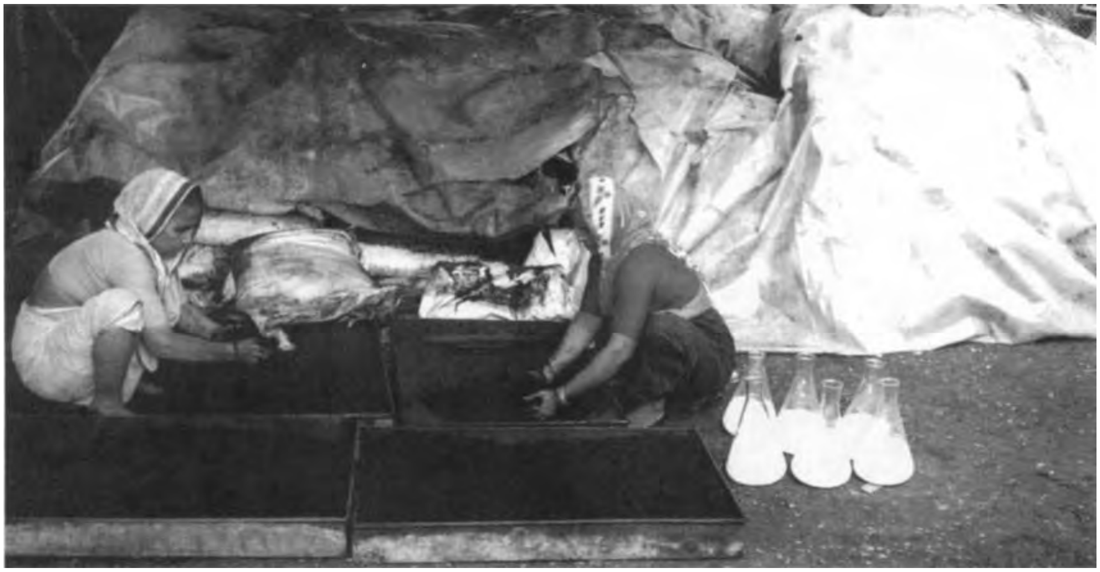


Fig.C.13: Inoculum of phosphate solubilizing micro-organisms being mixed with the carrier, lignite. The carrier-based inoculum is used for direct inoculation.

whereas it is impermeable to the free ion. After releasing the ion on the other side, the carrier moves back to start the process once again. This hypothesis can explain (a) the accumulation of salts against the concentration gradient, (b) the specificity in ion uptake which is found in all plants, and (c) the transport of ions through membranes which by themselves are impermeable. A single type of carrier may be operative in carrying several types of mutually competitive ions.

Carryover effect of fertilizer

Carryover effect or **residual effect of fertilizer** refers to the continuing action of a fertilizer in providing nutrients to a plant, for a season or more after its application. The unutilized nutrients from the previous season become available to the plant in the next season. Long-term residual benefits are encountered more for potassium and phosphorous than for nitrogen. Carryover effect is also seen in **manures**.

In practice, phosphorus and micronutrients, once applied, are generally available to the plants in the next season. The residual effect depends on the nature of soil, the amount of fertilizer added, the crop yield and the portion of the crop left in the field after harvest.

Crop residues left in the field are often important nutrient sources. For example, most of the potash taken up by cereals is found in straw. The same is true for several other crops (like sugar beet, potato and rape seed) when more than half the nutrients are left behind in crop residues. Management of the residue is, therefore, an important part of plant nutrient budgeting and soil management.

Carse

Carse is a Scottish term used for an alluvial riverside plain.

Caryopsis

Caryopsis is a fruit (**grain** or **seed**) of **cereals** and grasses where a dry, single-seeded indehiscent fruit has its fruit wall fused to the testa (seed coat) of the seed. Wheat, barley, corn and rice are examples of caryopsis fruit.

Cash crop

A cash crop is a high-value marketable crop produced for sale rather than for domestic consumption or green manuring. Sugar cane, cotton, turmeric, chilies and tobacco are examples of cash crops (Fig.C.14).

Fig.C.14: Cotton, a major cash crop is grown on a large cultivable area.

Casual worker

A casual worker is a person employed on a daily wage basis, usually for a short duration at a time or for a particular season, or as per requirement like for crop planting, weeding or harvesting (Fig.C.15).

Fig.C.15: Casual workers in a field at harvest time.

The casual worker is not entitled to normal benefits given to a regular employee, and his/her wages may be paid in cash or in kind. Sometimes a casual worker is also called a **daily worker** or **daily wager**.

Catacarb process for ammonia production: See Ammonia production processes

Catalysis

Catalysis is the process of increasing or accelerating the rate of a chemical reaction by use of a catalyst. (See also Catalyst.)

Catalyst

A catalyst is a substance which, in small quantities, facilitates a reaction or favorably alters the rate of a chemical reaction, without itself undergoing any permanent chemical change. This phenomenon is called **catalysis**. Acid-based catalysis is an important type of catalysis.

Catalysts that have the same phase as the reactants are known as **homogeneous catalysts** while those having a different phase are called **heterogeneous catalysts**. Generally, a catalyst that increases the reaction rate is known as a **positive catalyst** while one that slows down the rate is known as a **negative catalyst**, **retardant** or **inhibitor**.

Some examples of catalysts and their roles are as follows: (i) Protein catalysts, called **enzymes**, speed up many chemical reactions in living organisms. These play a key role in all metabolic or biological processes and in some manufacturing processes, such as the fermentation industry. (ii) Catalytic converters, in automobiles, employ a mixed oxide bed over which the exhaust gases pass after they are mixed with additional air. These catalysts promote oxidation of carbon monoxide and hydrocarbons to carbon dioxide and water.

Catalysts may be inorganic, organic or complexes of organic groups and metal halides. (**Zeigler-Natta catalysts**). They may be gases, liquids or solids. In some cases, their action is undesirable and destructive, as in the oxidation of iron to iron oxide, which is catalyzed by water vapor (rusting). The life of an industrial catalyst varies from 1000 to 10,000 hours, after which it must be replaced.

Catalysts are highly specific in their action and application and very essential for many industrial chemical reactions, as in petroleum refining and organic syntheses. The activity of a solid catalyst is centerd in a small fraction of its surface; adding promoters increases the surface area by increasing the porosity or the number of active points. Substances that act as poisons clog and weaken the catalyst surface, thus decreasing the catalytic activity.

Catalytic fertilizer

There are some fertilizers which do not carry any essential nutrients to the plant but nevertheless have a beneficial effect on plant growth. Such fertilizers are known as catalytic fertilizers or **stimulant fertilizers**. (See also Stimulants.)

Catch crop

Catch crop is a quick-growing crop, usually grown between two main crops in rotation. It is grown for green manuring. It is plowed back as a green manure before the next crop is sown.

Catch crops (called **cover crops** in the USA) are selected plant species grown in rotation for the purpose of retaining nitrates (NO_3^-) in the soil that might be otherwise lost by leaching. Catch crops also help reduce erosion.

Catch crops should have rapidly developing and extensive root systems that are efficient in absorbing nitrogen from the soil. They should easily decompose when the field is prepared for the next crop, and should have the following characteristics that fit into the crop rotation mechanism : (i) They should not provide a home to pests and disease causing agents.(ii) Surviving plants should not act as weeds. (iii) They should not affect the growth of the next crop and its yield.

Common catch crops in Western Europe are rye, radish, mustard, rape seed and Italian rye grass, whereas in India vegetable crops like cowpea, cluster bean and lettuce are grown as catch crops. Significant reductions or additions of nitrogen are reported, ranging from 20 to 45 kg per hectare, due to nitrate leaching or nitrogen fixation. Crops differ in their ability to deplete the soil nitrogen depending upon the season. A winter crop of wheat is less efficient than a specialized catch crop.

A large-scale use of catch crops places constraints on farmers because of (a) the labor and time needed for sowing and plowing back, (b) the costs of seeds and cultivation having to be added to the overall costs, (c) the weed control program needing revision, and (d) the catch crops having to compete with the main crop for water uptake in dry conditions. When the growing season is short, catch crops show little effect on nitrate leaching.

Catchment

A unit of treated or untreated area collecting run-off rain water to a common stream or river is called a catchment area (Fig.C.16). If this water were not collected or harnessed for agriculture or drinking, it would be lost to the sea.

Catchment basin

Catchment basin is another name for **watershed**. It is an area which drains all the run-off into a river or stream.

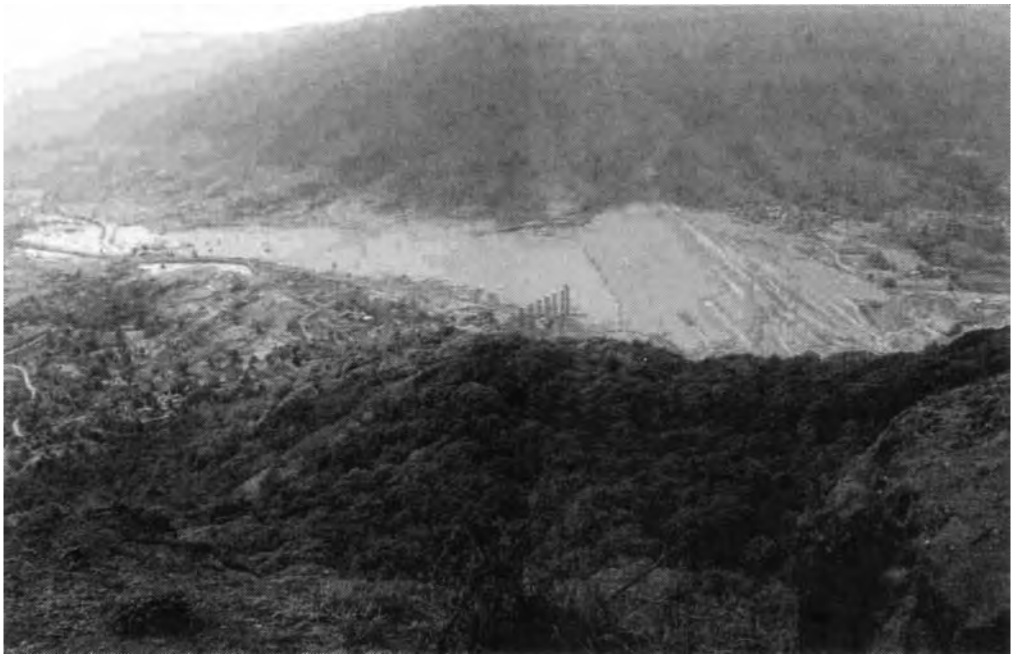


Fig.C.16: Basal land surrounded by mountains forming a catchment area.

Cat clays

Cat clays or **katteklei** are strongly acidic clays resulting from the aeration of anaerobic soils containing sulphide minerals. The sulphides present are oxidized to sulphates by chemical and bacterial actions, forming sulphuric acid. Hence, these soils have a higher acidity than pH 4.

Catena

A range of soils developed from similar parent materials of similar age and under similar climatic conditions is called catena. However, these soils may exhibit different characteristics owing to their differing drainage and relief patterns.

Catena is a fundamental concept which explains the pattern of soils on hill slopes. The term was coined by Milne to describe a repeating sequence of soils that are found between the top of a hill slope and the bottom of an adjacent valley.

There are two types of catenas. The first type occurs on hill slopes and is derived from a single kind of parent rock, despite which there is a sequential change in soils along the slope gradient. The change here is due to variations in subsurface drainage, lateral transport of sediments, and translocation of materials at or beneath the soil surface. The second type of catena also occurs on hill slopes which contain more than one type of parent rock due to variations in drainage and lateral transport.

Clarion-Nicolet-Webster soils that occupy 31,000 km^2 of the Des Moines Lobe in South Central Minnesota and North Central Iowa form a well studied catena.

Cathodic protection

The protection of iron or steel against corrosion (rusting) by using more reactive metals is known as cathodic protection or **sacrificial protection**. A common form of cathodic protection is galvanizing, in which the iron surface is coated with zinc. Even if the zinc layer is scratched the iron does not rust because zinc ions are formed in solution in preference to iron ions. Magnesium alloy is similarly used in protecting pipelines. (See also Corrosion.)

Cation

Cation is a positively charged ion and is adsorbed at negatively charged sites by electrostatic or coulombic attraction. When an atom loses its electrons and becomes a positive ion, it is called a cation. During electrolysis, cations are attracted to the cathode.

The process is as shown below:

$$\underset{\text{Calcium}}{\mathrm{Ca}\ (1S^2 2S^2 2P^6 3S^2)} \longrightarrow \underset{\text{Calcium ion}}{\mathrm{Ca}^{++}\ (1S^2 2S^2 2P^6)}$$

The most abundant cations in the soil are calcium, magnesium, hydrogen, sodium, potassium, aluminum and ammonium. The adsorbed cations resist their removal from the site or surface by leaching water, but can be exchanged by other cations in solution through mass action.

Cation exchange

The exchange of one **cation** by another is called cation exchange. This exchange takes place on the surface of clays, humus colloids and on the surfaces of plant root cell walls. Thus, if the soil is rich in sodium, as is the case in an alkali or alkaline soil, the application of gypsum causes calcium ions to exchange with sodium ions.

Cation exchange is an important factor in (a) soil fertility, (b) correcting soil acidity and basicity, (c) altering physical properties of soil, and (d) purification of water.

Plant nutrients such as calcium, magnesium and potassium are applied to plants mostly in exchangeable forms. Thus, soil acts as a cation exchanger. The nutrient cations like potassium, ammonium and calcium do not permeate far into the soil before they are adsorbed at the exchange sites. When water pollutants such as lead or cadmium are disposed of in the soil, they do not get leached but are adsorbed on the cation exchange sites. They may finally form insoluble hydroxides, carbonates or oxides.

When lime is added to neutralize acidic soils, most of the exchangeable hydrogen ions (H^+) and aluminum ions (Al^{3+}) are neutralized and this alters the pH. Even a temporary inundation of farmland by seawater replaces the soil calcium with sodium. A high proportion of sodium ions (Na^+) on the cation exchange sites of clays causes the breakdown of aggregates, altering the small dispersed particles which pass through the soil pores until they are lodged in the small openings. Soils with more than 15% of cation exchange sites occupied by sodium ion are undesirable for plant growth. (See also Cation exchange capacity.)

Cation exchange capacity

Cation exchange capacity (CEC) is the number of exchangeable cations per unit weight of dry soil. It is measured in milliequivalents of cations per 100 g of the soil (meq/100 g). The term milliequivalents is used because the number of negative sites in a given soil sample does not change, but the weights of the cations that may be adsorbed to those sites at a given time do change as they have different atomic weights. The quantities of exchangeable cations in most soils are large. The amounts of exchangeable ions present in soil up to normal rooting depths (30 to 90 cm) range from hundreds to thousands of kilograms per hectare. Cation exchange capacity is also commonly expressed in centimoles of positive charge per kilogram of soil (cmol [+]/ kg).

The extent of CEC varies with the amount of clay, the kind of clay and the quantity of humified organic matter. The capacity varies from 10 to 20 meq/100 g for clays such as kaolinite (found in tropical or subtropical areas), and goes up to 40 to 80 meq/100 g for clays such as montmorillonite (generally found in cooler temperate climates). Some tropical areas have very high CEC; for example, vertisols. CEC values for humified organic matter are much higher, touching 100 to 200 meq/100 g.

The measurement of CEC is complicated by (a) errors due to the dissolution of soluble salts, calcium **carbonate** ($CaCO_3$) and gypsum, (b) specific adsorption of potassium ions and ammonium ions (NH_4^+) in the interlayer position in vermiculites and micas, and (c) specific adsorption of trivalent cations such as aluminum (Al^{3+}) and ferric ions (Fe^{3+}) on the surface of soil particles. Errors can be reduced by using a method of CEC determination that employs reagents of similar concentration and pH to that of the soil analyzed.

The **barium chloride method** provides a rapid means of determining the exchangeable cations and the effective CEC of a wide range of soil types. In this method, CEC is calculated as a sum of the exchangeable cations (calcium, magnesium, potassium, sodium, aluminum, iron and manganese). This method is simple, rapid and particularly applicable to studies of environmental problems related to soils where information on the CEC at the pH of the soil in the field is of prime importance. However, this method is unsuitable for saline soil containing very high levels of sulphate (SO_4^{2-}), as barium sulphate ($BaSO_4$) precipitates.

The cation exchange capacity of a soil changes with its pH. All cations are not held or adsorbed with the same intensity of the force of attraction, nor do all the exchange sites have the same strength of negative charge at the particle surface. Some cations are held very tightly because of their relatively small size and/or higher charge per unit size. The most strongly held cation is hydrogen ion (H^+). The order of holding strength for some cations is:

$$H^+ \sim Al^{3+} \sim Ca^{2+} \sim Mg^{2+} > K^+ \sim NH_4^+ > Na^+$$

Cation exchange resins: See Anion exchange

Cationic resin

A cationic resin has built in positive ions and it exchanges negative ions. **Cation exchange** occurs with resins that have ionized acid side groups such as $-COO^-$ and $-OSO_2^{2-}$ with positive M^+ ions attached. Synthetic ion-exchange resins consist of various copolymers having a cross-linked three dimensional structure to which ionic groups are attached. (See also Ion exchange.)

Cationic surfactants

Cationic surfactants are one kind of surface active agents. They reduce surface tension and thus act as anticaking agents in fertilizers. Surfactants - anionic and cationic - function as crystal modifiers. Cationic surfactants, like fatty amine, act via three different mechanisms by (a) forming a hydrophobic coating on the surface of the particles, thereby improving the water repellency, (b) reducing capillary adhesion between particles, and (c) inhibiting nucleation or modifying crystal growth. (See also Anticaking agents.)

Cattle manure

The feces and urine and litter of cattle form cattle manure. Cattle manure is cool, wet but non-flowing. It decomposes more easily than horse manure. It also has less nitrogen loss than horse manure. Cattle manure is the most basic manure, generally accounting for the largest proportion in a manure mixture. When soil warmth is needed, horse and sheep dung is added to cow-dung. This manure contains half the amounts of ammonia and phosphorus contained in pig manure. Cattle manure has 0.55% K and is required in quantities of 105 kg per 90 square meters.

Causes du Quercy: See Phosphorite

Caustic-calcined magnesite

Caustic-calcined magnesite is a synonym for **magnesia**. (See also Magnesite.)

CCE

CCE is short for **calcium carbonate equivalent**. It expresses the relative chemical value of lime.

CD

CD is short for **coefficient of determination**, and is an indicator of the probability of occurrence of an event.

CDA sprayer

CDA sprayer is short for **control droplet applicator sprayer**.

CDU

CDU is short for **crotonylidene diurea**.

CEC

CEC is short for **cation exchange capacity**.

Cell

A cell is the basic structural and functional unit of an organism. Cell size varies, but most cells are microscopic (0.01 to 0.1mm) and consist of a mass of protoplasm, the hereditary material in the form of chromosomes in a nucleus, surrounded by a thin membrane called **plasma membrane**. The cell membrane regulates the exchange of materials in and out of the cell and plays an essential role in nervous transmission, contraction and interaction of cells with one another.

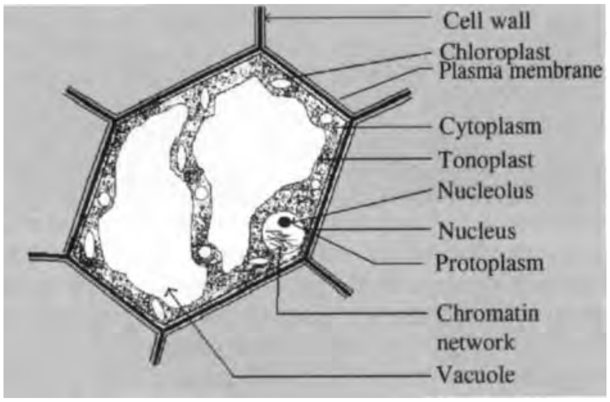


Fig. C.17: A cross-sectional view of a plant cell.

A cell wall is made up of cellulose in plants and chitin in fungi. The structure of a plant cell (Fig.C.17) is complex. Bacteria, certain algae, protozoa, yeasts and some fungal spores are single-celled organisms, whereas larger plants and animals contain millions of cells. Some of the plant cell structures and their important functions are given in Table-C.2.

Table-C.2: Plant cell structures and their functions.

Structure	Description	Function
Cell wall	Cellulose fibrils	Support and protection
Plasma membrane	Lipid bilayer with embedded proteins	Regulates passage of materials into and out of cell
Central vacuole	Fluid-filled sac	Storage of various substances
Nucleus	Bounded by nuclear envelope, contains chromatin	Control center of cell, directs protein synthesis and cell reproduction
Nucleolus	Concentrated area of RNA and protein within the nucleus	Ribosome formation
Ribosomes	Assembly of protein and RNA	Protein synthesis
Endoplasmic reticulum	Membranous channels	Transport and protein synthesis (rough ER)
Golgi apparatus	Stack of flattened membranous sacs	Processing and packaging of proteins; secretion
Chloroplast	Double membrane-bound; contains chloprophyll	Photosynthesis
Leucoplast	Colorless plastid	Storage of various materials, especially starch
Chromoplast	Pigmented plastid	Imparts color
Mitochondrion	Double membrane-bound	Cellular respiration
Microbodies	Vesicles	Various metabolic reactions
Cytoskeleton	Microtubules and microfilaments	Cell support and shape
Plasmodesmata	Cytoplasmic bridges	Movement of materials between cells

Source: "Plants and Society". 1996. Estelle Levetin and Karen McMahon. Wm. C. Brown Publishers. With permission from McGraw-Hill Education, New York.

Cellulose

Cellulose is a fibrous polysaccharide which consists of a long non-branched chain of glucose units (Fig.C.18). It is the main constituent of all plant cell walls, many algae and some fungi, and is responsible for providing rigidity to the cell wall. Normally, wood contains 40 to 50% cellulose. It is an important constituent of dietary fiber and occurs together with polysaccharides and hemicellulose derived from other sugars. In the woody parts of plants, cellulose is intimately mixed, and sometimes covalently linked with lignin. The extracted cellulose is used in the textile industry for the production of rayon, artificial silk, etc. because of its fibrous nature.

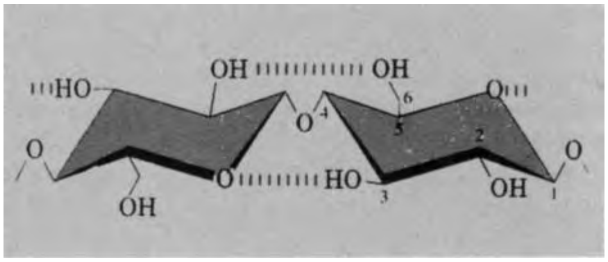


Fig.C.18: A part of the cellulose chain, with D-glucose units in (β1-4) linkage.

Cellulose exists in three forms - alpha (α), beta (β) and gamma (γ). Alpha cellulose has the highest degree of polymerization and is insoluble even in strong caustic soda solution. Cellulose is a polymer of β-D-glucopyranosyl units, which are linked to form chains of 2000 to 4000 units, eliminating water.

Cellulose of high purity is made from cotton. Using acetic anhydride, acetic acid and sulphuric acid, cellulose on acetylation forms **cellulose acetate**. There are many chemical modifications of cellulose, including its esters (cellulose acetate), ether (methylcellulose) and nitrated products (nitrocellulose), as well as rayon and cellophane (from cellulose xanthate). Thus, cellulose is the source of many plastics, fibers, coatings, varnish, lacquers, breakable glass, explosives and emulsion stabilizers. Alkali cellulose is an intermediatory product made by the action of sodium hydroxide solution on cellulose and is used for making cellulose ethers and rayon.

On acidulation with concentrated nitric and sulphuric acid, cellulose forms **cellulose nitrate**, also known as **nitrocellulose**, which is used in explosives and celluloid.

Cellulose acetate

Cellulose acetate is an ester in which cellulose (cotton linters or wood pulp) is treated with a mixture of acetic anhydride, acetic acid and concentrated sulphuric acid. This solution, when treated with water, forms a flocculent white mass of cellulose acetate which is used as a fiber and in lacquers, non-breakable glass and varnishes.

Cellulose nitrate

Cellulose nitrate is a highly flammable material made by treating cellulose (wood pulp) with a mixture of concentrated nitric acid and concentrated sulphuric acid. Despite the alternative name, **nitrocellulose**, cellulose nitrate is an ester of cellulose containing -ONO_2 groups and is not a nitro compound. It is used in explosives and celluloid.

Cell wall

Cell wall is the rigid outer layer that surrounds the cell membrane of cells of plant, fungi, algae and bacteria (but not animals). It protects and/or gives shape to the cell. In herbaceous plants, it provides mechanical support for the plant body. Most plant cell walls are composed of polysaccharide cellulose and are strengthened by lignin. The cell walls of fungi mainly consist of **chitin**. Bacterial cell walls consist of complex polymers of polysaccharides and amino acids.

The skeletal structure of the cell wall is made of cellulose. It serves as the first entry point for any material into the cell and regulates the movement of water throughout the plant, in addition to its major mechanical strengthening functions. It is sufficiently flexible and plastic to withstand mechanical stresses while permitting the growth of the cell. The cellulose of the cell wall is in the form of fibrils which are extremely fine fibers that can be seen under an electron microscope.

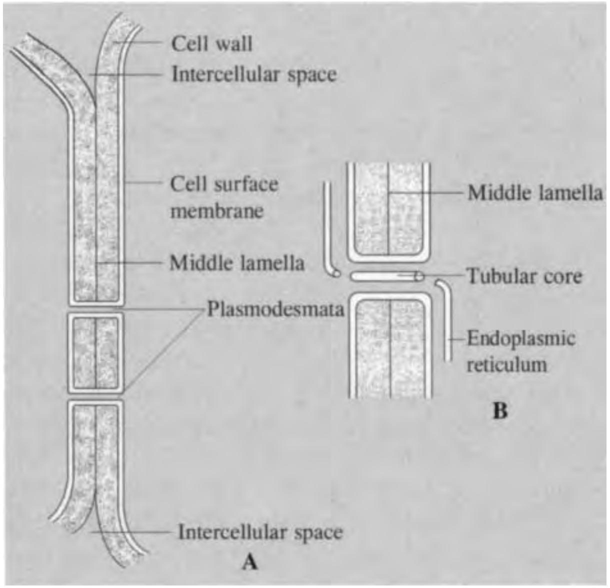


Fig.C.19: A. The rigid cell wall of a plant cell consists of cellulose microfibrils running through the matrix. B. Details of a plasmodesma.

Although the cell wall is one or two layers thick, it is not a solid structure. It has minute pores or pits which allow materials to pass through it which can be seen under a light microscope. Cytoplasmic connections, called **plasmodesmata**, occur between adjacent plant cells for the movement of materials from cell to cell (Fig.C.19). A sticky substance called **middle lamella**, composed of calcium pectate, glues the cells together.

Cementation of soil

Cementation is a digenetic process, by which clastic sediments are converted to rock through deposition or precipitation of minerals in spaces between the grains. As sediments are compacted, the matrix of fine silt and clay fuses and helps to bind the larger particles together.

Soil in which grains are made to adhere to each other by some material that acts as a cementing agent (such as calcium, colloidal clay, hydrated oxides of iron, silica and aluminum) is called cemented soil. Cemented soils become brittle and hard because of the cementing materials and fall into the categories of (a) weakly cemented, (b) strongly cemented, and (c) indurated soils.

The sediments are cemented together by chemicals left by the water in the original sediment. A soil layer with a hard and brittle consistency even when wet, caused by some cementing substances (like calcium carbonate, oxides of silica, iron, aluminum or humus), is termed cemented or **indurated**. A poorly cemented horizon can be broken by hand. A well cemented horizon can be broken only with difficulty; if it is strongly cemented it can be broken only with a hammer.

Cement kiln dust

Cement kiln dust is the potassium containing dust material formed during cement production. This is collected and used as fertilizer for its potassium and calcium content.

Central permanent: See Adventitious roots

Centrifuge

Centrifuge is an apparatus in which liquid suspensions are rotated at high speeds to separate the particulate matter from the liquid by centrifugal force. If various components of matter have different sedimentation coefficients, these are separated by removing the sedimented pellets at given intervals. During centrifugation, materials of similar densities can also be separated from a mixture of suspended materials.

Fig.C.20: A cooling, high-speed centrifuge.

The centrifuge has a chamber positioned over the axis, which rotates at high speed (e.g., 10,000 rpm or more) to impart high gravitational force (Fig.C.20). Materials of higher density are thrown toward the outer boundary of the chamber, while materials of lower density are concentrated at or near the inner portion. This technique is used effectively in a number of biological and industrial operations, such as the separation of components of blood, concentration of rubber latex and separation of fat from milk. The separation of isotopes, especially of uranium, is now possible by this method, and is used for producing enriched uranium.

Ultracentrifuge is an apparatus that develops centrifugal forces a few million times that of gravity and is used primarily in biochemical and molecular biology research to separate substances from a solution (Fig.C.21). Originally, ultracentrifuges were developed for analytical purposes to determine the size of colloidal particles.

Fig.C.21: An ultracentrifuge.

Cereals

All true cereals are members of the grass family. Gramineae (also called Poaceae) is the largest and economically most important family in the plant kingdom. Grasses grow everywhere - from sea level to high mountains, from the tropics to polar regions and from wet and humid areas to deserts and arid regions. About 50 species are cultivated worldwide, although 17 species alone provide 90% of human food and occupy about 75% of the total cultivated land on earth.

Domesticated cereals include wheat, rice, corn, barley, oats, sorghum, rye, *Elucine* sp. (ragi) and *Setavia*. (Fig.C.22). Triticale is a new cereal derived by crossing wheat with rye, followed by doubling of chromosomes.

Cereal crops are grown for their edible portion. Though botanically called **caryopsis**, they are popularly referred to as **grain**, **kernel** or **seed**. Cereal grains are the chief source of energy in our diet. They provide carbohydrate in the form of starch. Cereal grains provide 60% of the proteins consumed. Most cereal grains can be processed into malt, which can be used in a number of products and in the brewing process. A wide genetic variation exists among cereal crops, which offers considerable scope for future plant improvement through selection, breeding, bio-genetic engineering and induced mutation.

Fig.C.22: Cereals- A. Sorghum, B. Wheat, and C. Corn.

Ceylon agar

The **algae** from which **agar** is made in Sri Lanka is known as Ceylon agar or **Ceylon moss**. It refers to a dried red seaweed *Gracilaria lichenoides* found mainly in Sri Lanka.

Ceylon moss: See Ceylon agar

CGR

CGR is short for **crop growth rate**.

C-grade phosphate ore

Aluminum phosphate ore that occurs in Christmas Islands is called C-grade phosphate ore. Used as a fertilizer, it is mostly composed of aluminum and iron phosphates, and after calcination contains 29 to 33% phosphorus pentoxide (P_2O_5).

Chalk

Chalk is a soft, white or greyish porous limestone very rich in calcium carbonate. It is used as an agricultural liming material.

Chalk comprises essentially calcareous sedimentary remains of small marine organisms and shells in the sea, dating back to some 100 million years. It is found abundantly in the South East of England.

Chalk, in its rough or powdered form, is spread on land to correct effectively both soil acidity and calcium deficiency. Sometimes it is kiln-dried, finely ground and sold as lime.

Chalk is used in the manufacture of cement, crayons and fertilizers. (See also Calcium carbonate.)

Chamaephytes

Chamaephytes are woody shrubs and low plants which have low lying buds. These buds are less than 20 cm from the ground in cold areas and more than 100 cm from the ground in warm climates.

Chamaephytes is a class under the Raunkiaer classification system of plants based on the positioning of plant parts during unfavorable periods. The **Raunkiaer classification** is named after Danish botanist Christen Raunkiaer. It has four divisions, namely, phanerophytes, chamaephytes, hemicryptophytes and cryptophytes.

Chamaephytes are dwarf shrubs, usually found under the snow. They may be deciduous or evergreen. Examples of chamaephytes include *Andromeda polifolia* and *Calluna vulgaris*.

Charcoal

Charcoal is an amorphous form of carbon obtained by the destructive distillation of wood. It is used as an absorbent for gases and as a decolorizing agent in an activated form.

Chasmophytes

Plants that grow in rock crevices and fissures or on rocky ledges and rock faces are called chasmophytes. These plants are also called **chomophytes**. Chasmophytes are commonly seen in volcanic regions, coastal belts and dune areas. Such regions display hot and dry climates and sandy and rocky surroundings. *Cnidium japonicum*, *C. portulaca* and *Carex pumila* are examples of chasmophytes.

Check basin method of irrigation

An irrigation method in which relatively level plots are bunded on all sides is called check basin irrigation. It is widely used in pastures and orchards where each tree is within its own check basin.

Basin irrigation is not suitable for highly permeable soils, irregularly sloped land, very slowly permeable clays or for crops harmed by temporary flooding.

Chelate

A metal bound by an organic substance through two or more contacts, to form a ring of atoms including the metal is called a chelate. The organic molecule binding the metal in a ring structure is called **chelating agent** or **ligand**.

A chemical reaction involving a chelate ring formation is known as **chelation**. Chelation helps large amounts of metals to remain in a mobile form and facilitates movement of metals to the roots.

Chelation prevents the chemical effect of an ion without removing it from the solution. It is also a way of supplying ions in a protected form, as in the case of the removal of Ca^{++} ions as an EDTA complex in the water softening process.

Many functional groups of synthetic and naturally occurring organic compounds can form a coordinate bond to metal ions, producing metal-organic complexes or chelates, several of which are biologically active.

Chlorophyll, the green plant pigment, is the **magnesium chelate** of tetradentate ligand, whereas hemoglobin, is the oxygen transporter of the haem group of red blood cells, is an **iron chelate**.

Chelating agents play a very important role in biological systems. They function as critical trace metal carriers and also as sequestering agents. They can be used as aids in agriculture as they supply trace metals to deficient soils. For example, EDTA can be used as the carrier for bivalent metals such as Cu, Zn, Mn and Co. Using such carriers, certain plant deficiency diseases can also be controlled.

Ethylenediamine belongs to the bidentate group, while ethylenediaminetetraacetic acid (EDTA) is a polydentate ligand.

Chelate complex: See Chelate; EDDHA

Chelated fertilizer

A chelated fertilizer is one in which one or more micronutrient elements are held together by complex organic molecules namely, **chelating agents**. The solubility of all micronutrients (except chlorine and molybdenum) is reduced at higher (than neutral) pH, unless some special fertilizers are added.

Chelated fertilizers are water-soluble and stable complexes of metal ions, and belong to a class of special fertilizers. They may be used directly on the soil or sprayed through a water solution.

The effect of a single application of a fast-acting foliar **chelate** spray is not long lasting, so it requires quarterly spraying. Direct broadcast of chelates on the soil takes a longer time to act. This method of application requires 5 to 15 times more quantity of this expensive fertilizer than when sprayed.

The knowledge of chelate stability in soil provides the basis for developing a DTPA (diethylenetriaminepentaacetic acid) soil test for Fe, Zn, Cu and Mn. The **DTPA soil test** is calibrated for most crops and the general interpretation for extractable micronutrients is given in Fig.C.23.

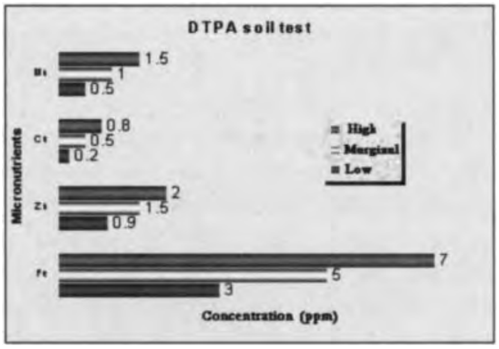


Fig.C.23: DTPA - extractable Fe, Zn, Cu and Mn.

DTPA has been the principal choice among a number of chelating agents because it has the most favorable combination of stability constants to obtain complexes of iron, manganese, copper and zinc. The extractant is highly pH dependent and buffered to pH 7.30 with triethanolamine and hydrochloric acid (HCl). The addition of 0.01M calcium chloride ($CaCl_2$) enables the extract to attain equilibrium with $CaCl_2$, so that it can minimize the dissolution of calcium carbonate ($CaCO_3$) from calcareous soils. DTPA-extracts of micronutrients from the soil correlate significantly well with plant uptake.

Some well-known chelate fertilizers are Zn-EDTA, Fe-EDDHA, Ca-EDTA and Cu-EDTA. The sodium-ferric salt of ethylenediaminetetraacetic acid (EDTA), known as **sequestrone**, is used in the prevention of **chlorosis** of plant leaves.

Chelating agents

Chelating agents or chelating **ligands** are organic molecules which contain atoms that can be attached to a metal ion to form a complex. This complex has a ring structure.

Chelation

A chemical reaction involving a **chelate** ring formation between a metal ion and an organic compound is known as chelation. (See also Chelate.)

Cheluviation

Cheluviation is a combination of **chelation** and **eluviation**. Cheluviation refers to the process of geometrical evolution by which minerals in the soil are weathered and decomposed under the action of the chelating organic, carboxylic and phenolic acids. This occurs mostly in cold climate zones, with an annual mean temperature of $<5°C$. Water, together with organic extracts, forms a chelate with sesquioxides in the soil and then moves down the soil profile carrying the oxides in solution.

Cheluviation is most effective in mobilizing iron and aluminum which are subject to leaching. In cheluviation, aluminum is also eliminated by way of weathering. In **soluviation**, in contrast to cheluviation, the weathering liquid does not contain chelating substances or acids. The weathering liquid is also not pure water, which would correspond to hydrolysis. In soluviation, aluminum is not eliminated through weathering, whereas silica is.

Chemical analysis

Chemical analysis is the determination of the composition of a chemical substance. The analysis may be either qualitative or quantitative.

Qualitative analysis determines the nature of an individual compound or compounds present in a mixture. Various chemical tests exist for identifying different elements and compounds, whereas systematic analytical procedures are usually used for mixtures.

Quantitative analysis involves measuring the proportions or quantities of known components in a mixture. Chemical analytical techniques fall into two main classes – volumetric and gravimetric.

There are also many physical techniques available for qualitative and quantitative analyses, such as spectroscopic techniques, mass spectrometry, polarography, chromatography and neutron activation analysis among others.

Chemical analysis is used to determine the need for soil fertilizers, or the compositional quality of fertilizers. Chemical analysis of plant tissues is used to assess the nutrient quantity as an index of the soil's ability to supply nutrients to crop plants.

Chemical combination, laws of

Chemical combination involves the combination of elements to give compounds. There are three **laws of chemical combination**. The **law of constant composition** (also called the **law of definite proportions** or the **law of constant proportions**) states that the proportion of elements in a compound is always the same, no matter how the compound is made. The **law of multiple proportions** states that when two elements X and Y form more than one compound, the mass of Y which combines with the fixed mass of X, are in simple proportion to each other. The **law of equivalent proportions** states that if each of the two elements X and Y forms a compound with a third element Z, then the compound of X and Y will contain X and Y in the relative proportions in which they react with Z.

Chemical compatibility of fertilizers

Compatibility is the ability of two or more materials to exist in close and prolonged association without any adverse effect of one on the other. Compatibility can be chemical or physical.

The chemical compatibility of a fertilizer is evaluated by a simple **bottle test**, a **large-bag test** or a **small-bag storage test**. In the bottle test for instance, a freshly blended fertilizer is kept sealed at 30°C and inspected at regular intervals for any wetting, caking, disintegration or obnoxious gas formation as a result of any chemical reaction between the ingredients in the blend. (See also Compatible.)

Chemical conditioners

Chemical conditioners are added to fertilizers during processing to improve the storage properties of the latter. They act as hardeners or crystal modifiers. For example, magnesium nitrate is added to ammonium nitrate to reduce the hygroscopicity of the latter. Similarly, formaldehyde is added to urea.

Chemical equilibrium : See Equilibrium

Chemical fertilizer

A fertilizer produced from inorganic or synthetic organic substances by chemical processes is called a chemical fertilizer. This includes single fertilizers, mixed fertilizers, compound fertilizers and organic fertilizers mixed with chemical fertilizers but excludes white lime, marl, plaster or gypsum. Each of these fertilizers may contain a certain percentage of one or more nutrient elements such as nitrogen, phosphorus and potassium.

Chemical laws

Chemical laws enunciate certain basic principles concerning the combining power and reaction characteristics of elements. Some of the important laws are listed below:

(i) **Law of mass action**: The rate of a homogeneous (uniform) chemical reaction at a constant temperature is proportional to the concentrations of the reacting substances.

(ii) **Law of definite or constant composition**: Any chemical compound invariably contains the same elements in the same fixed proportion by weight. However, exceptions to this law occur in solid compounds, such as silicates which are known as nonstoichiometric compounds.

(iii) **Law of multiple proportions**: When two elements unite to form two or more compounds (for example, nitrogen and oxygen can unite to form five oxides), the weight of one element combining with a given weight of the other is in the ratio of small whole numbers. Hydrogen and oxygen unite in the ratio of 1 to 8 in water and 1 to 16 in hydrogen peroxide. The weight of oxygen that reacts with one gram of hydrogen is in the ratio of 1 to 2.

(iv) **Law of conservation of mass**: Any chemical reaction between two or more elements or compounds leaves the total mass unchanged, the reaction products having exactly the same mass that was present in the reactants, regardless of the extent to which their other properties are changed.

(v) **Law of Avogadro**: Equal volumes of gases at constant temperature and pressure contain the same number of molecules, whether the gases are the same or different. 22.4 liters of any gas contain 6.02×10^{23} molecules.

Chemical messengers

Chemical messengers is another name for **hormones**.

Chemical oxygen demand

Chemical oxygen demand (**COD**) is a measure of the oxygen consuming capacity of inorganic and organic matter present in water and waste water. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specific test. The test is rapid and easy compared to calculating biochemical oxygen demand (**BOD**).

Chemical potential

Chemical potential refers to a thermodynamic function that expresses the ability of an uncharged atom or molecule in a chemical system to perform physical work.

Chemical potential is the change in Gibbs free energy with respect to change in the amount of a component, while pressure, temperature and amounts of other components remain constant. The components are in equilibrium if their chemical potentials are equal.

Chemical pruning of plants

Chemical pruning of plants is a method of controlling plant growth by applying non-nutrient chemical regulators which, when applied, influence the growth and development of plants. In ornamental plants, chemical pruning leads to more abundant flowering and improved branching.

Chemical weathering

Chemical weathering is the process by which rocks are decomposed, dissolved or loosened by chemical and biological processes. Chemical weathering alters the chemical structure of rocks. Major chemical weathering agents are water, oxygen and carbonic acid. An instance of chemical weathering is water combined with atmospheric carbon dioxide, that produces a weak carbonic acid. This weak carbonic acid dissolves soluble rocks and minerals.

Chemical weathering is aided by physical weathering since rocks heavily fractured and/or fragmented by physical processes are more easily amenable to chemical processes. (See also Weathering.)

Chemigation

Chemigation or **fertigation** is the application of pesticides or fertilizers through irrigation waters in either an open or closed system. The application of pesticides is called **herbigation**, **insectigation**, **fungigation** or **nemagation** depending on the nature of the pesticide. Nitrogen and sulphur are the principal nutrients applied by chemigation.

The advantages of chemigation include: (a) elimination of one or more field operations, (b) targetting nutrients, especially nitrogen, close to the time when the plant needs them most, and (c) correction of mid-seasonal deficiencies. Optimum results are obtained if the supply of fertilizers is made toward the middle of the irrigation operation and terminated shortly before its completion.

Foliar fertilizers are usually applied along with agricultural pesticides as these (a) lower the cost of application (pesticide spraying being necessary in any case), (b) reduce the stress caused by the application of pesticides, (c) improve the quality of pesticide spray liquids and stabilize them, (d) reduce evaporation at low air humidity to enable the fine droplets to reach the plant in a liquid form, and (e) lower the surface tension of water.

Some of the limitations of this system are: (i) It is not as effective as the surface application techniques for phosphorus and potassium. (ii) The application of fertilizer is not as uniform as that by water application. (iii) When pesticides are applied, it is sometimes difficult to control the area of application.

Chemisorption

Chemisorption is adsorption involving primary valence bonds. It is, therefore, stronger than physisorption where the bonding is by van der Waals forces. **Adsorption** is an important feature of surface reactions such as corrosion and heterogeneous catalysis. This property is also used in chromatography. (See also Adsorption.)

Chemoautotrophs

Chemoautotrophs are bacteria which derive their energy and nutrition from the oxidation of inorganic substances such as nitrogen, iron, sulphur and carbon from carbon dioxide. For example, *Thiobacillus* obtains energy by oxidizing hydrogen sulphide to sulphur. Other bacteria utilize energy from the oxidation of ferrous salts to their ferric form.

Chemodenitrification

Chemodenitrification is defined as denitrification that takes place in deep soil layers by chemical reactions. For example, reactions between nitrate (NO_3^-) and iron sulphide prevent the nitrate from entering groundwater, while contaminating it with sulphate.

Denitrification is a process of transforming nitrate either to nitrogen which is released to the atmosphere or to various oxides of nitrogen. This generally involves the action of microbes in the absence of oxygen (**anaerobic**).

Denitrification closes the nitrogen cycle and has four requirements: an anaerobic environment, the presence of nitrates, the presence of decomposable organic matter and the presence of denitrifying organisms.

In microbial denitrification, nitrates serve as the oxygen source for micro-organisms. Soluble organic carbon compounds are used for microbial growth. The loss of nitrate (by denitrification) can be reduced by blocking the nitrite (NO_2^-) formation by applying specific inhibitors such as nitrapyrin (2-chloro-6-trichloromethylpyridine), AM (2-amino-4-chloro-6-trimethylpyrimidine) or terrazole (5-ethoxy-3-trichloromethyl-1,2,4-thidiazole).

Chemoheterotrophic bacteria

Chemoheterotrophic is a subdivision of bacteria which obtains nutrition and energy from carbon in organic matter. Most soil bacteria belong to this group. It includes both nitrogen-fixing and non-nitrogen-fixing groups.

Chemoheterotrophic rhizobia: See Rhizobia

Chemolithotrophic sulphur bacteria

Chemolithotrophic sulphur bacteria is a class of bacteria involved in sulphur oxidation. For example, thiobacilli utilize the energy released from the oxidation of inorganic sulphur for the oxidation of carbon to carbon dioxide in organic matter. (See also *Thiobacillus*.)

Chernozem

Chernozem is an isohumic soil, rich in deeply incorporated organic matter and with a crumb structure. It is black or dark brown in color and derives its name from the Russian word for black earth.

Chernozem characterizes a slightly arid climate. Marked seasonal contrasts are essential for its genesis. Being stone-free and located on extensive flat and gently sloping terrains, it forms excellent agricultural soils. Chernozem is extensively used for cereal cultivation. Chernozem is very deep and may go upto 6 meters in some places.

Chernozemic soils

Chernozemic soils belong to a class of soil classification based on the nature of cations adsorbed by organic and inorganic soil colloids. These soils contain calcium in the adsorbing complex.

Chilean nitrate

Chilean nitrate is a commercial product containing more than 96% sodium nitrate. Its name is derived from the ore deposits found in Chile.

Chilean saltpeter

Chilean saltpeter is another name for sodium nitrate or **Chilean nitrate**. It contains 16% nitrogen and 26% sodium, and is one of the oldest nitrogen fertilizers known and used.

Chinese moss: See Agar-agar

Chiselling

Chiselling is the process by which soil layers are stirred or mixed with the help of a chisel cultivator or chisel plow, without inverting various soil layers.

Chisso-Asahi process

The Chisso-Asahi process produces a smooth coating of polymers for fertilizers. These polymer-coated, controlled-release fertilizers control the rate of nutrient release by means of the composition and thickness of the polymer coating. A hot solution 5% by weight of the coating material in a hydrocarbon solvent or chlorinated hydrocarbon solvent is sprayed on warm granules of fertilizers in a fluid bed drier and the solvent is then evaporated. Polyolefins, ethylene-vinyl acetate copolymers, etc. are used as coating materials. The incorporation of finely-divided materials such as talc and silica into the coating makes it possible to produce controlled-release fertilizers.

Chitin

Chitin is a polysaccharide comprising chains of N-acetyl-D-glucosamine, a derivative of glucose, linked by β-1, 4 bonds and containing about 77 nitrogen atoms. It may be visualized as cellulose in which the hydroxyl groups on the second carbon are replaced by $-NHCOCH_3$ groups (Fig.C.24). Chitin is structurally very similar to cellulose and serves to strengthen various invertebrates. It offers resistance to chemicals and is present in the cell wall of some fungi as well as in the exoskeleton of insects.

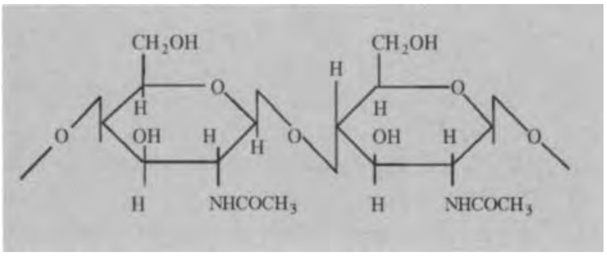


Fig.C.24: Structure of β-N-acetyl-D-glucosamine unit of chitin.

Chloride waters

Chlorides are salts of chlorine and a metal. Some common chloride salts are sodium chloride and magnesium chloride.

The quality of irrigation water is one of the key factors to be understood in irrigated agriculture. Chloride salts are commonly found in irrigated water and along coastal regions. And since irrigation water has a component of recycled and treated water, most crops face the risk of chloride toxicity.

Chloride salts enter plants through the roots and leaves. High temperature and high evapotranspiration rates increase the chloride concentration in plants. Thus, sprinkler irrigation can also contribute toward toxicity levels. These salts affect the physical and chemical properties of the soil, and hence crop growth.

Knowledge of crop sensitivity to chloride is very essential in view of the composition of irrigated water. Chloride levels of around 250 mg/liter are considered normal. Tobacco displays very low tolerance (below 50 mg/liter) to chlorides. Almonds, apricots, plums, avocadoes and strawberries are very sensitive and cannot tolerate > 180 mg/liter. The chloride content in water in the range of 180 to 700 mg/liter is suited to moderately sensitive (tomato and grape) to moderately tolerant (barley, corn and alfalfa). Crops that can tolerate very high amounts of chlorides include cauliflower, cotton, sunflower, safflower, sesame and sorghum.

Care has to be taken to ensure proper crop planning, based on the chloride content in water, especially because a chloride hazard is confused with a salinity hazard.

According to the FAO guidelines for quality of irrigation water, the chloride content of water less than 3 mmol/l is safe. Chloride concentration above 3 mmol/l creates moderate problems, but if the concentration goes above 10 mmol/l, it can cause severe problem.

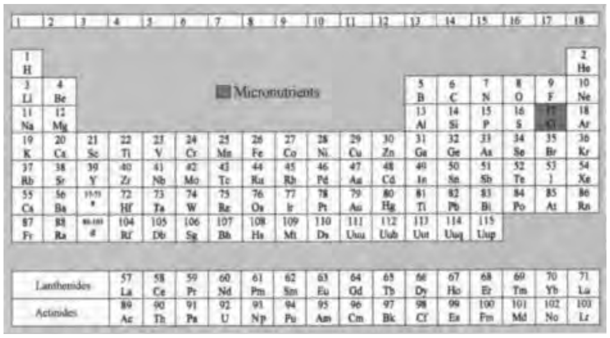


Fig.C.25: Position of chlorine, a micronutrient element, in the Periodic Table.

Chlorine

Chlorine (Cl) is a halogen, classified in Group 17 (formerly VII), Period 3 of the Periodic Table of elements. It is a greenish yellow gas and has an atomic weight of 35.5 (Fig.C.25).

Chlorine is one of the essential elements for plants, although it is not always listed as a micronutrient. It is absorbed in soil almost entirely as chloride ions (Cl^-) which are very mobile, soluble and mostly non-reactive in soil. The role of chlorine in plants is believed to be biochemical, osmotic and in balancing cell cationic charges.

Plants responding to chloride are tomato, pea, lettuce, cabbage, carrot, sugar beet, barley, corn, berries, vine crops, potato, cotton, woody ornamental plants and fruit trees like coconut.

Chlorine is involved in the splitting of water molecules in photoreaction II of photosynthesis. Several enzymes such as ATPase, alpha-amylase and asparagine synthetase require the chloride ion for activation. As the chloride ion is very mobile and is tolerated at high concentrations, it is ideal for maintaining the charge balance when cations (such as potassium) move across cell membranes. The chloride requirement of plants for biochemical functions is hardly more than 100 mg/kg of dry plant matter. However, chloride is usually present at much higher concentrations (2000 to 20,000 mg/kg), suggesting its involvement in functions other than those of a biochemical nature.

The chloride content in plants ranges from 0.2 to 2.0% but in some salt tolerant plants it can be as high as 10%. Excessive chloride accumulation is harmful to plants, causing the leaves to thicken and roll, lowering the quality of potato tubers and the smoking quality of tobacco. If plants sensitive to chloride receive more than 1 to 2% chloride ions (Cl^-), yields are often reduced.

The environment entertains the **chlorine cycle**. Air, water and soil are at the receiving end of the cycle. For instance, air gets chloride from volcanoes and sea spray, whereas water receives chloride from sewage, food, water-softener wastes, industrial effluents and de-icing salts used on roads. Soil gets its chloride supply from animal manure, rainfall, irrigation waters and potassium chloride fertilizers.

Chlorine in soil follows water movements and is taken up by plants as the chloride (Cl^-) anion. The greater the chloride concentration in a soil solution, the higher the plant uptake. It may also be taken up aerially as Cl^- anion or chlorine gas. Chloride, highly mobile in plants, is required in the splitting of water (Hill reaction) during photosynthesis. It enhances oxygen synthesis and photophosphorylation. The accumulation of excessive chloride ions can be toxic. Foliar sprays with chloride-containing irrigation water, if left to dry on the leaves, may cause salt burn.

Since field plots do not display any chloride deficiency and most fertilizers have some chloride (as contaminant), not much is done for chloride rectification. More studies are required to find out the effect of large additions of chloride ions (30 to 50 kg/ha).

The symptoms of chloride deficiency are not easily identifiable. In nutrient cultures, it was shown that chlorine deficiency is associated with a reduced root growth. **Chlorosis** in younger leaves and an overall wilting of the plants are the two most common symptoms of chlorine deficiency. Necrosis in some plant parts and leaf bronzing may also be witnessed. Excessive chlorine can be harmful but crops vary widely in their tolerance. The principal effect of too much chlorine is to increase the osmotic pressure of soil water and thereby lower the availability of water to plants.

Table-C.3: Plant disease suppression using chloride fertilizers.

Crop	Diseases suppressed and other benefits	Preferred Chloride fertilizers
Asparagus	*Fusarium* crown, Root Rot Suppresses weeds	NaCl
Barley	Common Root Rot Prevents lodging Strengthens straw	NaCl, KCl
Sugar Beet, Table Beet	Rhizoctonia root rot	NaCl, KCl, $CaCl_2$, $MgCl_2$
Coconut and Date Palms	Leaf spot diseases	NaCl
Corn	Stalk rot, Smut	NaCl, KCl
Wheat	Stripe rust, Take all Promotes healthy stands	NaCl, KCl
Pearl Millet	Downy mildew	NaCl

Chlorine in fertilizers suppresses many diseases (Table-C.3). Adequate quantities of chloride-containing fertilizers can mitigate diseases like 'take all root rot', 'stripe rusts', 'leaf rust', 'tan spot of wheat', etc. A moderately excess quantity of chloride is employed to fight such diseases (many times above the nutritional needs). For example, chloride banding of 40 kg/ha is recommended to reduce 'take all root rot' on winter wheat in western countries.

Potassium chloride, which contains large quantities of chloride, is a widely used fertilizer. Ammonium chloride, calcium chloride, magnesium chloride and sodium chloride are other sources of chlorine.

Chlorine cycle

The chlorine cycle, like the nitrogen or phosphorus cycle, is a complex cycle. Air, water and soil are at the receiving end. For instance, air gets chloride from volcanoes and salt spray from the seas. Water receives its quota of chlorides from sewage, food, water-softener wastes, industrial effluents and de-icing salts used on roads. Soil gets its chloride from animal manure, rainfall, irrigation water and potassium chloride fertilizers.

Chlorine in soil follows the movement of water. Plants take up chlorine as chloride ions. The greater the presence of ions in the soil, the greater the plant uptake. Chlorine can also be taken by the plant from the air.

Chloride, being very mobile in plants, helps in splitting water (Hill reaction), enhancing oxygen synthesis as well as photophosphorylation. When human beings or animals eat plants, or when plant residues are burned, they release chloride to complete the cycle. (See also Chlorine.)

Chlorine deficiency

Chlorine deficiency is caused by insufficient amounts of this nutrient element in the soil, in a form usable by the plants. As in the case of other elements, deficiency symptoms vary from plant to plant. Common symptoms, characteristic of chlorine deficiency, are wilting of the leaf blade tips, followed by **chlorosis**, bronzing and necrosis. A restricted root growth with stubby, club-tipped laterals is also characteristic of chlorine deficiency.

Coconut palm trees deficient in chloride have older leaves with yellow and/or orange mottling and dried leaf tips and edges. (See also Chlorine.)

Chlorite

Chlorite is a group of greenish clay minerals of variable composition (similar to mica in structure), which crystallizes in the monoclinic system. The term chlorite is derived from 'chloros', the Greek word for green.

Chlorites are composed of complex silicates of aluminum, magnesium and iron in combination with water, with the general formula :

$$(Mg_{2.6}Fe^{3+}_{0.4})^{+0.4}\,(Si_{2.5}\,Al/Fe_{1.5})^{-1.5}O_{10}(OH)_2$$

These are often called 2:2 type clays because they are similar to the unit lattice of vermiculite. But strictly speaking, they are 2:1:1 type clays. A layer of chlorite has 2 silicate tetrahedral units, one alumina octahedral unit and one magnesium octahedral sheet. It has a low **cation exchange capacity**. Chlorites are most commonly found in low-grade metamorphic rocks. They also occur as secondary minerals in igneous rocks as alteration products of pyroxenes, amphiboles and micas.

Chlorites are infrequent in soils and when present, make up a small fraction of clay minerals. Chlorites are primary minerals and form vermiculites and smectites. Chlorites do not swell on wetting.

Chlorophyll

Chlorophyll is a green pigment found in plants, algae and some bacteria. It is a complex **chelate of magnesium** containing porphyrins . It is a magnesium complex of the phytil ester of porphyrin propionic acid. These pigments belong to the tetrapyrrole family of organic compounds. Genetic and environmental differences alter the relative amounts of chlorophyll pigment production and also produce leaves, ranging in color from dark green to yellow. The principal chlorophyll is chlorophyll-a (Fig.C.26), found in oxygen evolving organisms.

The leaf chlorophyll content is related to nitrogen nutrition; therefore, the relative chlorophyll content can serve as an indication of the nitrogen status of the plant. A hand-held **chlorophyll meter** provides an indication of the leaf nitrogen status of the crop.

Chlorophyll molecules have three functions. They serve as an antenna to absorb light quanta; they transmit this energy from one chlorophyll molecule to another by a process of 'resonance transfer' till finally the chlorophyll molecule, in close association with enzymes, undergoes chemical oxidation. The resulting electron of high potential is ejected from the molecule; this electron can then be made to perform biochemical work (that is, reduction of another compound). Thus, the energy of light quanta is converted to chemical energy.

Chlorophylls a, b, c, d and e, bacteriochlorophyll and bacterioviridin are all chlorophyll pigments. Chlorophyll-a and chlorophyll-b are abundant in higher plants. Chlorophyll-a contains a methyl group and chlorophyll-b contains an aldehyde group at C_3 atom.

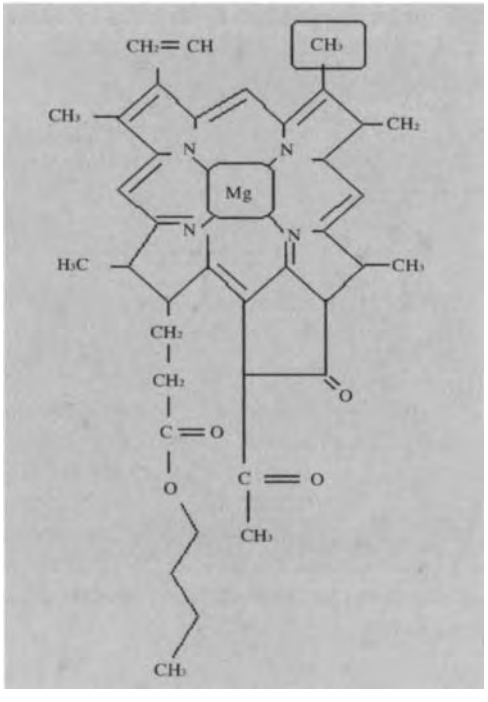


Fig. C.26: A structural formula of the chlorophyll-a molecule.

Chlorophyll meter

A chlorophyll meter measures the chlorophyll content in a plant, without damaging it. A chlorophyll meter provides an indication of the leaf nitrogen status of the crop. Chlorophyll meter readings do not directly indicate the chlorophyll content, but the value recorded can be related to the percentage nitrogen in the leaf and grain yield as influenced by the nitrogen rate. For nitrogen management purposes, in corn, for instance, chlorophyll readings have greater value at V8 stage, because the addition of nitrogen fertilizer at this stage increases the yield, as compared to the addition of nitrogen at the silking stage.

The advantages of early season chlorophyll meter testing are that (a) the readings are quick, easy to read and provide instantaneous values, (b) no samples need to be collected, and analysed (c) the only cost of sampling is labor, and (d) nitrogen recommendations are accurate. The disadvantages are that (a) the initial expense is high, (b) the early season corn leaf chlorophyll levels are affected by hybrid selection and environmental stresses, and (c) the chlorophyll meter test is not applicable to fields that have received pre-plant or at-plant nitrogen fertilizer applications beyond the starter nitrogen.

Chloroplast

Chloroplasts are chlorophyll-containing organelles in plant cells that perform photosynthesis. They are lens-shaped and bounded by a double membrane. Chloroplasts contain membranous structures called **thylakoids** (Fig.C.27) which are surrounded by a gel-like matrix (stroma). The light reaction of photosynthesis occurs on the thylakoid membranes, while the dark reaction takes place in the stroma.

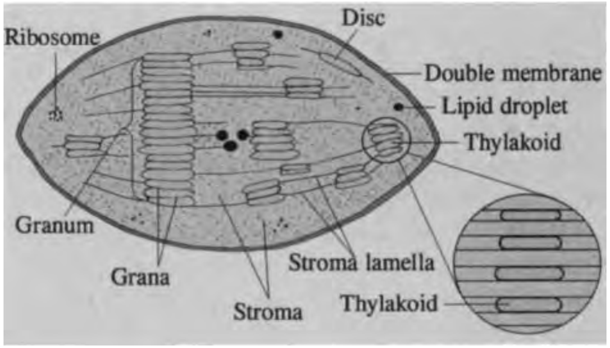


Fig. C.27: A schematic of chloroplast. The inset shows a portion of grana with large and small thylakoids.

Chlorosis

Chlorosis is a loss of green color accompanied by paleness and yellow coloration of tissue, caused by the loss of protein nitrogen from chloroplasts in green leaves.

Chlorosis may be due to the deficiency of nitrogen, magnesium, iron, manganese, zinc, etc. (Fig.C.28). It can also be caused due to fungi, viruses, nematodes, etc. The inadequacy of light, magnesium or iron, or an excess of calcium carbonate prevents chlorophyll formation. When chlorophyll formation is prevented by excess calcium carbonate, the condition is called **lime induced chlorosis**. Chlorosis commonly appears first in the lower leaves; when nitrogen deficiency is severe, the lower leaves turn brown and die.

Fig. C.28: Interveinal chlorosis of young leaves in beans.

The tendency of the younger upper leaves to remain green even as the lower ones turn yellow or die is an indication of the mobility of nitrogen in the plant. When plant roots are unable to absorb nitrogen, proteins in the old plant leaves are converted into soluble nitrogen for synthesis of new proteins.

Chlorosis is also called **green sickness**. (See also Iron.)

Chomophyte

Chomophyte is another word for **chasmophyte**.

C horizon

C horizon represents the parent material of soils from which solum is developed. It is a mineral layer or horizon which remains relatively unaffected by pedogenic processes. It does not exhibit the properties of O, E, A or B horizons. In the absence of **pedogenesis**, a C horizon can be altered by natural processes such as **weathering** or gleying, or by a reversible cementation, accumulation of carbonates of calcium or magnesium or cementation by alkali-soluble siliceous materials.

Christian (Hans) procedure for Gram staining:

See Gram staining

Chromatography

Chromatography is a term used for a group of laboratory techniques involving the separation of mixtures. Chromatography deals with the separation of a mixture by passing it in solution or suspension through a medium in which the components move at different rates. Accordingly, chromatography uses a set of separation techniques, the principle of which is based on selective absorption to identify the components of complex mixtures (vapors, liquids, solutions). Tswett, the inventor of the first chromatography technique, named it chromatography, because the plant pigments used in the early experiments produced bands of characteristic colors. Since then the method has been widely applied to many varieties of compounds, including colorless mixtures of hydrocarbons and metallic salts. The separation is due to redistribution of the molecules of the mixture between the thin phase (adsorption layer) and the bulk phase (adsorbent) in contact with it. As the latter phase sometimes approaches molecular dimensions, the size and shape of the molecules of the mixture are of great significance.

Chromatography involves the flow of a mobile (gas or liquid) phase over a stationary phase (solid or liquid). Liquid chromatography is used for soluble substances and gas chromatography for volatile substances. As the mobile phase moves past the stationary phase, there is repeated adsorption and desorption of the solute taking place at a rate determined chiefly by the ratio of distribution between the two phases. If the ratio is large enough, the components of the mixture will move at different rates, producing a series of bands (chromatographs) by which their identity can be determined.

Chromosequence

A complex unit of soils, the succession of which is constantly found in a defined order without any apparent genetic link between them, is called a **soil sequence**. The regular succession of soil is due to the preponderance and sustained influence of one of the factors of soil formation. When the differentiation is caused by a predominant pedogenic factor such as variation in color, it is called chromosequence.

Chronic toxicity

Chronic toxicity refers to prolonged exposure to a toxic substance. (See also Acute toxicity.)

Chronosequence

Chronosequence is sequence of soils that changes gradually from one to the other with time. (See also Chromosequence.)

CII

CII is short for **cropping intensity index**.

Ciliates

Ciliates are the most prominent group of protists and are a type of protozoa. Ciliates are commonly found in water bodies. They are unicellular, essentially aquatic, microscopic, eukaryotic organisms without a true cell wall, classified in various phyla of kingdom-Protoctista. They are called ciliates because of the large number of hair-like structures on their surfaces. **Protozoa** range in size from 1 to 106 μm.

Citrate-insoluble phosphorus in fertilizers

Phosphate in fertilizers is present in more than one form of the orthophosphate ion. Because these forms differ in their solubility, specific terms are used, such as **water-soluble, citrate-soluble**, citrate-insoluble and available as **total phosphorus**. Generally, neutral ammonium citrate is used for extracting the phosphorus from a fertilizer or soil. The residue remaining after citrate extraction is citrate-insoluble phosphorus.

The difference between the total phosphorus and citrate-insoluble phosphorus gives the amount of available phosphorus. (See also Phosphorus available form.)

Citrate-soluble phosphorus

The solubility of phosphorus in different phosphate fertilizers varies. **Plant available phosphorus** shows the extent to which phosphorus is absorbed by plants under conditions otherwise favorable for growth.

Phosphorus in fertilizers can be water-soluble, citrate-soluble, citrate-insoluble or available as total phosphorus (as P_2O_5). There are various chemical methods to estimate phosphorus availability in plants and its concentration in soils, plants, minerals and living tissues.

Most countries define water-soluble phosphates as the components that go into solution at room temperature when an aqueous suspension is made with 1 g of soil sample in 50 ml of suspension volume (in the USA, the proportion is 1 g soil in 250 ml suspension). The slurry is then filtered and the amount of phosphorus contained in the filtrate determined. The amount of phosphorus in the sample is expressed as the percentage by weight that is water-soluble.

The technique of citrate extraction determines phosphates such as $CaHPO_4$, which are insoluble in water but soluble in citrate salt solutions. In Europe, the most common techniques use ammonium citrate solutions (1N). Extraction is done in a strong alkaline medium or neutral citrate solution. Usually, the extraction is carried out for 30 minutes at room temperature and is followed by treatment at 40°C. 65°C is the prescribed temperature for neutral citrate extraction. The phosphorus content in the filtrate is referred to as citrate-soluble. The sum of water-soluble and citrate-soluble phosphorus represents an estimate of the fraction available to plants, and is termed **available phosphorus**. Most countries in the world use neutral ammonium citrate solution for extracting citrate-soluble phosphorus.

The lack of correlation between the plant availability of P_2O_5 and its solubility in ammoniacal citrate solution has led to other straight and mixed phosphate fertilizers being rated on the basis of their citric acid solubility. The treatment with 2% by weight citric acid solution (5 g agitated with 500 ml of citric acid solution for 30 min at 20°C) dissolves phosphorus-silicon heteropolyacids, which are hardly soluble in complex-forming solutions.

Citrate-soluble phosphorus content

Citrate-soluble phosphorus content denotes the phosphorus content in fertilizers. The residue, after water extraction, is extracted with 1N neutral ammonium citrate for a particular period. The phosphorus content in the extract is determined and is called the citrate-soluble phosphorus content. Along with water-soluble phosphorus content, it yields the total available content.

Citric acid cycle

The citric acid cycle, also known as **Krebs cycle**, is a cycle of reactions. It plays a major role in the metabolism of many heterotrophic micro-organisms capable of respiratory metabolism. An enzyme converts pyruvic acid to carbon dioxide in the presence of oxygen, simultaneously releasing energy which is captured in ATP molecules. Two molecules of carbon dioxide are eliminated during each cycle.

The citric acid cycle is also known as the **tricarboxylic acid cycle**. (See also Krebs cycle.)

City tankage: See Garbage tankage

Clamp

Clamp is the traditional form of storing potatoes or other root crops by neatly piling them and covering them with earth and straw. It is now mostly replaced by indoor storage, which is known by such names as **hog**, **bury**, **grave**, **pie** and **pit**.

A surface heap of silage, either walled or un-walled, using wooden boards, railway sleepers or concrete to reduce side wastage is also called a clamp. Some silage clamps are constructed underground, and are known as pits.

Clamps are often enclosed in polythene and the air is evacuated so that the carbon dioxide accumulation minimizes respiration losses, and reduce the likelihood of fermentation.

Clarification: See Clarifying agent

Clarifying agent

A clarifying agent is an agent that removes fine particles of solids to improve the quality of the liquid; the process is known as **clarification**. Clarification is used in the manufacture of pharmaceuticals, beverages, fiber and film polymers. It is also used in the purification of drinking water and waste water.

Clarity measurements of solution fertilizer

The clarity measure of a solution fertilizer is the amount of visible light that passes through a sample without being absorbed. It is expressed as the percentage of light transmitted at the desired wavelength of the absorption spectrum. A liquid with 25% light transmission, compared to 100% transmission for distilled water, is acceptable. Clarity measurements are made using a spectrophotometer.

Clarity measures are used for **fluid fertilizers** produced from wet-process phosphoric acids, which are derived from uncalcined phosphate ores, and are black in color because of the presence of finely divided carbonaceous material. The carbonaceous material does not affect the nutrient value but makes identification difficult, and clogs the equipment.

Classification of nitrogen fertilizers

Nitrogen fertilizers are divided into four groups based on the chemical form of nitrogen present. These are listed below.

Nitrate fertilizers: In these fertilizers, nitrogen is present in the form of nitrates. Examples are sodium nitrate and calcium nitrate. Nitrate fertilizers are made from natural salt deposits or by the oxidation of ammonia. Nitrate salts dissociate easily in soil solution, and hence are available for plant absorption. There is also a greater possibility of the nitrate salt getting leached out by rainwater. Nitrate fertilizers are used for top and side dressings. As nitrates are basic, they play a significant role in reducing soil acidity.

Ammonium fertilizers: Here, nitrogen is present in an ammonium ion form, such as in ammonium sulphate, ammonium chloride, ammonium phosphate, anhydrous ammonia and ammonia solution. Though ammonium fertilizers are readily soluble in water, they are less rapidly used up compared to nitrate fertilizers as ammonium has to be converted to nitrate before absorption. These fertilizers are not easily lost by leaching and leave acidic residual effects in the soil.

Nitrate and ammonium fertilizers: Nitrogen is present in these fertilizers in both the nitrate and ammonium forms, such as in ammonium nitrate, calcium ammonium nitrate and ammonium nitrate sulphate. Fertilizers of this group are readily soluble in water and suitable for a variety of soils and crops. They leave an acidic residual effect in the soil.

Amide fertilizers: In these fertilizers, nitrogen is present in an amide form, such as in urea and calcium cyanamide. These fertilizers are soluble in water and readily converted into ammoniacal nitrogen by micro-organisms.

Clay complex

Clays have a net negative charge which attracts positive ions. Specific ions fit into mineral lattices of clay depending on their size and charge. The negative charges in the crystal lattices are the sites of **cation exchange**. The clay fraction on which the cation exchange sites are located is called the clay complex.

Clayey soil, irrigation of: See Irrigation of clayey soil

Clay film

Clay films are coatings of clay on surfaces of soil peds and mineral grains. The coatings can be classified according to the type of surface affected (grain, aggregates, channel, crack, void and chamber vesicle).

Clay-humus complex

A clay-humus complex is formed by electrostatic or other bonds between clays and humic components of the soil. **Humus micelles**, which are electronegative, like clays, cannot be held directly on to clay. The elementary unit of the structure essentially consists of a condensed aromatic nucleus, forming a layer closely bound to the clay sheet via cations of calcium, iron, aluminum etc.

The bonding energy between clay and humus depends on the nature of the organic molecules adsorbed as well as on the nature of the clay, the bonding cations and the physico-chemical condition of the medium (pH, soil, climate, etc.). The elementary units are bound together by humic acids that form very weak bonds and thus, create these porous structures.

The clay-humus complex is chemically active. It exchanges nutrients which are then made available to plants with hydrogen ions (H^+) generated during the decomposition of the organic matter. This occurs partly because of a mass-action effect and partly because, under comparable conditions, hydrogen ions are adsorbed more strongly than calcium ions (Ca^{2+}) or other nutrient ions.

Clay minerals

Clay minerals or **layer silicates** are a group of aluminosilicates that are composed of layers of hydrated aluminum and magnesium silicates. They form a crystal lattice. Broadly, there are two major kinds of clay minerals: (a) minerals which have one layer each of silicon (Si)-tetrahedra and aluminum (Al) octahedra (1:1 layer silicates), and (b) minerals which have one layer of aluminum (Al) octahedra and two layers of silica-tetrahedra (2:1 layer silicates). The ultimate chemical constituents of the clay minerals vary not only in amount but also in the way they are combined in various clay minerals.

The following classification into two major subdivisions – amorphous and crystalline – has proved useful.

(I) Amorphous

(A) Allophane group

(II) Crystalline

(A) Two-layer type (1:1 type sheet structures, composed of units of one layer of silicon (Si) tetrahedrons and one layer of alumina octahedrons)

  (i) Equidimensional – kaolinite group

  (ii) Elongate – halloysite group

(B) Three-layer type (2:1 type sheet structure, composed of two layers of silica tetrahedras and one central dioctahedral or trioctahedral layer)

  (a) 2:1 Expanding structures
  (i) Equidimensional – montmorillonite group, vermiculite
  (ii) Elongate – montmorillonite
  (b) 2:1 Non-expanding structure
    (i) Illite group

(C) Regular mixed-layer types (ordered stacking of alternate structural types) – chlorite group.

(D) Chain-structure types (similar to hornblend – chains of silica tetrahedrons linked together by octahedral groups of oxygen and hydroxyls containing aluminum and magnesium atoms) – attapulgite, sepiolite, palygorskite.

The varied properties of clay minerals are important in view of their wide economic uses. Important properties of clay minerals are that (a) they can hold certain cations and anions, which are readily exchangeable for other cations and anions (the ion exchange property, for example, helps soils to retain potash in clay minerals in the soil), (b) their ability to hold water, and (c) their ability to react with organic materials. Clays with a high adsorbing capacity are used in decolorizing oils, while others provide catalysts in the breakdown of organic compounds.

Clays exist in many forms. For example, **Kaolinite** and **montmorillonite**, which are clay minerals, have different layer structures, differing abilities to absorb and retain water, and differing abilities to adsorb and exchange cations.

Productivity of soil depends to a certain extent on the nature of its mineral content and its ability to retain (and subsequently release for crop use) the cations, particularly those applied in fertilizers.

Clay minerals are responsible for the plastic properties of clay. Schematic diagrams of 1:1 and 2:1 layer silicates are given in Fig.C.29.

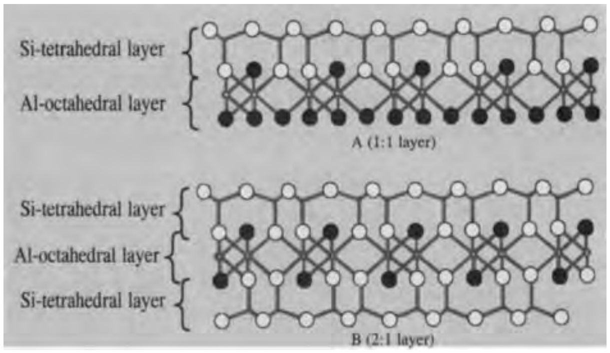


Fig.C.29: A schematic drawing of crystal lattice showing: A. 1:1 layer silicate, and B. 2:1 layer silicate.

Three planes of anion found in 1:1 layer silicate are: (a) basal plane of oxygen, formed by the bases of a silicon (Si) tetrahedral sheet, (b) a central plane of hydroxyls of aluminum (Al) octahedral sheet and shared oxygens of tetrahedral sheet, and (c) a top plane of hydroxyls of aluminum ions (Al^{3+}) octahedral sheet. The tetrahedral and octahedral cations occupy their appropriate places. In 2:1 layer silicates, there are four planes of anions, oxygen and hydroxyl (O, OH).

Clay pan

A dense horizon which has more clay accumulation (resulting from leaching of the surface horizon) than the horizon above is called a clay pan. Clay pans generally hinder drainage, movement of air and water, as well as growth of the root system. They are found, for example, in planosols. They become sticky when wet and very hard when dry.

Clays

Clays are active mineral portions of soils, less than 2 μm in diameter and are predominantly colloidal and crystalline alumino-silicates. They are characteristically plastic and virtually impermeable when wet. They crack when dry. A clay particle is called **micelle**.

Soil clays act in three ways: as particles of <2 μm diameter, as minerals, and as part of the soil structure.

Clays have a net negative charge which attracts and holds charged cations such as K^+, Na^+, NH_4^+, Ca^{++}, Mg^{++} and H^+. The amounts of positive ions held by clays vary with the type of clays. The quantity of cations that can be held or exchanged by a given amount of soil is the **cation exchange capacity** (**CEC**) of that soil. The exchangeable cations are not easily lost by leaching until they are exchanged by other cations, generally hydrogen ions (H^+). Plant roots can use these firmly-held cations as nutrients.

Clays are referred to by group names like **silicate clays** and **sesquioxide clays**. Montmorillonite, mica (illite), vermiculite, chlorite and kaolinite belong to the class of silicate clays, while iron oxides, aluminum oxides, manganese oxides and titanium oxides belong to the class of **sesquioxide clays**. These clays occur as a major constituent of young soils formed from volcanic ash, and include allophanes and imogolite. Sesquioxide clays do not swell, are not sticky and, therefore, do not behave like silicate clays.

Clay minerals are essentially crystalline and have a layer structure. These are responsible for the plastic properties of clay. Most clays become plastic when mixed with water. The type of clay mineral, particle size and shape, organic matter, soluble salts, adsorbed ions, and the amount and type of non-clay minerals are all known to affect the plastic properties of clay.

Irrigation techniques employed for clayey soils encounter problems which are due to (a) large volume changes caused when clays are wetted and dried, (b) great stickiness and plasticity, and (c) exceptionally high water retention capacity. These characteristics cause inadequate aeration when clay is wet.

The properties of clay minerals are controlled by at least six major factors. These are clay mineral composition, non-clay mineral composition, organic material, soluble salts, exchangeable ions and texture. Generally, the clay mineral composition is the most important factor and sometimes as little as 5% of a particular clay mineral may largely determine the properties of a whole body of clay.

The commercial value of clays is related to their mineral and chemical composition. Major mineral or soluble salt impurities are quartz, mica, carbonates, iron oxides, sulphides and feldspar.

Clays are used for various applications like pottery, insulation, etc.

Clay shins

The coating of clay on the surface of soil peds, mineral grains and soil pores is known as clay shins. It is another name for **clay films**.

Clay soil

A soil with 40 percent or more clay, less than 45 percent sand and less than 40 percent silt is called a clay soil. Its high clay content makes it very compact and, therefore, poorly suited for certain crops. Such soils are also called **heavy soils** because they require more effort and heavy machinery for plowing and cultivating than sandy or **light soils**.

The major problems of clay soils are (a) inadequate aeration when wet, (b) slow water infiltration, and (c) limited moisture range for tilling. These soils are usually reforested or used for permanent pasture if the clay content is very high.

Clay soils become sticky and retain moisture when wet, but shrink and crack when dry. Clay soils require artificial drainage, particularly for arable farming.

Cleaning crop

Cleaning crops are fallow crops like potato or turnip grown in well-spaced rows to enable the land between the rows to be hoed and cultivated, so as to control weeds.

Cleave landsite

Cleave landsite is the bluish-white feldspar that occurs frequently as a late stage mineral. It is also called **albite** and is associated with a gem pocket, bearing lithium-rich pegatites and platy varieties.

Climosequence

Climosequence is a sequence of related soils that differ from one another in some characteristics, mainly due to differences in climate as the soil forming factor.

Clod

A clod is an aggregate of small size (a few mm to 1 cm), resulting from the agglomeration of elementary particles of the soil. A clod is also defined as a compact and coherent mass of soil of variable size (a few mm to a few cm), produced artificially, mainly by human activity, such as tillage (Fig.C.30).

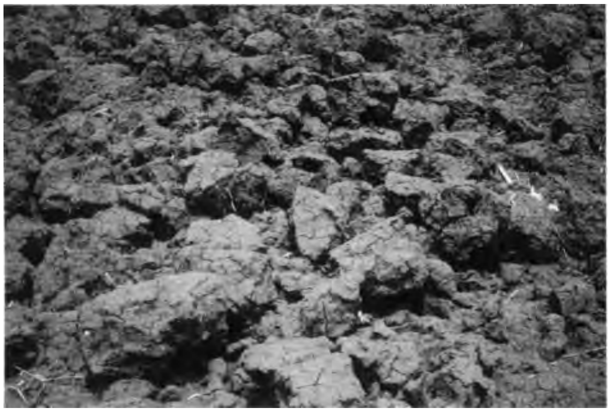


Fig.C.30: A plowed field showing clods.

Coalescence refers to the joining by compaction of clods that were originally separate.

Clover rhizobia

Clover rhizobia is a strain of fast-growing, acid-producing *Rhizobium* species. They form nodules on *Trifolium* (pea group of legumes) for atmospheric nitrogen fixation. (See also Rhizobia.)

CNC

CNC is short for **critical nutrient concentration**.

CNR

CNR is short for **critical nutrient range**.

C/N ratio

C/N ratio expresses the percentages of carbon to nitrogen in organic matter, humus or soil. This ratio determines the rate of transformation of nitrogen in organic matter. (See also Carbon/Nitrogen ratio.)

Coagulant

A substance that induces **coagulation** is known as a coagulant. Coagulants are used to precipitate solids or semisolids from solutions, such as casein from milk, rubber particles from latex or impurities from water. Compounds that dissociate into strongly charged ions are normally used for this purpose. Blood contains the natural coagulant thrombin.

Coagulation

Coagulation is the process by which colloidal particles come together irreversibly to form larger masses. It is brought about by adding ions, which changes the ionic strength of the solution and destabilizes the colloid. Ions with high charge are particularly effective (trivalent aluminum, Al^{3+}) in bringing about coagulation.

The formation of river deltas is a good example of coagulation, which occurs when silt particles in rivers come in contact with ions in sea water. Alum and iron sulphate are used for coagulation in sewage treatment.

Coal

Coal is a brown or black carbonaceous deposit, formed largely by the accumulation and alteration of ancient vegetation in swamps and other moist environments. The vegetation decomposes, forms layers of peat, and gets subsequently buried deep in the earth where, under increased pressure and temperatures, the peat gets transformed into coal. This, in short, is the **process of coalification**.

Two types of coals are known – **humic coal** or **woody coal** (derived from plant remains) and **sapropelic coal** (derived from algae, spores and finely divided plant materials).

As the process of coalification continues, the proportion of carbon rises relative to oxygen, and volatile substances and water are expelled. Various intermediates in the coalification process are referred to as the **ranks of**

coal. Some of them are **lignite** or **brown coal** (soft and brown with a high moisture content), **sub-bituminous coal** (used mainly for power generation) and bituminous coal (the most abundant type of coal). Other varieties are **semi-bituminous coal**, **semi-anthracite coal** (with a fixed carbon content of 86 to 92%) and **anthracite coal** (hard and black, with a fixed carbon content of 92 to 98%).

Coal is used as a fuel and in the chemical industry. When coal is heated in the absence of air, its volatile components are expelled and it is converted into **coke**. When **bituminous coal** is subjected to destructive distillation, it is converted into a thick black liquid, called **coal tar**.

Coal has varying amounts of ash and clinker and impurities like clays and sulphur (between 0.5% and 3%). The calorific value of coal increases with its grade till it reaches the anthracite level. The design of coal burning (or gasifying) facilities is dictated by its calorific content and impurities. Based on its moisture percentage, coal is specified with values of volatile combustible matter, fixed carbon, ash and percentages of carbon, hydrogen, oxygen, nitrogen and sulphur.

Coal, used for the large-scale production of hydrogen, is probably the world's largest source for producing ammonia. Coal-based power generation units and fertilizer production units are located near coal mines.

Coal is also an important source of raw material for the chemical industry. Pyrolysis or distillation of coal yields coal tar and **hydrocarbon gases** which are upgraded by hydrogenation or methanation to **synthetic crude oil** and **fuel gas**, respectively. Catalytic hydrogenation yields hydrocarbon oils and gasoline. Gasification produces **synthesis gas** (CO+H) from which ammonia and other fertilizers are made.

However, coal creates environmental pollution and entails high plant costs. As a result, its use at the current scale may decline in the years to come.

Coalescence

Coalescence is the joining of clods that were originally separate by compaction. The coalescence process is also witnessed in the aging and weathering of excrements of soil fauna into a dense undifferentiated mass. This process is facilitated when the excrements are composed of organic fine material.

Coal gas

Coal gas is a mixture of gases (chiefly hydrogen, methane and carbon monoxide) obtained by the destructive distillation of bituminous coal in a highly heated fire-clay (or silica) retort or in by-product coke-ovens.

Coal tar

Coal tar is a black, viscous liquid or a semi-solid obtained by the destructive distillation of **bituminous coal** in coke ovens. The chemicals found in it are (a) light oil at up to 200°C, which contains aromatic hydrocarbons like benzene, toluene, etc., (b) middle oil at 200 to 250°C, (c) heavy oil at 250 to 300°C, which contains naphthalene, acenaphthene, etc., (d) anthracene oil at 300 to 350°C, which contains phenanthrene and anthracene, and (e) pitch. Treatment with acids, bases and solvents is required to separate the individual chemicals.

Coal tar is a raw material for plastics, solvents, dyes, drugs and other organic chemicals. Crude as well as refined products or fractions of coal-tar are used for water proofing, paints, pipe coating, roads, insulation, as pesticides and sealants.

Coarse grains

The grains of cereal crops like corn, pearl millet and sorghum (Fig.C.31) are referred to as coarse grains (in contrast to rice and wheat). They are also used as livestock feed.

Fig.C.31: Sorghum, a cereal crop. Inset: Coarse grains of sorghum.

Coarse silt

Coarse silt is a type of silt with a particle size, that ranges between 20 and 50 μm. Silt is often carried in suspension in running water and is deposited on river beds or river banks or in lakes as an alluvial sediment. Silt is a constituent of soil and comprises particles which vary in size between those of clay and sand. According to international particle-size gradation, the size of silt particles should be about 2 to 50 μm in diameter.

Coarse texture soil

Coarse texture soils are those in which the coarse fraction of particles is more than the fine fractions. Sands, loamy sands and sandy loams come under the coarse texture soil group.

Coated fertilizers

Coated fertilizers are conventional soluble fertilizers which (after granulation, prilling or crystallization) are coated with a protective coating to control water penetration, dissolution rate and nutrient release in the soil. They are also called slow release fertilizers.

After testing many condensation polymers, drying oils, waxes and bitumen for their suitability as a coating material, three categories have been found the most useful.

These are (a) **polymer coatings** (for example, PVDC copolymers, polyolefines, polyurethanes, **urea-formaldehyde resins**, polyesters and alkyd resins), (b) **sulphur-polymer coatings** (hybrid products with a multi-layer coating of sulphur and polymer), and (c) **sulphur coatings**.

To maintain the particulate consistency of a fertilizer during storage and handling, it is tested with internal and external conditioners to prevent caking. External conditioning, also called **coating** and **surface treatment**, involves applying a thin layer of powders or surfactants to the fertilizer granule surface to reduce caking tendency. The addition of wax, and/or oil enhances the caking action by suppressing dust formation. This coating process is carried out in a rotating drum or a fluid bed dryer.

Although coating with a fine, inert powder (kieselghur, talc, lime, kaolin) has long been practiced as an external form of inorganic conditioning, surface treatment with non-ionic organic sealants (like polythene waxes, paraffins and urea-aldehyde resins) is also practiced. Coatings with surfactants (like fatty amines and sulphonates) to make the particle surface hydrophobic are also practiced.

Coating agents

Coating is the process of applying a layer on base materials like fertilizer granules or seeds, to make them moisture resistant or oxidation resistant.

Generally, a substance is coated by electrolysis, vapor deposition, vacuum, or mechanical means such as brushing, spraying, calendering and roller coating.

Coating agents are substances used to protect base materials from moisture, corrosion or oxidation. Commonly used coating agents include metals, alloys, resin solutions and liquid suspensions.

Fertilizers are coated to give them a slow-release property and to make them free flowing.

Some materials used in fertilizer coatings are waxes, polymers, elemental sulphur and asphaltic compounds.

Cobalt

Cobalt (Co), a metallic element with an atomic weight of 58.94, is one of the transition elements belonging to the Group 9 (formerly Group VIII) of the Periodic Table (Fig.C.32). However, in extremely low concentrations ranging from 0.1 to 1.0 parts per billion (ppb), cobalt have been observed to improve growth, transpiration and photosynthesis of cotton, mustard and beans. Cobalt is required by symbiotic micro-organisms (e.g., rhizobia) for the fixation of elemental nitrogen through the formation of vitamin B_{12}.

Cobalt forms a complex with nitrogen atoms of the porphyrin ring structure and provides a prosthetic group for association with nucleotides in vitamin B_{12} co-enzyme. This complex is called **cobamide**. Other cobalt functions include leghemoglobin metabolism and ribonucleotide reductase in *Rhizobium*, and activation of enolase, lecithinase and succinic kinase.

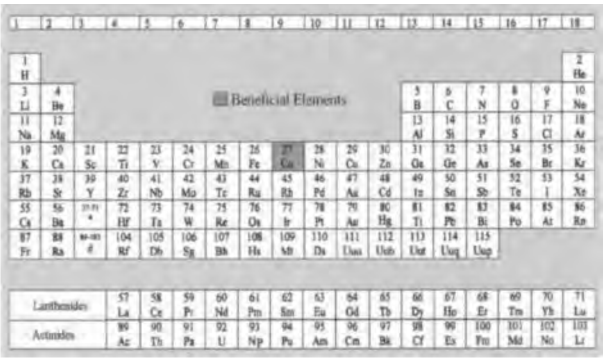


Fig.C.32: Position of cobalt in the Periodic Table.

The concentration of cobalt in dry matter of plants ranges from 0.02 to 0.5 ppm. One ppb of cobalt in nutrient solution was found adequate for nitrogen fixation in alfalfa. The water content and catalase activity in leaves increased and the concentration of the cell sap decreased with cobalt application.

Cobalt content in soil is low and variable. In India, for instance, it ranges from 4 to 80 ppm. The humus content of the soil influences the availability of cobalt in it. The nature of clay affects the absorption of cobalt from solutions, in the order muscovite > hematite > bentonite = kaolin. An increase in the pH of the soil decreases the availability of cobalt. **Cobalt deficiency** is more pronounced in coarse sandy soils and under high rainfall conditions. To overcome deficiency, cobalt fertilization with 100 to 200 g/ha as cobaltous sulphate ($CoSO_4$) is recommended.

Cobalt deficiency

Cobalt deficiency causes interveinal **chlorosis** in new leaves, followed by induced iron chlorosis and white leaf margins and tips, besides damaged root tips.

Cobalt is involved in nitrogen fixation and in the stimulation of synthesis of chlorophyll and proteins. Cobalt is also involved in the synthesis of vitamin B_{12}. Inadequate dietary cobalt in humans can lead to anaemia and loss of appetite.

Cobamide

Cobamide enzyme is the cobalt complex formed between the cobalt-porphyrin ring structure and the nucleotide in vitamin B_{12} co-enzyme.

Cobb-Douglas equation

Cobb-Douglas equation gives the response functions between nutrient addition (X) and product yield (Y). This power function is given by

$$Y = aX^{6}$$

where a is a constant. (See also Response function.)

COD

COD is short for **chemical oxygen demand**. It is a measure of the total oxidizable organic matter. (See Biochemical oxygen demand.)

Coefficient of utilization

The efficiency of nutrient utilization is the ratio of the **biomass** to the total amount of nutrient in biomass, and is termed as the coefficient of utilization or the **efficiency ratio**. The coefficient of nutrient utilization can be separated into two components, namely, utilization quotient and biomass production.

Coefficient of variation

The coefficient of variation (CV) is a measure of variation in observations. It is defined as:

$$\% \text{ CV} = \frac{\text{Standard deviation}}{\text{Mean of observations}} \times 100 = \frac{\sigma}{\bar{x}} \times 100$$

According to professor Karl Pearson, CV is the percentage variation in the mean, standard deviation being considered as the total variation of the mean. It helps in comparing the variability of two series. The series having greater a CV is said to be more variable than the other and one having lesser CV is said to be more consistent than the other. (See also Standard deviation.)

Coefficient of viscosity

The coefficient of viscosity is defined as the backward dragging force (F) acting per unit velocity gradient (dV/dx). This backward viscous force (F) acting tangentially on a liquid layer is directly proportional to its surface area (A) and velocity (V), and inversely proportional to its distance (x) from the stationary layer. Thus, the backward viscous force (F) can be arrived at by the following formula:

$$F = \frac{-nAV}{x} \text{ or } F = \frac{-nA\,dV}{dx}$$

where n is the coefficient of viscosity and is a constant; its value depends on the nature of the liquid and it decreases with increase in temperature.

Cohesion

Cohesion is the resistance of a particle to being pulled apart, due to surface tension of the moisture film surrounding it. Cohesion provides the force that holds up a column of water in the xylem tissue of plants. The cohesion tension theory offers an explanation for the continual flow of water upwards through the xylem of the plant.

Coke

Coke is a carbon form made by destructive distillation of coal. It is used mainly for the reduction of iron ore in blast furnaces, and as a source of synthesis gas. Lower grade cokes, made by heating coal to a lower temperature, are used as smokeless fuels for domestic heating. Coke from petroleum residues is used for refractory furnace linings in aluminum electro refining and as electrodes in the electrolytic reduction of alumina to aluminum.

Coke oven gas

Coke oven gas is a mixture of gases produced in steel plants during the carbonization of coal. It contains 50% hydrogen, 25% methane, 8% carbon monoxide, 6% nitrogen, and minor amounts of hydrocarbon, carbon dioxide and impurities. It has a calorific value of 3750 cal / NM^3.

Coke oven gas is used for the production of ammonia (the principal source of all nitrogen fertilizers since 1945) by steam reforming after purification or by the separation of hydrogen by a cryogenic process.

Ammonia manufacture by the **Haber-Bosch process** requires nitrogen and hydrogen, of which the latter is made from natural gas, LPG, naphtha, refinery gases or coke-oven gases.

Cold manure

Manure is classified on the basis of the way it is collected and stored. Cold manure is one such type of manure. It is made by decomposing manure anaerobically and at temperatures not exceeding 30°C. The benefit of such a process is the prevention of ammonia volatilization.

While cold manure also prevents germination of weed seeds, it is hazardous to incorporate it directly because of the toxins that get added in the making of cold manure.

Cold method for determining organic carbon

The cold method for determining organic carbon in soil is a wet combustion process, wherein the organic carbon-containing soil is refluxed with excess potassium dichromate. The excess dichromate is back titrated with ferrous sulphate using diphenyl anthranilic acid as an indicator. Dichromate oxidizes carbon to carbon dioxide. (See also Walkley-Black method.)

Cold-mix fertilizer solution

In a cold-mix fertilizer solution, the acid content of the ingredients is neutralized before blending so that no heat is emitted while blending the ingredients in a fertilizer plant.

Cold-mix liquid fertilizer plant

Cold-mix or hot-mix liquid fertilizers are made by blending liquid fertilizers with suitable solids or micronutrients. The mixing plant is classified according to its type of operation – whether hot or cold. In a **hot-mix plant**, heat is generated when fertilizers are mixed; this heat needs to be reduced to avoid volatilization losses. In the cold-mix plant, no heat is generated in the blending operation.

Cold sky

Kanten, which means cold sky, is a name for **agar-agar** in Japan. Different countries use different local species of algae for making agar. Often, algae carry the name of the country where they are used. In Japan, agar-agar made from *Gelidium* sp is called *kanten* because it is made on winter days or at high altitudes in the mountains.

Cole

Cole is defined as the soil's moist length minus dry length multiplied by dry length. Various moisture states have been used for the moist length, but the field capacity is often used. Cole is often got from the clods' volume change rather than their change in length. In such cases

$$\text{Cole} = \sqrt[3]{\frac{\text{dry bulk density}}{\text{moist bulk density}}} - 1$$

Cole generally varies from near zero to 0.12. The degree of probable limitations on the soil's use is correlated with the concept of cole.

Cole-coefficient of linear extensibility is a measure of soil's capacity for shrinking and swelling. It is determined by measuring a specimen in wet and dry states.

Cole crops

Cole crop is a type in the classification of **vegetable crops**. Cabbage and cauliflower belong to this group (Fig.C.33).

Fig.C.33: Cabbage and cauliflower are examples of cole crops.

Colemanite

Colemanite ($Ca_2B_6O_{11}\cdot5H_2O$) is a boron-bearing mineral that releases boron at a slow rate for plant uptake. It can be applied directly.

Collagen

Collagen is an insoluble fibrous protein found extensively in the connective tissue of skin, tendons and bones. Polypeptide chains of collagen predominantly contain glycine and proline. These form triple-stranded, helical coils to form fibrils, which have strength and elasticity. Collagen accounts for over 30% of the total body protein in mammals.

Collenchyma

Collenchyma is the cell of a tissue, located near the surface, usually beneath the epidermis. Its principal role is to give strength and flexibility to growing organs like young stems. Collenchyma is also formed in petioles and vein ribs of leaves as well as in pedicels of flowers. When seen in cross section collenchyma appears polygonal (Fig.C.34). It has unevenly thickened walls which are prominent at the corners.

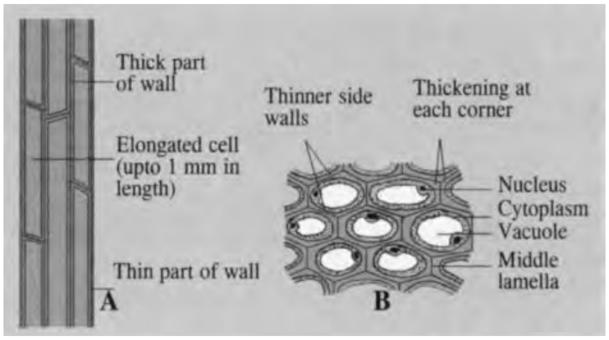


Fig.C.34: A schematic diagram of collenchyma cells (not to scale) A. Elongated cells. B. Outline of polygonal cells.

Collenchyma cells may contain chloroplasts and starch grains. The cell walls, composed of **cellulose** and pectic compounds plus a high proportion of water, are plastic and have a tensile strength comparable to that of sclerenchyma fibers. This combination of strength and plasticity makes collenchyma effective as a support tissue in developing stems and leaves without any other supporting tissue.

Colloid

A colloid is a mechanical mixture that appears to be in solution. Two phases exist in a colloidal system. One is the dispersal phase and the other, a continuous phase. Because the size of the particle is very small, the surface to volume ratio of colloid is high, resulting in pronounced adsorptive properties. Clay particles and humus in the soil are considered colloidal because they can be dispersed in the adsorbed water (making the soil swell and become sticky). On drying, the particles lose their water and the soil shrinks resulting in cracks in clayey soils. Clay and humus can also become colloidal by adsorbing cations.

Colloids are classified as sols, gels or emulsions. The other type of colloids is aerosol which is a dispersion of liquid or solid particles in a gas. Examples are mist or smoke. Examples of colloidal systems are presented in Table-C.4.

Table-C.4: Examples of colloidal systems.

Dispersed phase	Dispersion medium	Examples of colloidal systems
Solid	Solid	Colored glass
Solid	Liquid	Gold sol
Solid	Gas	Smoke, dust
Liquid	Liquid	Milk
Liquid	Gas	Fog, liquid sprays

The unique properties of colloids are primarily due to the large surface areas in the dispersed phase, which results in adsorption of ions and other materials. The adsorbed ions impart an electric charge to the colloidal particles because of which they repel each other. **Lyophobic colloids**, which exhibit little affinity between the dispersed phase and the solvent, are strongly associated with the solvent.

Colloidal particles are so small that they cannot be separated by filtration, nor can they be seen by the naked eye. An electron microscope serves as a means to determine the size and the shape of colloidal particles. The solvent and dissolved substances can be separated by dialysis and ultrafiltration. The stability of soil colloidal suspensions is affected by electrolyte concentration, pH, and adsorption of small ions and polymer ions.

Colloids are either lyophilic or lyophobic (they can also be called **hydrophilic** or **hydrophobic colloids** respectively when water is the dispersion medium) when their dispersion requires the application of mechanical or electrical force to provide a suspension. Hydrophobic colloids are unstable and precipitate under the action of electrolytes. They are characterized by strong ion exchange properties. Colloids diffuse through membranes very slowly, if at all.

Principal **soil colloids** are clay, humus, silica (electronegative), alumina and iron (electropositive). On an average, the proportion of colloids in soil is 80% aluminosilicates, 10% free sesquioxides, 5% humus and 5% silica and other colloids.

Colloidal silicates

Colloidal silicates are a type of soil conditioners used to optimize and stabilize soil and substrate properties that are otherwise unsuitable for plant growth. They help restore soils affected by heavy metals and salts.

Colloidal silicates include compounds of polysilisic acid, produced and stabilized by synthetic means. 'Agrosil', a colloidal silicate, consists of (a) partly dehydrated sodium silicate neutralized with acids, (b) electrolytes, and (c) an organic additive to retard aging.

Colloidal suspension

Colloidal suspension is a very fine, heterogeneous dispersion of one or more substances in another substance or material. Colloidal particles may be gaseous, liquid or solid, according to the nature of suspension. For example, solid/gas (aerosol), solid/solid (ruby/glass), liquid/liquid (emulsion) and gas/liquid (foam) are colloidal suspensions. Rubber latex, milk, blood and egg-white are examples of natural colloidal suspensions.

Colluvium

Colluvium is a heterogeneous mixture of soil materials, with or without rock fragments, that accumulates at the base of steep slopes by gravitational action. A colluvium has a rounded character to its elements, and is different from alluvium which is angular.

Colorimetric method

The colorimetric method is based on the Lambert-Beer law and is used for the determination of certain elements (such as phosphorus) in soil. Colorimetry is a technique by which an unknown color is evaluated in terms of known colors. Colorimetry may be visual, photoelectric or indirect by means of spectrophotometry (Fig.C.35).

The **Lambert-Beer law** states that the intensity of a monochromatic beam of light decreases exponentially with the concentration (c) and the thickness (l) of the absorbing substance ($\log I/I_0 = Acl$), where A is a constant and I and I_0 are the intensities of transmitted and incident light, respectively.

Some colorimetric methods, such as the **Comber method**, are used for rapid determination of pH. In this method, the Comber reagent used is a 4% solution of potassium thiocyanate (KCNS) in pure alcohol. It rapidly precipitates colloidal substances in the soil, whereas the potassium thiocyanate combines with free iron in the soil and forms a red ferric complex. The more acidic the soil, the clearer the reaction and the redder the color.

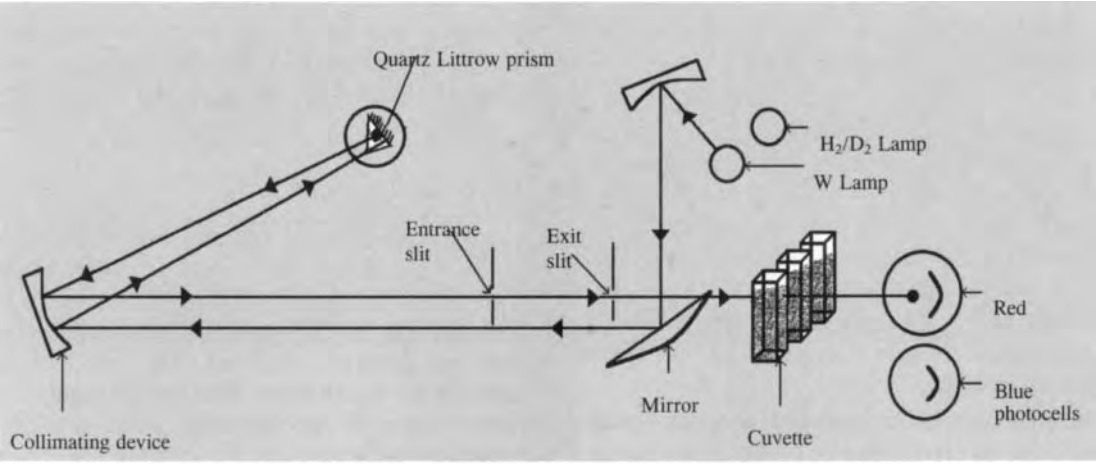


Fig.C.35: A block diagram of UV-visible spectrophotometer.

Colored dyes

Colored dyes are also known as stains. (See Staining.)

Columnar structure

Columnar is one type of soil structural units (peds) decided on the basis of three characteristics of the soil – its type, class and grade. When the tops and sides of the aggregates are rounded, they look like columns; and are called columnar structures. Columnar peds are either vertically oriented or round-topped prisms. They can be seen in some sodic soils.

Comber method for soil pH determination

The Comber method is a quantitative method for evaluating the acidity of soils and is conducted through the following steps: (i) Dry soil is sieved through a 1 mm sieve into a test tube upto a height of about 2.5 cm. (ii) **Comber reagent** to a height of about 4 cm. (iii) It is shaken well for a few seconds and the mixture allowed to settle. The supernatant liquid is blood red for a pH below 4, dark red for a pH of 5, red for a pH of 5.5, pink for a pH of 6 and colorless for a pH of 6.5 and above.

Comber reagent

An alcoholic solution of potassium thiocyanate is called comber reagent.

Combine drill

Combine drill is an equipment or a machine in which application of the fertilizer is done in bands, together with the seed.

Combustion

An exothermic oxidation reaction which may occur with any organic compound or elements like hydrogen, sulphur, phosphorus and magnesium with oxygen is called combustion. The end products of elemental combustion are oxides; those of organic compounds are carbon dioxide and water.

$$2H_2 + O_2 \longrightarrow 2H_2O$$

$$\underset{\text{(carbohydrate)}}{C_6H_{12}O_6} + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

Here, combustion is the reverse of photosynthesis. The heat evolved by combustion is due to the rupture of chemical bonds and formation of new compounds.

Substances differ greatly in their combustibility; that is, in their ignition points (in the case of solids and gases) or flash points (in the case of liquids). Rubber and nylon are difficult to ignite at any temperature, whereas carbon disulphide burns with almost explosive violence at 100°C. Oxygen actively supports combustion. No oxygen is necessary when an oxidizing agent is present, as in the combustion mixture of hydrogen and chlorine to form hydrogen chloride.

Spontaneous combustion may occur at or below room temperatures by (a) exposure to air of substances that are highly sensitive to oxidation (like phosphorus), (b) heat build-up due either to bacterial activity (compost, sewage sludge) or due to oxidation catalyzed by moisture as in wet waste materials (paper, cotton, wool), and (c) internal heat accumulation due to auto-oxidation (fish oil, linseed oil).

Commercial fertilizer: See Fertilizer

Commercial rock phosphate

Commercial rock phosphate is rock phosphate mined and ground to 100 mesh fineness. This is the raw material from which phosphate fertilizers, including phosphoric acid, are made.

Commodity grade of diammonium phosphate: See Ammonium phosphate

Common superphosphate

Common superphosphate or ordinary **superphosphate** is a principal phosphate fertilizer that has been used for more than a century. It is made by treating ground phosphate rock with sulphuric acid. After 2 to 6 weeks of aging, the product is ground and used as a fertilizer.

Compacted density

Compacted density of a material like soil, which can be up to 10% higher than its **settled density** (loose pour bulk density) of the same material, represents the **maximum bulk density** that can be achieved through vigorous shaking of the container. **Loose pour density** or bulk density is the mass per unit volume of the material after it is tipped freely into a container.

Loose pour density is the minimum density expected, the knowledge of which is used in designing storage containers and in calibrating volumetric feeders or applicators.

Compacted density is measured in accordance with international specifications (ISO-5311). In fertilizers, it is estimated by using a bulk density box.

Compaction: See Compaction of soil

Compaction in fertilizers

Compaction in fertilizers is done by mixing raw materials and agglomerating the mixtures by pressure. The process increases the **bulk density** and reduces the porosity of the granulated fertilizer.

Compaction of soil

The process of slow squeezing of sediments to form hard rock (or putting the loose particles together by mechanical force to form a compacted mass) is known as **compaction**. As sediments pile up on top of each other, they are gradually squeezed. The extent of squeezing depends on the sediment. Mud may be highly compacted when it changes into mudstone, while sand is squeezed very little as it changes to sandstone. Sediments often contain a great deal of water, which is gradually squeezed out during compaction.

Soil compaction results in a change in volume brought about by application of a load by way of rolling, tapping or vibration. When soil particles are pushed close together, the mass per unit volume increases and the soil is compacted. The increase in bulk density of the soil can be due to mechanical forces such as those from tractor wheels. Water percolation and root penetration become difficult in compacted soil.

Companion crops

Companion crops are two mutually beneficial crops grown together in the same field. For example, sorghum and pigeon pea, if grown together, can be considered companion crops. Pigeon pea facilitates nitrogen fixation in the soil, which is beneficial to the growth of sorghum, whereas sorghum increases the harvesting index of the system. Wheat and chickpea or wheat and mustard are other examples of companion crops.

Companion crops have similar cultivation and management needs and produce easily separable seeds after harvesting.

Compatibility

Agrochemicals, fertilizers or their mixtures, which do not adversely interact or exhibit their individual characteristics, are considered to be compatible with one another. This compatibility can be chemical or physical. The knowledge of compatibility is essential for preparing fertilizer blends from individual salts.

The only **completely incompatible combination** in fertilizer blends is ammonium nitrate and urea, which results in a mixture with an extremely low critical relative humidity (CRH) of 18%. This is due to a chemical reaction between the two compounds.

Chemical compatibility of fertilizers can be evaluated either by a simple **bottle test** or in a **large-bag** or **small-bag storage test**. In the bottle test, a freshly-mixed blend is tightly capped in a glass bottle, stored at 30°C, and inspected after a period of one day to several months for any signs of wetting, caking, disintegration or obnoxious gas formation.

Physical compatibility of fertilizer blends is the ability of two or more fertilizer materials to remain thoroughly mixed during storage, handling and application. Segregation can be a major problem while handling a bulk-blended fertilizer and is caused by mismatched particle sizes. The most common method to determine physical compatibility of bulk-blend ingredients is to perform a particle-size analysis of each ingredient and compare the data. There are two techniques based on the particle size analysis to determine physical compatibility, namely, cumulative particle size distribution and **size guide number** (SGN). If the difference in cumulative particle size distribution between the ingredients is more than 20%, the ingredients are incompatible and if it is between 0 to 10%, they are compatible.

SGN difference $< 10\%$ represents good compatibility
SGN difference $> 20\%$ represents incompatibility

The **size guide number** technique, developed by the Canadian Fertilizer Institute, entails median particle size determination of each blended ingredient by locating the 50% cumulative retained point from the size distribution curve. The particle size (in millimeters) at the 50% cumulative retained point is multiplied by 100 and rounded off to the nearest five. This number is referred to as the SGN of that blend ingredient. The SGN for each bulk-blend ingredient is compared, and its compatibility evaluated.

Competitive inhibition

Enzyme inhibition affects biochemical reactions. These reactions are divided into competitive and non-competitive inhibition. Competitive inhibition occurs when the inhibitor molecules resemble the substrate molecules and bind to the active site of the enzyme, thereby preventing normal enzymatic reactions. Competitive inhibition can be reversed by increasing the concentration of the substrate. (See also Inhibitor.)

Complementary cation effect

The influence of one adsorbed cation on the release of another from the surface of a colloid is known as a complimentary cation effect. For example, ammonium ion (NH_4^+) exchange for calcium ion (Ca^{2+}) occurs more easily when trivalent aluminum ion (Al^{3+}) is more predominant than sodium ion (Na^+).

Complete complex fertilizer: See Complex fertilizers

Complete disinfectant : See Disinfectant

Complete fertilizer

Crops need nutrients in sufficient quantities in order to grow rapidly and produce high yields; but in excess quantities they can become toxic to the crops. A complete fertilizer is a mixture of different plant nutrients, including macronutrients N, P and K in sufficient quantities to ensure healthy plant growth.

Completely incompatible combination of fertilizers

Components of fertilizer mixtures should not adversely interact with each other. If they do, their storage and blending pose problems. The only completely incompatible combination in fertilizer blends is ammonium nitrate and urea. This mixture has an extremely low **critical relative humidity** of 18%. The cause of the chemical incompatibility is the chemical reaction between urea and ammonium nitrate.

Complex fertilizers

Complex fertilizers contain more than two plant nutrients, of which at least two major nutrients are in a chemical combination. Each granule of a complex fertilizer contains all the nutrients of the fertilizer.

Complex fertilizers are generally granulated, free flowing and can easily be applied uniformly. Their packaging and transporting costs tend to be lower than those of conventional individual fertilizers.

Many crops need N, P and K at the same time and a wide range of complex fertilizers containing all three primary nutrients are produced for this purpose. Other nutrients such as sulphur can easily be incorporated, if required, into these fertilizers. Complex fertilizers cost more than individual fertilizers, but the cost of application tends to be lower in the long term. There is also greater consistency of quality in complex fertilizers and a more effective spread can be achieved on the farm. As a general rule, if the extra cost of nutrients in a complex fertilizer varies within 15% of the costs of individual nutrients, the use of complex fertilizers is considered to be justified.

A large share of the multi nutrient fertilizer used in the European Union are complex fertilizers. Despite the need for fairly advanced technology in their production, complex fertilizers are routinely produced in developing countries like India and China.

Among complex fertilizers are ammonium phosphates, nitrophosphates, and NPK complexes. Ammonium phosphates are generally manufactured by neutralizing ammonia with phosphoric and sulphuric acid, or phosphoric, nitric and sulphuric acid.

There are four types of ammonium phosphates currently under production: (a) ammonium phosphate (18-46-0), (b) ammonium nitrophosphate (23-23-0), (c) urea ammonium phosphate (24-24-0) or (28-28-0), and (d) ammonium phosphate sulphate (16-20-0-5S or 20-20-0-5S). The first three figures in the bracket indicate the content of nitrogen, phosphorus and potassium respectively. All of them are almost entirely water-soluble.

Nitrophosphates are made by treating phosphate rock with nitric acid or with a mixture of sulphuric and nitric acids, followed by ammonia treatment. The final product is made up of ammonium nitrate, dicalcium phosphate and mono-ammonium phosphate.

NPK complex fertilizers are based on either ammonium phosphates or nitrophosphates. Potash and additional nitrogen in the form of urea are added and the slurry is then granulated.

A fertilizer containing two elements is called an **incomplete complex fertilizer**, and one containing three elements (N, P and K) is called a **complete complex fertilizer**.

Complexing agent

A complex ion has a metal ion or atom surrounded by a number of other molecules, atoms or ions. These molecules, ions or atoms which donate one or more electrons or share their electrons with the central ion or atom are called complexing agents or **ligands**. Ligands can be a part of positively charged or negatively complex ions. Ammonia in $[Co(NH_3)_6]^{3+}$ and chloride ions in $[PtCl_6]^{2-}$ are examples of ligands or complexing agents.

Foliar sprays of micronutrients such as Fe-EDDHA or Cu-EDTA contain the ligands EDDHA and EDTA.

Complex lipids

Lipids are fatty acids and substances that are functionally related to these compounds. Lipids are one of the chief structural components of living cells and are classified as complex lipids and **simple lipids**.

Complex lipids yield three or more primary products per mole on saponification. They are esters of long chain fatty acids and include glycerides (which include fats and oils of animals and plants), glycolipids, phospholipids and waxes. Lipids are a convenient and concentrated means of storing food energy in plants and animals. Glycolipids are lipids that contain carbohydrate residues. Examples include sterol glycosides and plant phytoglycolipids. Phospholipids are lipids which contain phosphorus and include lecithin cephalin. Waxes provide vital water proofing for body surfaces.

Composite fertilizer

A composite fertilizer contains two or more primary nutrients, produced through chemical reactions in a factory. Unlike dry mixtures or blends, it is made from raw materials and intermediates rather than from finished products. It is invariably granulated, with an identical composition for each granule.

The term composite fertilizer is also used to denote a **compound fertilizer** or a **complex fertilizer**, the nutrient contents of which have undergone chemical interactions during the manufacturing process.

Composite sample

A composite sample is a uniform sample, made to prevent sampling errors. Fertilizers taken from various bags or lots are mixed and homogenized to get a uniform composite sample. Composite samples can also be made by drawing samples from different portions of a container using a suitable instrument and mixing these samples.

Composition guarantee

A composition guarantee, also known as **guaranteed analysis**, or **declarable content**, is given in terms of quantitative and/or qualitative characteristics that a market product must comply with tq meet the contractual or legal requirements. When any plant nutrient or chemical compound is guaranteed, the regulatory authority shall subject it to inspection and analysis in accordance with the prescribed methods and regulations.

Compost

Compost is an organic manure formed by the slow decomposition of (a) various plant or animal residues, (b) wastes (like dung, crop waste, slaughterhouse waste, etc.), (c) pre-sorted household wastes, and (d) **sediments** of sewage purification units.

Composting is the process of preparing compost for soil conditioning by the microbial degradation of organic waste, by using aerobic and anaerobic micro-organisms to hasten decomposition. The carbon to nitrogen (C:N) ratio of the material, its water content, aeration, pH and temperature, etc. regulate the prevalence and multiplication of the microbial population and the rate of decomposition of the material.

Organic material is decomposed by aerobic saprotrophic organisms, mostly fungi and bacteria. Some decomposition is also carried out by detritivores. Decaying organic matter is used as manure.

Anaerobic composting is a method of composting farm wastes with insufficient air/oxygen supply. When decomposable raw material like farm or crop wastes is filled in composting pits to a height of 40 to 50 cm and decomposed by micro-organisms in an anaerobic environment, the process is called **anaerobic decomposition**. The compost is generally ready within 4 to 5 months and contains 0.8 to 1% nitrogen.

Conventional methods of composting require a long period to produce good compost, often 8 weeks or more. There is a combined action of organisms like earthworms, bacteria, nitrogen fixers and cellulolytic as well as lignolytic fungi, which hasten the process of composting. Such decomposition of organic matter results in a product which is rich in humus and has a low carbon to nitrogen ratio. In recent years, there has been considerable interest in the use of earthworms for composting. This practice is called vermi-composting (Fig.C.36).

There are different methods of composting, depending on the availability of raw materials and specific requirements of the region. For composting, the organic matter is piled in a specially built pit. Decomposition is facilitated by keeping the pile warm and moist, and encouraging the growth of micro-organisms. After a specified period of time, the compost is ready for use. If the organic matter is deficient in nutrients, these are added in the form of nitrogen, phosphates, manure and animal wastes.

Compost is produced primarily from plant residues is called **artificial manure** or **synthetic manure**. Compost produced by a partial aerobic fermentation of diverse organic material like cattle dung, urine, crop residues, farm waste or agricultural waste (such as weeds, straw, groundnut husks, etc.), is called **rural compost**. If produced from materials of urban origin – like street sweepings and dustbin refuge – the product is known as **urban compost**.

When sewage sludge and municipal garbage are composted, **municipal compost** is produced. This compost can cause health hazards because the organic and inorganic waste material may carry pathogens, viruses and parasite eggs. This problem can be partially solved by the self-heating of compost during decomposition. But heating does not remove non-organic material like lead, strong acids, etc. which harm plants. Some toxic substances, harmful to plants and animals are also produced during composting.

Composts are comparatively less effective than fertilizers, as they contain less than 2% NPK, half of which is mineralized during the growing season.

A rural compost generally contains 0.5 to 1.0% nitrogen, 0.2% phosphorus (as P_2O_5) and 0.5% potassium (as K_2O), whereas urban compost has about 1.5 to 2.0% nitrogen, 1.0% P_2O_5 and 1.5% K_2O.

Table-C.5 shows the ideal involvement of each parameter for obtaining good quality compost.

Compost can be made entirely from plant materials. Some examples are kitchen waste, plant litter, garden pruning and industrial waste of plant origin.

The nutrient composition or concentration (%dw) in fertilizers, based on wastes of plant origin, are given in Table-C.6.

Fig.C.36: Vermi-compost heaps being decomposed in a shed.

Table-C.5: Role of various parameters for good quality compost.

Parameter	Role in composting
Activators	Efficient cellulolytic fungi and biofertilizers.
Agitation	No agitation or periodic turning in simple systems and short bursts of vigorous agitation in mechanized systems.
Air flow	0.6 to 1.8 m^3 air/day/kg of volatile solids during thermophilic stage or maintain oxygen level at 10 to 18%.
C/N ratio of material	25 to 35
Heap size	Any length, 1.5 m high and 2.5 m wide for heaps using natural aeration. With forced aeration, heap size depends on need to avoid overheating.
Moisture content	50 to 60 % (higher values possible with bulking agents).
Particle size	10 mm for agitated systems and forced aeration, 50 mm for long heaps and natural aeration.
pH control	Normally unnecessary
Temperature	55 to 60°C held for 3 days

Source: "Dictionary of Soil Fertility, Fertilisers and Integrated Nutrient Management", by HLS Tandon. Fertiliser Development and Consultation Organization, New Delhi. With permission.

Compost has numerous uses, depending on its quality. High quality compost can be used to replace the lost topsoil in farms. The amount of compost needed for this purpose is enormous; 160 tons of compost is required for 2.54 cm of topsoil over one hectare of land. Composting the organic wastes of a community of one million people could produce an estimated 600 tons of compost daily. Compost is widely used in nurseries and landscaping industries and in inland reclamation. Sanitary landfills also need compost or soil between the trash layers and as a cap on the top, once the landfill is closed.

Compost accelerators

Composting material and microbial cultures (such as *Aspergillus* sp., *Paecilomyces fusisporus, Trichurus spiralis* and *Trichoderma viride*) are added to organic substances to hasten decomposition. These are called compost accelerators.

Composted bark mixtures with mineral fertilizers

Mixtures of mineral and organic fertilizers are used to improve soil aeration and water retention capacity, in addition to providing necessary nutrients for plant growth. One such mixture is composted bark with mineral nutrients. The organic substance of composted bark is highly stable against biological degradation and resembles peat.

Composting

Composting is the process of microbial degradation of organic matter in the presence of aerobic and anaerobic micro-organisms, to lower the C/N ratio and create a well-rotted manure called **compost**. The major objectives of composting are to stabilize putrescible organic matter, to conserve as much of the plant nutrient and organic matter as possible, and to produce a uniform, relatively dry product suitable for use as a manure. (See also Compost.)

Compound fertilizers

Compound fertilizers are fertilizers formulated with two or more plant nutrients. A compound fertilizer is also defined as a homogeneous product containing two or more of the following plant nutrients. These nutrients are nitrogen, phosphorus, potassium and magnesium. A compound fertilizer, in the form of granules, pellets, prills or crystals is free-flowing and can contain micronutrients. It is also called a **complex,** composite or **multi-nutrient fertilizer**.

Compound phosphatic fertilizer: See Phosphatic fertilizer

Table-C.6: Nutrient concentrations (% dry weight) in fertilizers based on wastes of plant origin.

Fertilizer	N	P	K	Ca	Mg	S	C/N
Castor cake	5.5	0.8	0.8-1.6	0.4	0.3	80	8
Coco waste	2.3-3	0.4-0.5	2.5-3.0	0.6	0.5	90	17-24
Brewers' grains	4	0.4-0.7	0.5-1.0	0.3	0.2	65-75	10-12
Fruit pulp	1.0	0.3	1.3	0.8	0.1	85-95	40-50
Rape	1.5-2.5	0.4-0.8	3-3.5	1.0-1.8	0.2	75	20-30
Vinasse	3-4	0.15	6-7	0.6-1.2	0.3	50	8
Pulp	5-6	0.7-1.0	0.8-6.0	-	-	75-85	8-10
Potato starch wastewater	4-8*	0.7-0.9*	10*-12	-	-	-	5*-7
Filtration diatomaceous earth	0.7	<0.1	<0.1	0.2	<0.1	6	4-8

* In fresh potato starch wastewater. (*Source : "Agrochemicals", 2000, Edited by Franz Muller, Wiley VCH Verlag GmbH. With permission.)*

Concentrated organic manure

Concentrated organic manures are organic manures with a higher percentage of major plant nutrients (nitrogen, phosphorus and potash) compared to organic manures like **farmyard manure** and **compost**. Materials of animal or plant origin are the starting raw materials for producing concentrated organic manures like **oil cakes**, **blood meal**, **fish manure**, meat meal and wool waste.

Concentrated superphosphate

Concentrated superphosphate is produced by acidulating phosphate rock in a rotating drum with superphosphoric acid (not ordinary phosphoric acid). Concentrated superphosphate has a higher phosphorus content than triple superphosphate. Concentrated superphosphate has a high bulk density of 1150 kg/m^3. It is water-soluble, remains free flowing for long durations and has less free acid.

Concentrated superphosphate, which can also be made by removing water from triple superphosphate, contains about 54% phosphorus pentoxide (with 19 to 23% phosphorus), most of which is monocalcium phosphate. The crop response to concentrated superphosphate is very similar to that of triple superphosphate.

Concentration

Concentration defines the quantitative relationship of the components of a mixture. The amount of a chemical or pollutant in a particular volume or weight of a medium like air, water or soil is known as its concentration. The term concentration is used to describe the relative amounts of solute and solvent in a solution. It is expressed as mass, volume or number of moles of solute present in proportion to the amount of solvent or total solution. A solution in which a large amount of solute is dissolved in the solvent is said to have a high concentration of the solute. Conversely, a dilute solution has a lower concentration of the solute. For example, a solution that contains 0.01g of sodium chloride (NaCl) per cubic decimeter is dilute as compared to the one that contains 0.10g of NaCl per dm^3.

Concentration is measured in various ways. One gram molecular weight of a substance dissolved per unit volume has units of mol per dm^3 or mol per liter. This is called **molarity**. The mass concentration is the mass of solute per unit volume of solvent (g/dm^3). The **molal** concentration or **molality** is the amount of the substance in gram moles per unit mass of the solvent (mol/kg). The simplest scale to measure is a percentage (w/v or v/v) and, therefore, it is often used for medical and household solutions. When it is important to know the reactive capacities of reagents, as in volumetric analysis, a normality scale is used. **Normality** (N) of a solution is the number of equivalents of the solute per liter of solution, whereas molarity (M) of a solution is the number of moles of solute per liter of solution.

Concretions

Concretions are chemical compounds like calcium carbonate or iron oxide that sometimes accumulate in the soil, in the form of aggregates or nodules of varying sizes, shapes, hardness and colors.

Condiments and spices

Condiments and spices form a classification under vegetable crops, based on their use. Some examples are sesame, chili, ginger and black pepper.

Conditioners: See Conditioning materials

Conditioning materials

Conditioning materials or **conditioners** are anti-caking materials added to fertilizers to control moisture ingression and caking during their storage in bags. These chemical additives keep the fertilizers free-flowing, and make their mechanical distribution easy and uniform.

Materials ordinarily added to fertilizers are diatomaceous earth, rice hull, ground peanut hulls and vermiculites. Nowadays, liquid organic surfactants are also being included as coating material for fertilizer granules. Internal or chemical conditioners are sometimes added during the processing of fertilizers to improve their storage properties; the proportions vary. For example, 0.3 to 0.5% formaldehyde is added to urea, and 1.8% magnesium nitrate to ammonium nitrate.

Conductivity, electrical

Electrical conductivity is the reciprocal of the resistivity of a material. It is measured in Siemens per meter in SI units. When a fluid is involved, the electrolytic conductivity is given by the ratio of the current density to the electric field strength.

Electrical conductivity between two electrodes set apart at a fixed distance inside a small block is an indirect measure of the soil moisture from the **field capacity** to **wilting point**. These blocks are made of nylon, gypsum, fiberglass, etc., and buried in the soil with wires attached to each block for measuring conductivity.

The electrical conductivity of a solution is the conductance measured between the electrodes, 1 cm^2 in area and placed 1 cm apart. The resistance is expressed in ohms and the conductivity is expressed in Siemens per meter or deciSiemens per meter. The measurements are important mainly for the classification of the aridisols in soil taxonomy and soil salinity. In fact, the conductivity of aridisols in the saturation extract is higher than 2 deciSiemens per meter at 25°C.

The saline phase in FAO legend requires that the conductivity of the saturation extract be higher than 4 deciSiemens per meter at 25°C, whereas high salinity implies conductivity greater than 15 deciSiemens per meter at 25°C. In the French classification, the lower limit for the classification of a soil in the class of saline soils is a conductivity of saturation extract of

8 deciSiemens per meter over a thickness of at least 20 cm. A limit of 4 deciSiemens per meter is acceptable if the salt is only magnesium carbonate.

Coniferous forest

A coniferous forest is a forest made up mostly of cone bearing or coniferous trees such as pines, firs, hemlocks and cypresses. Resistant to acidity and cold weather, coniferous forests occur not only in the temperate regions of Europe, Asia and America, but also in several parts of South America.

Coniferous trees have small needle-like or scale-like leaves and most of them are evergreen. The softwood they produce is used for construction, furniture, paper and resin.

Conservation

Conservation refers to the protection of environmentally and culturally important things from harm or destruction. Conservation is concerned with the sustained utilization of resources - the rate, purpose, and efficiency of use. **Soil conservation** is the protection of soil against erosion or loss of fertility. Water conservation is the protection, management and development of water and control of pollution.

Conservation also means the improvement and use of natural resources according to principles that will ensure economic and social justice, and sustained production benefits for a long period.

Conservation facilitates the optimal and rational use of natural resources and environment, taking into account the demands on them and the need to safeguard and maintain them for the future.

A generalized definition of conservation that fits many interpretations is the optimal maximization over time, of the net social benefits in goods and services from the resources.

The term 'conservation' is currently used to denote the wise use of resources for the greater good of the largest number. In particular, reducing the rate of consumption of non-renewable resources and introducing management and planning programs seek to improve the quality of both the natural and man-made environment.

Conservation terrace

Conservation terraces are man-made innovations intended to increase the use of run-off water. They are small, one-field watersheds that collect run-off for use in an adjacent area. Conservation terraces have about two to four times as much area under watershed as under the planted level terrace area.

Conservation tillage

Conservation tillage refers to tilling the land to the barest minimum requirement. In this method of growing crops, seedbed preparation is avoided or excluded and the seeds are placed at the required depth by opening a slit or punching a hole into the soil. Conservation tillage includes **no tillage**, **zero tillage**, **minimum tillage** or **reduced tillage**. In zero tillage or no tillage the field is not plowed and the plant residues remain standing. In reduced or minimum tillage, fewer tillage operations are carried out, compared to the conventional methods of tilling. The practice of minimum tillage, suitable only in some situations, involves tilling the land to the barest minimum.

Conservation tillage is a way of reducing erosion by water and wind. Erosion is caused by soil detachment and soil transport. Soil particles are detached by falling rain drops, and these detached soil particles are carried by wind or water. In areas where conservation tillage is practiced, the residue cover absorbs the impact of the falling raindrops and consequently reduces the detachment. Similarly, water may collect around the residue creating puddles. The puddles absorb raindrop impact which reduces the detachment of soil particles. Erosion is reduced if the soil remains covered with crop, and the next crop is planted straight into it. For this to happen, at least 30% of the soil surface should be covered by plant residues, according to a study by the U.S. Soil Conservation Service.

The limited success of conservation tillage may be related to low fertility in the root zone. Phosphorus (P) and potassium (K) accumulate in the upper layer of the soil (top 5 to 10 cm) in conservation tillage, unlike in moldboard plowing. With chisel plowing, more of P and K are incorporated into the soil over the years than is done by till planting or **no till**. Periodic plowing once in 4 or 5 years is desirable as it allows proper mixing of soil for distribution of nutrients throughout the plow zone. It also minimizes the run-off and erosion of surface soils containing high amounts of plant nutrients, thereby preventing environmental pollution and financial loss.

Conservation tillage leads to a higher accumulation of the surface residues that create cooler and wetter conditions at planting time, and a lower availability of nutrients in the soil. The surface crop residues in reduced tillage immobilize a large portion of broadcast-applied nitrogen. A higher rate of surface-applied nitrogen is required with no till than with conventional tillage. The reasons for this are that (a) fertilizer nitrogen is immobilized by micro-organisms in the organic layer that accumulates on the surface with no-till, (b) more nitrogen is mineralized from the soil organic matter when plowed, (c) there is a higher yield potential with no-till in some areas, (d) there is more water movement through the soil with a higher loss of nitrates, and (e) denitrification/volatilization may reduce nitrogen use efficiency. Hence, the fertilizer nitrogen is generally placed below the surface residue to avoid immobilization, denitrification and volatilization losses.

Potassium and phosphorus applied through broadcasting are usually effective, particularly in humid areas. A lower potassium content in maize leaves occurs at silking with no-tillage, whereas a potash application increases the potassium content in the leaves in both the **tillage** and no-tillage systems. The yield increases with band-applied fertilizers in no-till system compared to plowed systems.

The application of nitrogen on the soil surface may turn the soil acidic with no-till. This calls for monitoring the pH of the surface soil. Certain herbicides, such as triazines, are inactivated by a low pH at the soil surface, with the result that weed control becomes ineffective.

Conservation tillage has the following advantages: (i) There is reduction of energy, time, labor and machinery costs. (ii) Plant residues protect the soil from rain and wind erosion. (iii) More area can be planted in a short time. (iv) Relay cropping in rows (with crops such as soybean, sorghum or corn planted immediately after wheat) is possible. (v) Steeper lands can be farmed for row crop production. (vi) A higher organic matter content in the soil and an increased water utilization efficiency is possible (more water is stored in the root zone).

Conservation tillage has the following disadvantages: (i) It is not applicable under all farming situations. (ii) It has less active humus incorporation in soils. (iii) It can accentuate weed problems. (iv) It is prone to herbicides build-up. (v) It requires more seeds. (vi) It is prone to pest damage from birds, mites and insects. (vii) It favors crop pests and diseases. (viii) It is not suitable for poorly-drained soils and for crops that require fine tilth, as in the case of nurseries and small-seed crops like sesame and mustard.

Consistence of soil

Consistence of soil is the resistance of soil to deformation and the degree of cohesion of the soil mass. The attributes of soil material are expressed in terms of its degree of cohesion and adhesion or its resistance to deformation or rupture. The consistency of soil varies with its water content and degree of cementation. If a soil adheres to other materials, it is considered **sticky soil**. There are degrees of stickiness, like non-sticky, slightly sticky, sticky and very sticky.

If a soil changes its shape under pressure and gets back to its original shape when the pressure is removed, it is called **plastic soil**. A soil can be non-plastic, slightly plastic, plastic or very plastic.

The moisture content of a soil determines its consistency which can be termed loose, very friable, friable, firm or very firm.

When soil is dry, its consistency can be rigid or brittle, loose, soft, slightly hard, hard or very hard.

Cementation of soil gives it a brittle or hard consistency. It can be weakly cemented, strongly cemented, or indurated.

Soil consistency is useful in estimating the soil flow or support strength under applied forces. The **consistency limits** (**Atterberg limits**) of soil are used primarily in classifying cohesive soil materials for engineering purposes and are strongly correlated to other fundamental soil properties. The consistency limits are also used in the estimation of soil properties such as shear strength and bearing capacity, compressibility and swelling potential.

Consistency limits, Atterberg

The Atterberg limits of consistency denote the range of water content over which the clay has plastic behavior. They consist of plasticity limit and liquid limit.

Soil can be solid, plastic or liquid depending on the quantity of water it contains. Plasticity is the property by which soil can be deformed easily and still maintain the shape given to it. If clay is moistened till it flows and is then allowed to dry, it will go progressively from the liquid stage to the plastic stage, thus, it passes from the liquid limit to reach the plasticity limit.

If the drying of the clay is continued, the plasticity limit passes, and the clay becomes a solid which is friable.

Constant composition, law of: See Chemical combination, laws of

Constant proportions, law of: See Chemical combination, laws of

Consumptive use

Consumptive use in the context of crops refers to the total quantity of water used for crop growth in a given area. This includes the water lost by evapotranspiration (evaporation plus transpiration or ET), and the water contained in the plant tissues. Consumptive use of water is determined by using lysimeters.

Consumptive use is increased by conditions like warm weather, dry air and wind, which together increase evaporation. Daily consumptive use ranges from 2 mm to 15 mm. The estimation of consumptive use of water is needed to optimize the use of available water for irrigating crops.

Contact fungicide

Contact fungicides, also called **non-systemic fungicides** or **residual protective fungicides**, are one of the two types of fungicides that do not penetrate plant tissues. They serve a protective function by forming a barrier on the plant surface that prevents the fungus from entering the host, by inhibiting spore germination or mycelial growth. Most non-systemic fungicides react with thiol groups that are present in the enzymes of fungi, thereby inhibiting many metabolic processes and acting as multi-site inhibitors. Sulphur, copper oxychloride and cuprous oxide are examples of inorganic contact fungicides, while dithiocarbamates, phthalamides and dicarboximides are examples of organic contact fungicides.

Contact placement

Contact placement is a method of applying fertilizer close to seeds. This is also called **drill placement** as the seeds and the fertilizers are sown together by drilling in the soil (Fig.C.37). It ensures that a small amount of fertilizer

Fig.C.37: Tractor-mounted combined seed and fertilizer drill for contact placement of fertilizer.

gets spread with the seeds in each row. Contact application can be damaging to seeds only if the seeds have excessive concentration of fertilizer. Otherwise it benefits plants in a variety of ways as it (a) enhances the development of root and above the ground plant parts, resulting in early cultivation, increased competition with weeds, reduced heat stress during pollination, and early harvest, (b) provides quicker soil cover by plants and decreases run-off or erosion losses, (c) reduces grain moisture content at harvest time and cut production costs, (d) improves nitrogen use efficiency, increasing production efficiency and reducing the potential for water pollution, and (e) boosts the crop yield, quality and ultimately the farmer's profit. (See also Localized placement.)

Contact process

The contact process is one of the processes for making sulphuric acid. The acid is made from sulphur dioxide which in turn, is made by burning sulphur or roasting sulphide ores. A mixture of sulphur dioxide and air is passed over a hot catalyst to get sulphur trioxide.

$$2SO_2 + O_2 \longrightarrow 2SO_3$$

The reaction is exothermic and the conditions are controlled so as to keep the temperature to an optimum 450°C. Formerly, platinum catalysts were used, but they have now been replaced by vanadium oxide catalysts. The sulphur trioxide is dissolved in sulphuric acid to get oleum which is diluted to get the required concentration of sulphuric acid. (See also Sulphuric acid.)

Container

Storage vessels, commonly made of steel, concrete or wood are called containers. Efficient storage of farm produce is important to meet market demands and to increase the profitability of a farming enterprise. If the product deteriorates in storage, its economic and nutritive values tend to decrease. Farmers store food products either in a specially designed structure, in any convenient place or in a receptacle (especially jute bags or baskets). Similarly, fertilizers are stored in 50 kg jute or polythene bags, as well as in piles. These container bags have to be moisture resistant, as some fertilizers tend to absorb moisture from the atmosphere. Agricultural silos and bins, constructed of aluminum, galvanized steel or reinforced concrete are commonly used to store and transport large quantities of cereal grains. Such containers are provided with an air plenum through which air is passed at about one fifth the level needed for drying an equivalent quantity of grain. Circular butyl rubber bins are also used to store grains. Seeds are stored in sealed containers to extend their storage life.

Contaminant

Contaminant is an undesirable foreign material present in a product. Contaminants, when present in air, water or food products, make them toxic or otherwise harmful. Sulphur dioxide resulting from the combustion of high sulphur fuels, pesticide residue in vegetables and industrial dusts are some examples of contaminants.

Continental dunes

A dune is a ridge or hillock of sand created by winds. It can attain a height of several hundred meters. The continental dune formed inland exhibits a near perfect symmetry when there is no dominating wind.

Continuity

Continuity, in the context of soils, is the length of unbroken, continuous, or coherent soil pores. Alternatively, continuity is a smooth or unbroken sequence or graduation of soil. In such cases, distribution is continuous rather than divided into distinct groups.

Continuous cropping

Continuous cropping, also called continuous cultivation, is another name for **crop monoculture**. It involves the cultivation of the same crop, on the same land, year after year. Repeated growing of the same crop on the same soil leads to soil sickness and this calls for large amounts of fertilizers and pesticides to be added to it. Crop rotations, prevent soil sickness and increase crop productivity.

Continuous drying

Drying carried out with continuous flow of grain and air in contrast to a batch process is called continuous drying. (See also Drying.)

Contour cultivation

Contour cultivation refers to tilling and planting across the natural slope of a land. On terraced fields, contour tillage forms ridges and effectively controls soil erosion during light rainfall on moderate slopes of 2 to 8%. A combination of contour tillage, terracing and **contour strip cropping** is more effective in controlling erosion than contour cultivation alone (Fig.C.38).

Contour cultivation is found to increase yield along the slope by 35% in sorghum and 20% in solaria, at no additional cost. Experiments have proven that contour

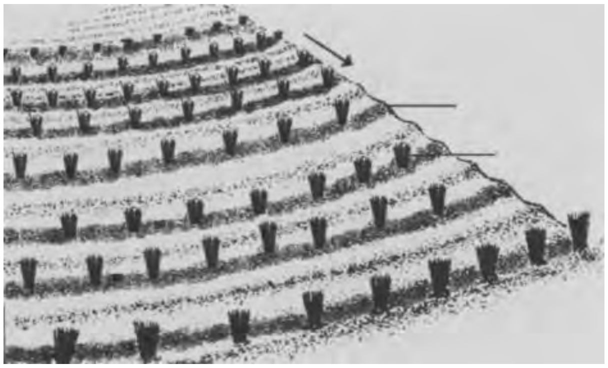


Fig.C.38: Contour strip cropping. Ridges and trenches formed during contour cultivation reduce soil erosion.

farming reduces run-off and prevents soil erosion compared to the up-and-down cultivation in major groups of soil in a country like India.

Contour strip cropping

Contour strip cropping is a method of planting crops in strips of suitable width across the slope or contour, alternating with strips of soil-protecting and erosion-resisting crops. Contour strip cropping shortens the length of the slope, checks the movement of run-off water, helps to desilt water and increases the absorption of rain water by the soil.

Control droplet applicator

The control droplet applicator uses high-speed spinning nylon discs with fine-toothed margins to produce uniform size droplets in the range of 250 to 300 microns. Unlike the common spray nozzles which produce a wide range of droplet sizes, the control droplet applicator gives less spray drift and uses material economically (Fig.C.39).

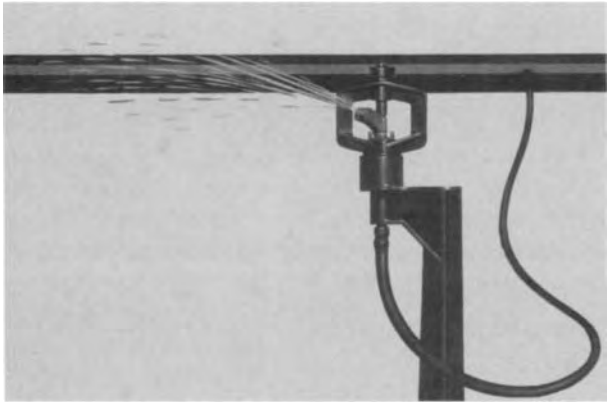


Fig.C.39: Control droplet applicator; nozzle produces uniform droplets.

Controlled-release compound

A controlled-release compound is one which releases the material contained in it at a fairly defined rate over a period of time. This not only provides more effective control but also reduces the waste involved in using unnecessarily high concentrations. Fertilizers and pesticides are formulated using controlled-release compounds, to increase shelf-life. Controlled-release compounds can be effected by (a) encapsulation, (b) incorporating them into a neutral matrix such as a rubber or plastic, (c) coating them with sulphur as in the case of urea coated with sulphur, and (d) absorbing them into substrates of various types.

Controlled-release fertilizer

A controlled-release fertilizer is the one, the rate of release of which is regulated by the use of coatings of sulphur, neem, polymeric compounds, etc. on the fertilizer granules. This enables the nutrients to be available to the plants over a long period of time.

The term 'controlled-release' is sometimes replaced by other terms, such as delayed release, slow release, controlled availability, slow acting, or metered release to designate controlled dissolution of fertilizer at a lower rate than that of conventional water-soluble fertilizers.

Control section

Control section is the predetermined depth of a soil profile used to determine the water section, texture control section, or temperature control section of a soil, for that specific determination.

Conventional tillage: See Tillage

Conversion factor of fertilizer: See Recommended dosage of fertilizers

Converted rice

Milling and polishing of rice lead to the loss of nutrients from the grain. Processing of rice has hence been found necessary in order to retain its valuable nutrients and taste. After such a process is carried, involving soaking and steaming the rice prior to the milling operation the rice get transformed into converted rice.

Converted rice contains potassium, folic acid and phosphorus in lesser quantities than brown rice. Converted rice is commonly enriched with thiamine, niacine and iron.

Cool semi-arid region

Generally semi-arid regions have a higher moisture content than arid regions. Cool semi-arid regions are those where the annual precipitation is as low as 38 cm. The low moisture in semi-arid areas limits plant growth. Dry-farming methods or irrigation are required for producing crops in such regions.

Coordination compound

A coordination compound is a compound formed by the union of a metal ion (usually transition metal) with a non-metallic ion, atom or molecule called a **ligand** or **complexing agent**. The ligand may be positively charged or negatively charged (Cl^- or $NH_2^- \cdot {}^+NH_3$) or it may be a neutral molecule like water or ammonia.

The most common metal ions are those of cobalt, platinum, iron, copper and nickel, all of which form largely stable compounds. When ammonia is the ligand, the compounds are called amines. The total number of bonds linking the metal to the ligand is called its **coordination number**. It is usually 2, 4 or 6, and depends on the type of ligand involved. All ligands have free electron pairs on the coordinating atom N, O or S. These free electrons can be donated or shared with the metal ions. The metal ion acts as an electron acceptor (**Lewis acid**) and the ligand, an electron donor (**Lewis base**). The bonding is intermediate between covalent and electrostatic or ionic bonds. The charge on the complex ion is the sum of the charges on the metal ion and the ligands. For example,

$$4NH_3 + 2Cl^- + Co^{3+} \longrightarrow [Co\,(NH_3)_4(Cl^-)_2]^+$$

The coordination compounds of micronutrient metal ions are used as foliar sprays to overcome nutrient deficiency.

Coordination number: See Coordination compound

Copper

Copper (Cu) is a transition element, belonging to Group 11 (formerly Group IA) of the Periodic Table. It is an important non-ferrous metal and a micronutrient (Fig.C.40) with two distinct functions - to serve as a plant nutrient by being an activator or by being a part of certain enzymes like tyrosinase, lactase, ascorbic acid oxidase, cytochrome oxidase, etc., and secondly to play a role in many electron transfer processes.

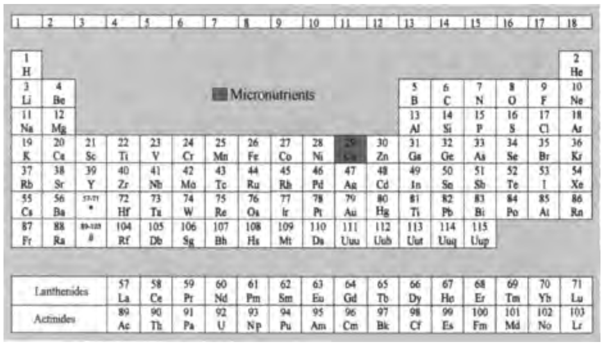


Fig.C.40: Position of copper, a micronutrient element, in the Periodic Table.

Copper is a component of several enzyme complexes that influence carbohydrate and nitrogen metabolism in plants. Its other function is to neutralize harmful soil conditions. This is done by adding copper sulphate to the soil to maximize the crop yield. The addition of large quantities of copper in certain peat soils in Kerala (India) was found to precipitate or inactivate some toxins present in the soil and neutralize the harmful conditions. About 70% of copper in a plant is found in chlorophyll and plays an important metabolic function.

Plants absorb copper through leaves as cupric ions (Cu^{2+}) in the form of a complex, such as **EDTA**. In soils, copper is found mostly in the cupric (Cu^{2+}) form, adsorbed by clay minerals as well as organic complexes to an extent of 2 to 100 ppm. The content of soil organic matter, pH and other metallic ions such as iron, manganese or aluminum influence the availability of copper in the soil. The amount of exchangeable copper decreases as the pH increases. Enhancing the concentration of aluminum beyond 0.1 ppm in soil solutions is found to decrease copper uptake in wheat plants. The ratio of copper to other metallic ions in the rooting medium is more important for plant growth than the absolute concentration of copper.

The retention of copper in soil increases in proportion to the organic matter content. Depending on their stability, copper-humus complexes make copper available to plants. The copper content in soil ranges from 5 to 60 mg per kg, although both lower and higher values are not uncommon. The average amount of copper in soils is about 9 to 10 mg per kg. The most familiar copper mineral in soils, chalcopyrite ($CuFeS_2$), has copper in the cuprous (Cu^+) form. These minerals have very low solubility which increases with pH. The nature of the reactions of copper with various organic matter is still to be fully explored. Soils which are high in organic matter are more prone to copper deficiencies than those with a lesser organic matter content.

The symptoms of **copper deficiency** vary with crops and are similar to those of **potassium deficiency**. Copper has low soil mobility and is considered to be deficient when the copper level is below 4 ppm in dry matter. Copper deficiency causes the early aging of chlorophyll and a subsequent fall in crop yield. Lucerne, carrot, onion, barley, oats, wheat and orange are sensitive to copper deficiency. Copper deficiency is common in vegetables, small grains and fruits growing on sands, organic soils or over-limed acidic soils. In corn, the youngest leaves become yellow and stunted. As the deficiency becomes severe, the young leaves turn pale and the older ones die (Fig.C.41). In many vegetable crops, the leaves lack turgor and assume a bluish-green hue. **Stem melanosis** is a disease occuring in certain beet varieties due to copper deficiency. Organic soils are often copper deficient, as are calcareous soils, the pH of which falls in the range of 8.0 to 8.4. A foliar spray of a few kilograms of copper salt per hectare is enough to correct

Fig.C.41: Leaf fall in chilli, caused by copper deficiency.

copper deficiency for many years. Copper deficiency increases the incidence of lodging, when simultaneous growth occurs as a response to nitrogen fertilization. Since pollen and ovaries are very sensitive to copper deficiency, flowering and fruiting may be adversely affected or even become absent.

Like most micronutrients, excess copper is toxic to plants. It reduces the iron activity and leads to **iron deficiency**.

Copper toxicity symptoms include a reduced shoot vigor, a poorly developed and discolored root system and leaf-chlorosis. The toxicity can be seen at places of iron ore deposits and copper smelting. In citrus and lettuce, high copper levels induce iron chlorosis. Copper also significantly inhibits the uptake of zinc, and vice versa.

The most common copper fertilizers include copper sulphate and copper ammonium phosphate. Copper sulphate solution is sprayed on plant leaves. Copper ammonium phosphate is added directly to the soil or sprayed on plants as a suspension in water. Copper salts, produced as **frits** or **chelates**, are suitable for soil application. **Copper chelates** are available for soil as well as for foliar application, in view of the slow release of copper to plants and prevention of copper ions getting converted into insoluble compounds in the soil.

Copperas

Copperas, also called **green vitriol**, is ferrous sulphate heptahydrate. It is an iron salt fertilizer, which is most effective in overcoming iron deficiency.

Copper chelates

Copper chelate (Cu-EDTA), a stable complex of cupric ion and an organic ligand like EDTA is a good source of copper and can be used as a foliar spray. The strong chelating action of the soil organic matter for copper ions supplied as a salt, is due to multiple ligand groups, primarily carboxyl groups, present in it. Plants can utilize copper from copper complexes even when the soil pH is high. This is because the complexes prevent the adsorption and precipitation of copper on the soil surface.

Copper deficiency: See Copper

Copper frits

A **frit** is a mixture of silica and fluxes which are fused at high temperature to make glass. Copper frits are melted glass particles containing measured quantities of copper. These are mixed with fertilizers before application. Frits, which release micronutrients slowly, are inert, easy to handle and easy to mix with fertilizers.

Copper toxicity

Copper toxicity, like the toxicity of most micronutrients, is caused by an overdose of copper which significantly inhibits zinc uptake. Copper toxicity symptoms include a reduced shoot vigor, a poorly developed and disfigured root system and leaf **chlorosis**. The toxicity is seen at places of iron ore deposits and copper smelting.

Co-precipitation

Co-precipitation is the precipitation of a trace element with the major constituent element which occurs while doing gravimetric analysis. To overcome impurities, the precipitate is dissolved and re-precipitated, or the precipitation is carried out in dilute solutions.

Cork cambium

Cork cambium is a type of cambium cells arising within the outer layers of the stems of woody plants, usually as a complete ring surrounding the inner tissues. The cells of cork cambium divide to produce an outer corky tissue and an inner secondary cortex. Cork, cork cambium and phelloderm together make the **periderm**, an impermeable outer layer that protects the inner stem tissues, if the outer tissues split due to the increasing stem girth with age. The periderm then takes over the functions of the epidermis.

Corn

Corn, a native of the American continents, is a member of the grass family. It was called maize by the native Indians, and is botanically known as *Zea mays*.

Although the ancestry of corn is being debated, today's corn is commonly believed to be the descendant of a Mexican wild grass called teosinte, *Zea mexicana*. Teosinte had ears on many stalks that dispersed the seeds easily. Teosinte over the years probably mutated to form the less adaptive corn of today.

The corn plant grows to around 2 meters and bears separate staminate inflorescence (which are the tassels on the stalk) and pistillate inflorescence (which gives rise to the ear of corn). The ear, containing the kernels, is tightly covered with a husk or bract, making it difficult for the seeds to disperse.

According to the nature and composition of starch in the endosperm, corn can be of various types, such as sweet corn, popcorn, flour corn, etc.

The corn plant grows on all soils, except very clayey or very sandy soils. It cannot tolerate waterlogging and is moderately sensitive to salinity. Corn grows best in temperate to tropical climates, with daily average temperatures above 20°C.

Corn contains large amounts of carbohydrate but low amounts of proteins. It is used as animal feed and as an ingredient of many processed foods and industrial products. They include corn starch, corn flour, corn oil and syrup, laundry starch, glues, etc.

Corn cultivation management practices

Effective management practices for corn cultivation involve common strategies that help optimize yields, reduce the risk of pathogens and maintain ideal soil conditions.

It is a common practice to cultivate hybrid corn varieties that respond well to local soil conditions and increase yields. Such varieties ideally include plants with a robust root system.

Early planting is an accepted practice to minimize rootworm attack. The eggs hatch in spring, and the larvae feed on young roots while the adults feed on leaves and pollens. If the plant completes the growth and pollination stages, before the worms grow into adults, the loss caused by these pathogens can be minimized.

Crop rotation is considered a useful management practice in corn production. Corn is usually rotated with soybean to fight pathogen attack, considering the nature of residues left behind by either crop. Corn generates more residues than soybean. Corn residues break down gradually while soybean residues disintegrate easily. A lower soybean residue bulk helps keep waterlogged conditions at bay, thus aiding corn crop.

Generally accepted tillage practices for corn in low-rainfall areas are ridge tillage and no-tillage. A one-pass field cultivation, or fall chisel plowing and spring cultivation are considered ideal on poorly drained soils. However, the corn yield (in a corn-soybean rotation) gradually decreases, if the no-till practice is continued.

Considering that poor soils lead to poor crops, the management of nutrients is another crucial task for optimum corn yields.

Nitrogen may be commonly supplied through anhydrous ammonia along with soybean residues. Injecting **UAN** (urea-ammonium nitrate) into the soil also supplies N to the crop.

Phosphorus and potassium are also required for corn and may be applied by (a) incorporation with a tillage implement, (b) deep banding within the ridge with ridge tillage, and (c) applying as a starter fertilizer. A post-harvest broadcast of P and K fertilizers is ideal for corn in its second year of rotation. However, since excess of phosphorus leads to zinc deficiency in corn, phosphorus management has to be proper and realistic.

Liquid livestock manure can be injected into the soil before planting. Alternatively, may be side-dressed between crop rows.

Magnesium deficiency affects corn with whitish stripes on the veins of the lower leaves. The addition of dolomite limestone is effective in correcting Mg deficiency. On average, 22 kg/ha of dolomite is seen to increase the dry weight of corn significantly, although the exact application depends on the extent of deficiency.

As far as implements are concerned, row cleaning devices are useful in reduced tillage conditions. They remove band residues over the corn rows, thus aiding stand establishment, early growth and maturity.

Corn, major diseases

Corn, like any other crop, is susceptible to pathogenic attacks. One such pathogen is the **corn rootworm**, which is of two types, the western corn rootworm and the northern corn rootworm. Both are common in the corn fields of Colorado, USA.

Western corn rootworm, which can create major losses, has black wing covers. After overwintering in the egg stage, the larvae hatch around the middle of May when soil temperatures start to increase. The larvae feed on root hairs, small roots and even primary roots. The larvae grow into adult beetles which start feeding on leaves and pollens of nearby crops. The beetles mate, lay eggs and multiply. In highly affected fields, loss in yields can be as much as 10%.

Crop rotation, insectigation and planting management are some of the measures to control this disease.

Another disease is the **southern leaf blight** caused by *Bipolaris maydis*. It can damage corn crops, if not controlled.

Corn smut is a major fungal disease of corn caused by *Ustilago maydis*. This fungus has two spore stages, namely teliospores and basidiospores. The pathogen overwinters on plant residues or on the soil in the teliospore stage. It germinates in spring as the mean temperatures start to increase and the basidiospore stage begins. The fungus reaches young and growing tissues of corn plants and produces masses of brownish black spores which then rupture through the membranes. In this way, propagation of the fungus is carried on. Corn smut affects most corn fields, at least to some extent.

Corn oil

Corn oil is an adjuvant used in herbicide sprays. It improves their function by improving wetting, reducing evaporation, increasing penetration and enhancing deposition and compatibility. Corn oil is not phyto-toxic; it is added for better penetration in plant leaves.

Corn rootworm: See Corn, major diseases

Corn smut: See Corn, major diseases

Corn stover

Dried and mature stalks and leaves after the removal of grains of cereals like corn, sorghum and pearl millet are called **stover**. Corn stover can be used as a feed, as bedding or as residue material to be incorporated into the soil. It is also used as surface mulch.

Coronet phosphate

Coronet phosphate is a defluorinated calcined phosphate rock.

Corrective fertilization

Applying fertilizer to a soil to correct its nutrient deficiency is known as corrective fertilization. For example, adding urea to correct nitrogen deficiency in soil is corrective fertilization.

Corrosion

Corrosion is the erosion of metal in the presence of air, water or chemicals by a chemical or electrochemical attack on the metal surface. Corrosive reactions are oxidation-reduction reactions, which produce compounds that lack metallic properties. For example, iron or steel left exposed to air or moisture forms iron oxide on the surface, resulting in the loss of some metal. Corrosion reduces the intrinsic properties of the metal.

The simplest method of protecting a metal from corrosion is to cover it with paint or some other impervious protective coating. Another method is to plate the metal with a thin layer of another metal. For example, iron can be plated with copper by electroplating, with tin by dipping the iron into molten metal, or with zinc (galvanized iron). Yet another protective method is to bring the metal into contact with a more active metal like magnesium, that corrodes preferentially. This type of action is called **cathodic protection** because the protected metal acts as a cathode, where reduction occurs.

Around 40% of corrosion problems are due to stern-corrosion cracking, hydrogen embattlement and corrosion fatigue. These corrosion phenomena arise out of mechanical and chemical failures. They constitute some of the worst corrosion problems because failure of the structure occurs often without warning and sometimes with catastrophic results. Other forms of corrosion attacks include fretting corrosion, liquid metal embrittlement and corrosion by gases.

Corrugation

The creation of V-shaped, small, close furrows is known as corrugation. These furrows are used for irrigation.

Corrugation method of irrigation

The corrugation method of irrigation, which is a modification of furrow irrigation (with closed furrows), is the oldest method of irrigation. Here, water flows from a main ditch through a series of narrow and shallow furrows by gravity. The crop is planted on top of the ridges before water is let in. Field crops, such as corn and cotton are irrigated via a single furrow to carry water to all plants. Crops like berries and grapes, as well as orchards, which are planted widely, have two furrows for irrigation. Generally, this method of irrigation results in severe soil erosion, especially when the slope is more than 2%.

Corundum

Corundum is a colorless mineral form of aluminum oxide. It is transparent when pure, and assumes color in the presence of other elements. Rubies contain chromium and are red. Sapphires contain iron and titanium and are blue.

Corundum occurs as a rock-forming mineral in both metamorphic and igneous rocks. It is resistant to weathering and occurs in alluvial deposits. It is the second hardest material known and is used as an abrasive.

Cost-benefit analysis

Cost-benefit analysis involves assessing the relation between the cost of an operation (including all social and financial costs) and the value of the resulting benefits. This gives the **cost-benefit ratio**, which indicates whether the benefits of a project are higher than its cost. When applied to agriculture, it means that the expenditure involved in applying fertilizer to the soil (that is, the fertilizer cost plus the cost of applying it) must be less than the net gain by way of an increased crop yield to justify the use of fertilizer. In practice, the cost-benefit ratio varies, depending on the soil type, the crop to be harvested, climatic conditions and management practices adopted.

Cost-benefit ratio: See Cost-benefit analysis

Cottonseed meal

Cottonseed meal or cake is the pulverized cottonseed press cake that remains after the removal of oil. Depending on the extractive process, varying percentage of protein remain in the meal and it is normally sold with 36 to 45% protein content. The 42% product contains approximately 42% crude protein, 6% crude fiber, 25% nitrogen free extract, 10% ether extract and 7% ash. Ash is high in potash and phosphate. The total digestible nutrient averages 79%. Some types contain gossypium, which is toxic.

Cotyledon

Cotyledon is a part of the embryo in a seed plant. Cotyledons forms the first leaves of a plant. The number of cotyledons is an important feature in classifying plants. Among flowering plants, the class known as monocotyledonae has a single cotyledon, and the class called dicotyledonae has two cotyledons (Fig.C.42). Conifers have either two cotyledons, as in *Taxus* (yews) or between 5 and 10 as in *Pinus* (pines). In seeds without

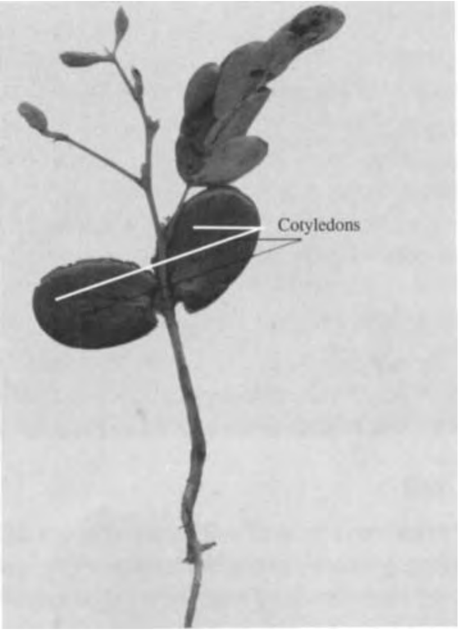


Fig.C.42: Cotyledons of a dicot plant.

an endosperm (such as garden pea or broad bean), the cotyledons store food for use during germination. In seeds showing epigeal germination, like runner bean, the cotyledons emerge above the soil surface and become the first photosynthetic leaves.

Cotyledon leaf: See Leaf

Counter staining

Counter staining is a technique in which cells or thin sections of normally transparent biological tissues are immersed in two or more color dyes (stains) to make them more clearly visible through a microscope. Staining increases the contrast between the various cells or tissue components. Counter staining involves the use of two or more stains in succession, each of which colors different cell or tissue constituents. Methylene blue in acid fast staining or safranine in Gram staining are examples.

Cover crop

A cover crop, also called a **nurse crop**, is a crop that protects soil, protects another crop sown beneath it, or provides cover for game birds. Temporary leys, for example, are usually sown using a cereal as the cover crop and grass is sown immediately after the sowing of the cereal seeds. The effectiveness of a cover crop depends on the closeness of the spacing and the development of a good canopy for intercepting raindrops and exposure of the soil surface.

CP

CP is short for **crude protein**.

Cracked gasoline: See Gasoline

Cracking

Cracking is a process of using heat to break down chemical compounds. The term is usually applied to the cracking of petroleum crude into various fractions.

Cracking is an important process, as a source both of branched chain hydrocarbons (suitable for gasoline) and of ethylene and other hydrocarbons.

Catalytic cracking is cracking which uses a catalyst for lowering the temperature and for modifying products according to the need. Cracking of naphtha yields the hydrogen required for ammonia synthesis.

Cracking clays

Clays that shrink during dry periods, causing gaps between large clods are called cracking clays. Cracking is a characteristic of black soils.

Creep, soil

A slow mass movement of soil material down relatively steep slopes, primarily under the influence of gravity and without the intervention of water or wind, is called creep. It is facilitated by saturation with water and by alternate freezing and thawing.

Creep is most effective in the upper soil layers and is usually absent below the depth of 90 cm. The rate of movement rarely exceeds 2.5 cm per year. The economic cost of creep can be considerable due to the repairs it demands.

CRH

CRH is short for **critical relative humidity**, beyond which a fertilizer starts absorbing moisture.

Crinkled leaf, cotton

The crinkled leaf of cotton is a symptom of **calcium deficiency**.

Crinkly leaf

Crinkly leaf or curly top is a disease of cotton and leafy green crops, caused by manganese deficiency.

Critical concentration of nutrient: See Critical nutrient concentration

Critical depth: See Critical water table depth

Critical difference

Critical difference is the difference between two experimental treatments. The difference must be statistically significant and considered real. (See also Least significant difference.)

Critical nutrient concentration

Critical nutrient concentration (CNC) is the minimum concentration of a nutrient in a plant tissue at maximal growth. CNC is commonly used in interpreting plant analysis results and diagnosing nutritional problems. As the determination of the exact CNC is difficult, the use of **critical nutrient range** (CNR) is resorted to. CNR is defined as the range of nutrient concentration at a specified growth stage above which the crop is amply supplied with the nutrients and below which the crop is deficient.

Critical concentration describes that degree of concentration at which growth or yield begins to decline significantly. It is derived from calculating the yield of a plot as against its nutrient concentration.

Critical nutrient range: See Critical nutrient concentration

Critical relative humidity

Critical relative humidity is the atmospheric relative humidity at which a material begins to absorb moisture from the atmosphere. A high critical relative humidity is advantageous because materials can then be better handled and even exposed to more humid atmospheric conditions, without the risk of getting wet, absorbing moisture, turning non-flowable or caking. (See also Hygroscopicity.)

Critical value

A critical value is the concentration of an element, below which any supply of the element leads to an increased growth of the plant. The concentration of an element in plant tissues and their growth are closely linked. Various symptoms and signs of disorder indicate the deficiency of one or more essential elements in a plant, which are visible only after the plant has suffered growth retardation.

To diagnose nutrient deficiency, critical values have to be determined for individual crops and soils, preferably when no other nutrient element limits the growth. For example, the critical values in corn are about 3% nitrogen, 0.3% phosphorus and 2% potassium in the leaf opposite and below the uppermost ear at silking time. It should be noted, however, that moisture supply to plant has a significant influence on the critical value.

As it is difficult to determine the exact critical value, it is more realistic to use a **critical nutrient range**, above which the crop is amply supplied with the nutrient, and below which the crop is deficient. While using the critical nutrient range, the critical value becomes independent of soil type.

The critical nutrient ranges for micronutrients and macronutrients for various crops have been recorded. Under severe deficiency, a rapid increase in the yield due to the addition of a nutrient can cause a small decrease in the nutrient concentration. This is known as the **Steinberg effect** which results from dilution of the nutrient in the plant. When the concentration reaches the critical range, the plant yield is maximal. Nutrient sufficiency occurs over a wide range of concentrations at which the yield is unaffected. When a plant absorbs nutrients without increasing production, it is known as **luxury consumption**. Excess nutrients beyond the critical range, reduce plant yield through toxicity.

Critical water table depth

Critical water table depth is defined as the depth of the water table above which the salts in groundwater can rise through capillary action to cause a salt build up on the surface horizon. A close relationship exists between the critical depth of ground water and its salt content, which leads to salinization of the surface soil.

When a water table is lowered, evaporation decreases hyperbolically, which sets the critical maximum evaporation rate at 0.1cm/day. Based on this criterion, the critical water table depth for sandy loam soils of Sonepat district of the state of Haryana (India) is observed to be 80 cm.

The depth above which groundwater is liable to salinize surface soils decreases with increasing salt concentration. For salt concentration of 1, 2.5 and 5 g per liter, the critical water table depths are roughly 3, 2 and 1 meter respectively. The maximum quantity of salts (Q_s) that can be accumulated in the soil profile during a year, equal to the natural leaching potential of the soil, is related to maximum permissible (critical) flow velocity (V_m) as follows:

$$V_m = \frac{10 \cdot Q_s}{C_w T}$$

where C_w is the salinity of groundwater and T is the time in days. The depth of water table that prevents the flux from being higher than V_m is defined as the **critical depth**; it is 70 cm for sandy soils and 225 cm for loam soils.

Crop

Crops are plants grown on a cultivated land to produce yields like (rice, wheat, sorghum) (Fig.C.43) for human consumption or as animal fodder. Even plants which are not sown but which come up naturally in a cultivated land from wild seeds (e.g., crop thistles) are all called crops. The term also applies to a produce harvested from a

Fig. C.43: Sorghum crop in a field.

cultivated land by combined operations (such as mowing, cutting, reaping and gathering).

Crops are classified on the basis of the duration of growth as annuals, biennials and perennials. They are grouped on the basis of usage as food, feed, industrial crops and cash crops. Crops are also grouped according to the purpose they are grown for, or according to their products.

Crops are classified based on the type of production - such as field crops, forage crops, horticultural or plantation crops and also on their market value or grades.

Crops may also be classified according to their botanical family. Over 80% of crops are grasses (Gramineae), legumes (Leguminosae) and crucifers (Crucifereae). They are also classified according to their dominant economic function for the cultivar.

Crop circle

Crop circle refers to a circular area in a field of standing crops, especially of wheat or other cereals, in which the stalks have been flattened to the ground.

Crop dusting

Crop dusting refers especially to the aerial spraying of powdered insecticide or fertilizer on crops.

Crop geometry concept

The crop geometry concept, refers to actual spacing between two eye bud sets (of sugar cane) or two plantlets in each row, and the number of rows unplanted for growing a short duration intercrop, to make farming more economical. It is recommended for cash crops like sugar cane.

The relationship of crop geometry to crop productivity is based on the solar energy that becomes available to the crop and is actually used by the crop at the given location in that season.

The economic benefits of crop geometry depend on the nature of the intercrop grown, proximity to a market, rates realized from the intercrop, fertility status of the soil, crop variety used, fertilizer dose applied and irrigation and management practices adopted. There is a wide scope for economy in the use of water and fertilizer. There is also an increase in the microbial activity in the soil, making it healthier and leading to a better environment for crop growth.

In implementing the crop geometry concept, it is essential to carefully decide the row distance, the spacing between the two eye bud sets or two plantlets, the number of rows to be left unplanted for growing an intercrop, irrigation resources and the variety to be planted. Depending on the crop geometry pattern on a large scale, it is possible to get a higher yield at a lower cost of cultivation, leading to higher profits.

The concept needs to be tested on different types of soil, in different crop varieties differing in their tillering habits, abilities, leaf angle, leaf size, leaf area index, yield potential due to variation in maturity habits and nutrient needs.

Crop growth rate: See Leaf area index

Crop log system

The crop log system, also called foliar diagnosis, is a reliable method of assessing the nutritional status and needs of the crop. Plant indices, which indicate the level of nutrients in the plant tissue (usually the leaf), help assessing the nutritional status of the crop and its impact on the crop yield. For crop logging, sugar cane plants are sampled every 35 days and analyzed.

The maintenance of the nutrient level in a plant (leaf nitrogen) helps to optimize the fertilizer dose for optimum yield. Soil moisture is a limiting factor in maintaining the nitrogen index in the leaf. The changes in tissue indices at the early stages of crop growth are dependent more on irrigation and temperature than on fertilizer alone. This is typically seen in crops like sugar cane.

A higher dose of nitrogen fertilizer does not always result in a higher nitrogen index in the leaf tissue (in sugar cane). For determining the optimum index, the knowledge of the fertility status of the soil is necessary. By adopting the crop log technique, it is feasible to achieve a maximum crop yield with the most economic fertilizer dose. The index value, once fixed for a particular variety of crop under a given set of weather conditions, helps to achieve a fairly good economic cultivation of the given crop. The plant index for a particular nutrient is maintained by applying a small dose of fertilizer as and when necessary.

The nitrogen index in the leaf of a sugar cane crop fluctuates between 2.1% (during the early growth phase) to 1.2% (during the maturity stage). In the early growth phase, 1.3% nitrogen in the leaf blade indicates a deficiency of nitrogen in the plant. Thus, the crop log technique can be profitably used for reducing the nitrogen dose. A normal level of leaf nitrogen in sugar cane is found to be 1.4% under tropical conditions. The sheath moisture and leaf nitrogen are all correlated with the uptake of nitrogen by the sugar cane crop.

The range value noted for other indices are sheath moisture (72% to 85%), phosphorus index (0.18% to 0.22%) and potassium index (1.8% to 2.75%). The sheath moisture in 3 to 6 leaves in the first four months and again at the harvest time, acts as a reliable guide for predicting the crop (sugar cane) yield and the quality of the crop respectively. Plant index studies indicate the necessity of adjusting the staggered instalment of the nitrogen dose during the grand growth period, leading to a maximum utilization of the applied nitrogen.

Crop mark

Crop mark is a local variation in the color or growth of a crop, especially when seen from the air, caused by a varying depth of soil.

Crop monoculture

Crop monoculture or **continuous cropping** involves the growing of a single crop at one time, year after year, in the same region. A repeated growing of the same crop on the same soil (Fig.C.44) can potentially result in soil sickness, caused by the combination of the build-up of soil pathogens, nutrient depletion, change in soil structure, soil exhaustion and accumulation of toxic substances. A monoculture crop usually requires large amounts of fertilizers, pesticides, etc. A continuous monoculture of both corn and soybean is reported to give in successive years a lower yield and lower tissue concentrations of phosphorus, copper and zinc, than in the first year.

Fig.C.44: Sugar cane is grown as a monoculture crop.

Crop rotation increases the long-term crop productivity compared to that from continuous cropping. The legume and meadow-based rotation and conservation tillage systems often maintain more favorable soil properties than those of monoculture and plow-based methods. In addition to decreasing the incidence of disease, crop rotation may also improve physical and nutritional properties of the soil. Meadow and leguminous cover crops improve the soil structure and fertility.

Crop rotation significantly improves the corn grain yield which averages at 1.22 tons per hectare in a corn-oat-meadow-rotation, compared to 0.96 ton per hectare in a corn-soybean rotation or in corn monoculture.

Increasing the frequency of corn and sorghum in rotation with soybean increases the surface organic carbon and nitrogen, especially under a no-tillage situation. Crop rotation increases the yield and profitability (via diversification) and decreases environmental risks due to reduced chemical inputs. (See also Agriculture.)

Cropping intensity index

Cropping intensity index is a measure of the crop yield advantage. It is used in multiple cropping data interpretation. The growing of a double crop in a year gives a cropping intensity index of 2.0, whereas a monoculture crop gives an index of 1.0.

The criteria generally adapted to measure the yield advantage of multiple cropping over the monoculture relate to the (a) land equivalent ratio, (b) relative crowding coefficient, (c) aggressivity index, and (d) competition index.

The form of multiple cropping varies from area to area, depending on the farmer's total resources. Multiple cropping increases the agricultural production from 12 to 22%, depending on the region and the crop.

Cropping pattern

Crops are grown all the year round in most parts of the world and especially in tropical regions, when sufficient water is available.

In most parts of the Indian subcontinent, seasons are distinctly demarcated based on climatic and cropping patterns. In Northern India, for instance, there are two distinct seasons, known as ***Kharif*** (June to September) and ***Rabi*** (October to April).

Kharif (meaning in Arabic, the summer rains) is also called the **wet season** or the monsoon season in which the autumn crop is sown just before the onset of the summer rain or the crop season during the monsoon period. *Rabi*, in Hindi, means the post-monsoon **dry season** or the **post-rainy season**. The crop is sown in September-October and reaped during spring. Crops grown between April and June, which is a relatively short crop season between the two main *Rabi* and *Kharif* seasons, are known as ***Zaid*** crops.

Crop price support

Crop price support involves a subsidy granted by the government or by a public body as an alternative to fertilizer subsidy. Subsidies are normally granted to keep commodity prices down. The most common forms of subsidy are direct fertilizer subsidy, storage and transport subsidy, and purchase credit subsidy. However, input subsidies are often preferred to output subsidies for a variety of techno-economic, accounting and administrative reasons.

Crop rotation

Crop rotation refers to the growing of crops in a regularly scheduled sequence in contrast to growing one crop continuously or different crops haphazardly on the same land or area. In crop rotation, two or more crops are grown in a field in a fixed sequence. A traditional farmer usually resorts to crop rotation to produce several crops in a season. Rotation facilitates stable production, diversity in crop availability, and income and labor distribution. Rotational systems are usually associated with livestock production; if ley is included, it is known as **ley farming** or **alternate farming**.

One of the earliest agriculture systems practiced was the four-course rotation. The **Norfolk rotation** follows a root crop-cereal-ley-cereal sequence. This was modified at the beginning of the 20th century to meet the changing needs of agriculture. In Norfolk, Britain, sugar beet replaced other root crops and in some cases potato was introduced in a still widely used five-course rotation which comprises a sugar beet-barley-ley-potato-wheat sequence. In some areas, six-course rotation (**East Lothian rotation**) is followed, whereas elsewhere, other course systems have been evolved (e.g., **Fenland rotation**).

In comparison to monoculture practices, crop rotation is beneficial owing to (a) reduced chances of diseases and pests, and risks arising from these, (b) a better weed control and maintenance, (c) improved fertility, and (d) a more even distribution of annual labor requirement.

Crop rotation is greatly beneficial in reducing the build-up of species-specific pests because a change in the crop species breaks the life cycle of the pest. A non-host plant in rotation prevents the pest from increasing its numbers on the crop plant. While crop rotation does not totally eliminate the pest, it helps control pest numbers. For example, corn rootworm which thrives only on corn root, is reduced to a manageable level by crop rotation. When crop rotation is not adequate, insecticides should be used on the soil.

Crop rotation has also an indirect effect on crop pests. Cereal crops produced on legume-grass sod with good drainage, aeration and organic matter may lead to healthier plants that are more tolerant to plant pests, thereby indirectly reducing crop losses. Corn grain, in rotation with a legume sod, always outperforms monoculture corn, regardless of how much nitrogen is applied. Fungal diseases like 'take-all', 'eye-spot' (also called *Cercosporella* foot rot), 'straw breaker' and 'collar rot' can be controlled by crop rotation with a non-grass crop, as these diseases do not survive in the soil in the absence of cereal plants. Under intensive cropping, a rotation of more than three years may not be economically desirable.

Crop rotation is useful in the management of short-lived pests, but for pests surviving for several years in the soil, longer rotations may be required.

Crop yield

Crop yield can be looked at as production of economically important biomass. The yield of crops is expressed either in terms of a plant or the area in which they are planted. For example, grains per plant, ears per plant, tons of grain per hectare, etc. (See also Yield.)

Cross-fertilization

In plants, fertilization is caused by pollens from the same flower or another flower, either of the same plant or a different plant. This occurs either by self-fertilization or cross-fertilization. Cross-fertilization or **allogamy** is supposed to have happened when the male and female gametes are derived from different individual plants.

Cross-inoculation groups

Cross-inoculation groups are the seven species of rhizobia, which have the ability to form nodules on roots of limited species of legumes. (See also Rhizobia.)

Cross-pollination: See Allogamy

Crotonylidene diurea

Crotonylidene diurea (**CDU**) or **crotonylidene urea** is a fertilizer containing 28% nitrogen which is released slowly. CDU is made by reacting crotonaldehyde with urea in a 1:2 ratio. (See also Urea.)

Crotonylidene urea: See Crotonylidene diurea

Crown drip

Crown drip is the drip of rainwater, melted snow or fog from vegetation which helps nutrient cycling in some ecosystems.

Crude protein: See Crude protein level

Crude protein level

A proximate analysis indicating the nitrogen content of protein in animal food is the **crude protein** (**CP**) level. Assuming that protein contains all nitrogen in the food, and that all proteins contain 16% nitrogen, CP is given by:

$$\mathrm{CP} = \%\mathrm{N} \times \frac{100}{16}$$

Crushing strength of a granule

Crushing strength of a granule is the ability of a granular or other particulate product to resist breakdown by physical pressure. The knowledge of crushing strength of the fertilizer granule helps in devising methods for handling and storage of granular fertilizers. (See also Granular strength.)

Crusting

A crust is a hard layer, coating or deposit on a surface (like soil). An increase in the bulk density of the top layer of the soil results in a crust, the thickness varying from a few millimeters upwards to around 25 mm. The impact of raindrops, clay dispersion and translocations are among the reasons for the crust to form, but the actual crusting happens when the soil is dry because of dispersions and a subsequent illuviation of fine particles into soil pores (Fig.C.45). A high proportion of silt and the absence of organic matter help form the crust. Rainfall and sprinkler irrigation often form the surface seal crust, especially when the bare soil surface is wet and has the pores blocked. When heavy rains followed by hot and dry spells create a crust of soil particles, the soil pores get blocked and the crust is called **capping**.

The flocculation of suspended soil colloids plays an important role in surface crust formations. Dispersed soil

Fig.C.45: Crust formation in laterite soil (Courtesy: Dr. Vrishali Deosthali, Department of Geography, University of Pune, India.)

particles have a negative impact on soil structure, and contribute to soil erosion as well as contaminant movement. Flocculation at a given soluble bivalent cation charge fraction increases as the organic carbon content of the soil colloids decreases. Crusting occurs at a particular ratio of the coarse to the fine fraction.

Crusting index, defined by the Food and Agricultural Organization (FAO) to characterize soils, is as follows:

$$\text{Crusting index} = \frac{\%\ \text{fine silt} + \%\ \text{coarse silt}}{\%\ \text{clay}}$$

This index exceeds 2.5 for soils prone to intense crusting. An index based on soil organic matter content is also used by **FAO**.

$$\text{Crusting index} = \frac{1.5\,(\%\ \text{fine silt}) + 0.75\,(\%\ \text{coarse silt})}{\%\ \text{clay} + 10\,(\%\ \text{organic matter})}$$

This index exceeds 2 for soils prone to intense crusting.

Crusting index: See Crusting

Crystal bridges

Fertilizer caking results from the formation of contact points among particles. Three known types of contact points are (a) **phase contacts**, (b) **adhesive contacts**, and (c) **surface diffusion**. Crystal bridges are formed at the contact points between particles in phase contacts. This results in caking during storage as a consequence of continued internal chemical reactions, dissolution and recrystallization processes and thermal effects.

Crystallization process for granulation of ammonium nitrate: See Ammonium nitrate production processes

Cultural profile

Cultural profile is a newly-prepared pit in a cultivated land, extending from the surface of the soil to a depth reached by the majority of plant roots (usually upto 1 m). It comprises a succession of layers individualized by intervention of agricultural implements, plant roots and natural factors reacting with them.

Culture

Culture is a general term for the cultivation of microorganisms, animals, plants or their cells *in vivo* or *in vitro* in a medium which provides appropriate conditions for multiplying their numbers and/or improving their breed. Culture optimization is an interactive procedure, whereby the composition of nutrient media and growth conditions are changed a little at a time to identify conditions under which maximum growth rate occurs. Cultures of cells are prepared in the laboratory for a wide spectrum of scientific research (Fig.C.46).

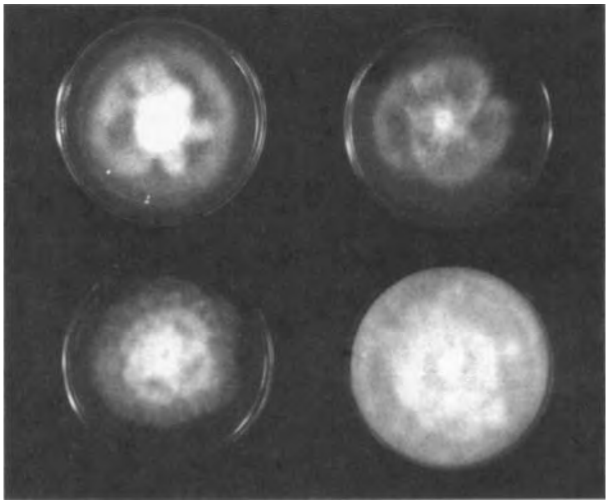


Fig.C.46: A fungal culture grown on different culture media.

Cumulative particle size

Fertilizer blends must be physically compatible for preserving their quality. The most common method to determine the physical compatibility of bulk blend ingredients is to perform a particle size analysis of each ingredient and compare the data obtained. The two techniques of particle size analysis to determine physical compatibility are the cumulative particle size distribution and the **size guide number**. If the difference in cumulative particle size of each ingredient is more than 20%, the ingredients are incompatible, and if it is between 1% and 10%, they are compatible.

Curasol

Curasol is the commercial name for a synthetic soil conditioner based on polyvinyl acetate.

Curly top of cotton

Curly top of cotton, also called **crinkly leaf,** is a disease caused by **manganese deficiency** in cotton.

Current suppressant

Current suppressants or **transpiration retardants** are substances that retard or inhibit the transpiration stream or current in plants. The flow of water through the xylem of a plant (from the roots to the stem and leaves) and its evaporation through the stomata of leaves is called **transpiration stream** or **transpiration current**. The three types of suppressants are (a) polar substances like cetyl alcohol or oxyethylene decosanol, (b) plastics like polyethylene, and (c) substances that lead to stomatal closure, like phenylmercuric acetate and decenyl succinic acid.

Custom fertilizer mixture

A custom fertilizer mixture is a fertilizer formulated according to specifications based on the results of soil tests, furnished by the consumer prior to mixing.

Cutans

In the micromorphological analysis of soils, cutans refer to a modification in the texture, structure or arrangement of the natural surfaces of the pedological material (due to the concentration of particular soil constituents or the modifications *in situ* of plasma). Cutans can be composed of any of the component substances of the soil material.

Cuticular transpiration

Transpiration of a plant or leaf refers to the release of water vapor through it. Unlike foliar transpiration, transpiration also takes place by direct evaporation from the outer walls of the epidermal cells through the cuticle. This is called cuticular transpiration.

CV

CV is short for **coefficient of variation.**

Cyanamide

Cyanamide, the trade name for calcium cyanamide, contains calcium hydroxide and carbon in small quantities as impurities. It is used as a fertilizer, the powdered form of which contains about 22% nitrogen.

Cyanobacteria

Cyanobacteria, earlier called **blue-green algae (BGA)**, are unicellular, filamentous bacteria whose nitrogen fixing ability - both independently as well as in association with plants - makes them a valuable biofertilizer.

Anabaena azollae (Fig.C.47) form large colonies in the leaf cavities of the free floating fern *Azolla pinnata*. Rice cultivation in South-East Asia uses enormous amounts of this fern as a source of biofertilizer. The water fern and tropical herb *Gunnera macrophylla* have a symbiotic relationship with blue-green bacteria.

Cyanobacteria can also fix nitrogen without associating with the plant. They are the main micro-organisms in desert soils, and are known to increase the nitrogen content of that soil. It should be noted, however, that only some species of **blue-green algae** of the genera *Nostoc*, *Scytonema* and *Anabaena* can fix atmospheric nitrogen in a solution culture. These bacteria derive food from sunlight and nitrogen from the atmosphere. Their respiration is either aerobic or anaerobic. The aerobic filamentous bacteria form heterocysts, the site of nitrogen fixation. **Heterocysts** are large, thick-walled cells that grow between pigmented cells on the algal filament. Vegetative cells and heterocyst cells are interdependent for nitrogen fixation. Heterocysts derive the enzyme reductase in the form of D-glucose-6 phosphate, pyruvate or isocitrate from photosynthesising vegetative cells. Vegetative cells depend on heterocysts for nitrogen nutrition in the form of glutamine, glutamate and other amino acids.

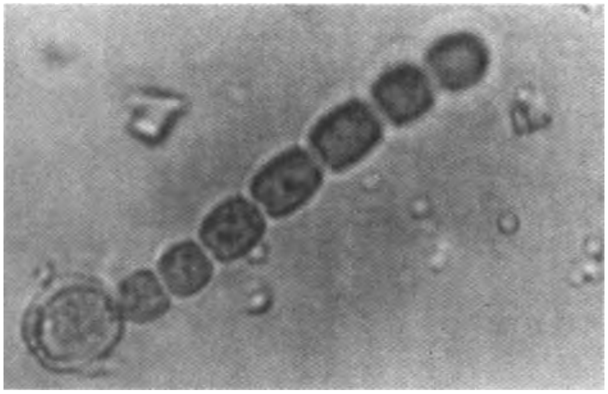


Fig.C.47: Anabaena azollae, an associative cyanobacterium of Azolla. (Courtesy: Dr. P. L. Patil, Pune, India.)

Mass production of cyanobacteria used in the production of biofertilizers utilizes soil-based algae inoculants. BGA production involves four methods which are (a) pit method, (b) trough method (Fig.C.48), (c) field method, and (d) nursery-cum-algae production method.

Fig.C.48: 1. Production of blue-green algae in small tanks. 2. A closeup of dried algal flakes.

Anaerobic bacteria are facultative, meaning, they can live in different environments. They fix nitrogen without forming heterocysts. Cyanobacteria take 20 hours to double. This biofertilizer is recommended for submerged rice crops as it enhances the yield by about 15 to 20%. Besides their ability to fix nitrogen, the cyanobacteria also produce some useful substances like auxins, vitamins of B_{12} group, indolacetic acid and gibberellic acid.

Blue-green algae are a source of biofertilizers and are available in the form of dried algal flakes (Fig.C.49). They may contribute 25 to 30 kg of nitrogen per hectare per cropping season, depending on the ecological conditions.

Fig.C.49: BGA biofertilizer is available in the form of dried algal flakes.

Ten days after the transplantation of rice, the dried algal flakes are applied to the soil at the rate of 10 kg/ha. Best results are obtained when the fields have adequate levels of available phosphorus. The nitrogenase activity could account for a daily input of approximately 0.5 kg of nitrogen per hectare.

Cycad-cyanobacteria association for biological nitrogen fixation

Many instances of symbiotic associations exist in nature, among plants and micro-organisms. They result in an overall benefit to not only the interacting parties but also the soil mass and the environment at large. One such instance of a symbiotic relationship is between a few species of cyanobacteria and cycads. Their association brings about biological nitrogen fixation.

A cycad is a tropical evergreen seed plant which has a large crown of fernlike compound leaves, a thick trunk and fleshy seeds enclosed in large cones. Often confused with a palm, cycads form mutualistic, facultative symbioses with nitrogen fixing cyanobacteria. The plant provides fixed carbon and a stable environment to the chemoheterotropic bacterial species which, in return, fixes nitrogen for the plant. The bacteria colonize the coralloid roots of the plant and grow, degenerate and fix nitrogen throughout the life of the cycad. This symbiosis is estimated to have many applications in agricultural and medicinal fields and is considered beneficial to the soil environment.

Cyclone

A dust-collecting device consisting of a cylindrical chamber, the lower portion of which is tapered to fit into a cone-shaped receptacle below it, is called a cyclone. Dust-laden air enters through a vertical slot-like duct on the upper wall of the chamber at the rate of at least 30 meters a second. Since the particles enter at a tangent, they whirl in a circular or cyclonic path within the chamber. The centrifugal force exerted on the particles is proportional to their weight and square of their velocity. The particles slide along the walls of the chamber and gradually circulate down into the conical receptor, while the clean air escapes through a central pipe at the bottom. The dust accumulates in the cone and is discharged continuously or at intervals. The larger the particles, the more efficient the process of their removal. In simple cyclones, particles below 50 microns in diameter are not retained, but improved models retain particles as small as 20 microns.

Cyclones are used in handling and granulating fertilizers to avoid air pollution and are a safety requirement in the production plants.

Cytochrome

Cytochrome is any of the numerous compounds comprising haem bonded to a protein. (**Haem** is an iron containing compound of the prophyrin class which forms the non-protein part of hemoglobin and some other biological molecules). They are pigments occurring in the cells of nearly all animals and plants. Several types are known; cytochrome C is the most abundant and is obtained in pure form. Cytochromes and cytochrome oxidase have important functions in cell respiration. Out of these, cytochrome oxidase is an iron-porphyrin containing protein which is an important enzyme in cell respiration. It catalyzes the oxidation of cytochrome C and is reduced in the reaction. It is then reoxidized by oxygen.

Cytokinins

Cytokinins are chemicals which, apart from their other activities, promote cell division in cells of various plants. These are usually grown as a callus in a culture, free from any contamination. They are correctly applicable to the cytoplasm changes accompanying mitosis or to the cleavage of cytoplasm into daughter cells after nuclear division.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

D

2,4-D

2,4-D is short for 2,4-dichlorophenoxyacetic acid. It is known for its weed-killing properties. There are two types of weedicides, namely, selective and non-selective. 2,4-D is a selective weedicide used for eliminating weeds without causing injury to the crop.

Daily wager

Daily wager is another name for **casual worker** or **daily worker**. He or she is a person employed on a temporary, day-to-day basis or whenever required. The daily wager is generally not entitled to such benefits as pension, provident fund, medical expenses etc. that are given to a regular employee.

Daily worker: See Daily wager

Dal soil

Dal soil is the local name for a type of **peat soil** in The Netherlands where young peat layers cover sandy subsoil. (See also Peat soil.)

Dalton

Dalton is a unit used for expressing the molecular weight of proteins. It is equivalent to atomic mass unit and is 1/16th of the mass of oxygen, 16.

Danish agar

Furcellaria fastigiata, a type of algae harvested in Denmark is called Danish agar.

DAP

DAP is short for diammonium phosphate.

Darcy and Ritter law

The Darcy and Ritter law relates to the movement of water through a porous medium (like soil) and is defined as:

$$Q = \frac{R.S.P}{L} \quad \text{or} \quad Q = \frac{K.A.t.H}{L}$$

where Q is the volume of water passing in unit time, R is a constant (the value of which depends on the nature of the mineral) known as the saturated hydraulic conductivity (for an impermeable soil, R is less than 0.4 and for a highly permeable soil, R is higher than 20), S is the area of the medium receiving the water, P is the water pressure, which depends upon the water column height, L is the soil thickness traversed by water, A is the soil area in square centimeters, t is the time in seconds, H is the water height (head) in centimeters, and K is the rate constant in centimeters per second.

Darcy's equation takes the same form as several other laws in science, like **Fick's law** for chemical diffusion, Ohm's law for current diffusion and Fourier's law for heat flow. The equation shows that there must be a difference in water potentials for water to flow, and the rate of flow depends on the hydraulic gradient and the hydraulic conductivity of the soil.

Darcy's equation for one-dimensional flow

Darcy's equation computes the one-dimensional flow of water through saturated homogeneous soil.

$$q = \frac{khA}{L}$$

where q is the flow rate, k is the hydraulic conductivity of the flow medium, h is the head or potential causing flow, A is the cross sectional area of flow and L is the length of the flow path. (See also Infiltration.)

Darcy's law for flow of water through sand columns

Darcy gave a simple law for the flow of water through sand columns. The rate of flow of a fluid through a unit cross-section of a porous mass under a unit hydraulic gradient at 15°C, is given by the following expression:

$$V = \frac{K + H}{L}$$

where V is the rate of flow in cm, H is the water column height in cm, L is the sand column height in cm and K is the permeability coefficient, which has the dimensions of velocity, called the **filtration velocity**.

Darcy's law for flow of water through soil

Darcy's law of vertical flow of water through soil says that the volume of water passing through the soil is directly proportional to the soil area and the water pressure, and inversely proportional to the thickness of the soil traversed by the water.

At low hydraulic gradients, a threshold gradient was noticed in some studies, below which there was no flow in fine-grained soils. Similarly, at high hydraulic gradients corresponding to Reynolds number in excess of 10, the flow in the soil may not follow Darcy's law. Fortunately, in majority of cases of groundwater flows, these conditions do not occur. When the conditions are such that the fluid can be categorized as Newtonian, and the flow conditions represent laminar flow, Darcy's law is generally believed to be applicable to soil systems.

Dark fen land soil

Dark fen land soil is another term for **black land**.

Dauer humus

The Dauer humus is a kind of **humus** that is resistant to attack by micro-organisms.

Davies compactometer

A Davies compactometer measures soil compactness. The device consists of a fixed part placed against the vertical side of the profile, and a mobile part that turns around the axis at a constant force and speed, allowing a graduated shaft to penetrate the soil perpendicularly. The depth to which the shaft penetrates is a measure of soil compactness.

DCD

DCD or **DD** is short for **dicyandiamide**.

DD: See Dicyandiamide

Dead-burned magnesite

Dead-burned magnesite, **caustic-calcined magnesite** and **synthetic magnesite** are loose synonyms of magnesia.

Magnesite usually occurs as a compact white microcrystalline mass. It refers to magnesium carbonate crystallized in the trigonal system.

Dead-end serpentine irrigation

Dead-end serpentine irrigation scheme, also known as the **serpentine scheme for irrigation**, is used to hold water for long periods on the soil surface, especially on clayey soils. This is done by lengthening rows in undulating form (serpentine rows) and by cutting passageways across the furrow to connect several channels, so that water flows back and forth like a snake's tail.

Dealkalization

Dealkalization is the leaching of sodium ions (Na^+) held on soil particles. These ions are substituted by other ions like Ca^{2+}, K^+ and NH_4^+, usually by chemical treatment. Sodium concentration is harmful to most plants.

Alkaline soils are reclaimed by amending a part or most of the exchangeable sodium by more favorable calcium ions at the root zone. Agronomic practices, like the application of low-nitrogen organic manure, facilitate this amendment.This practice is common for rice crops.

Chemical amendments for reclamation of alkaline soils are grouped as (a) soluble calcium salts (e.g., gypsum, calcium chloride, phospho-gypsum), (b) partially soluble calcium salts (e.g., calcium carbonate), and (c) acids and acid formers (e.g., sulphuric acid, iron and aluminum sulphates, lime-sulphur, pyrites).

The atmospheric oxidation of sulphur and pyrites to sulphuric acid is very slow, unless accelerated by microbes like *Thiobacillus ferroxidans*. All amendments are made to supply soluble calcium. Leaching, after a chemical amendment, removes soluble salts and other reaction products. Table-D.1 shows comparative efficiencies of various amendments used for reclamation of sodic soils.

Deb method

Deb method is an analytical method for determining free iron in soil and is particularly useful for dissolving the free (nonsilicate) iron in soils. In this, iron is first extracted using sodium dithionate, to which a mixture of sulphuric and nitric acids is added to destroy organic matter. The quantity of iron present is then determined colorimetrically with potassium thiocyanate or phenanthroline chlorohydrate by shaking the samples overnight at ambient conditions in a reducing and complexing solution.

Table-D.1: Expected efficiencies of various amendments used in sodic soil reclamation.

Amendment	Chemical composition	Gypsum (kg)*	Sulphur (kg)*
Gypsum	$CaSO_4 \cdot 2H_2O$	1.0	5.38
Sulphur	S_8	0.19	1.00
Sulphuric acid	H_2SO_4	0.57	3.06
Calcium carbonate	$CaCO_3$	0.58	3.13
Calcium chloride	$CaCl_2 \cdot 2H_2O$	0.85	4.59
Ferrous sulphate	$FeSO_4 \cdot 7H_2O$	1.61	8.69
Ferric sulphate	$Fe_2(SO_4)_3 \cdot 9H_2O$	1.09	5.85
Aluminum sulphate	$Al_2(SO_4)_3 \cdot 18H_2O$	1.29	6.94
Pyrite (30% S)	FeS_2	0.63	1.87

* Amount equivalent of 1kg of chemically pure substance

Source: Gupta and Abrol, 1990. As adapted by U. Aswathanarayan's "Soil Resources and the Environment," 1990, Oxford and IBH Publishing Co. Pvt, Ltd, New Delhi. With permission.

Debris

Debris refers to scattered pieces, remains, or loose natural material of broken rock. It is also the coarse resultant of decay and disintegration of rocks. Debris is found either at the place where it is produced or where it is transported by water streams and glaciers. The gravitational soil flow, down a slope, can be as slow as a few centimeters per day or as rapid as the mudflow or earth flow. Wreckage, ruins, dead stalks and leaves left behind in the field after harvest are also called debris (Fig.D.1). Debris also denotes interplanetary material, including cosmic dust, meteorites, comets and asteroids.

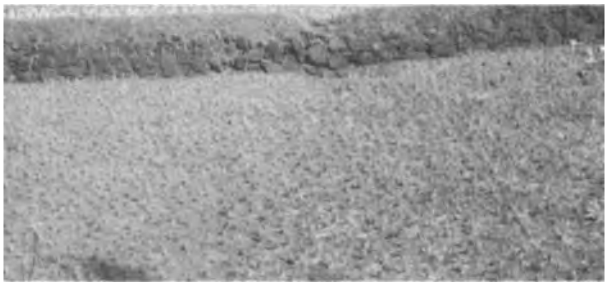


Fig.D.1: Plant debris in a field.

Decalcification

Decalcification refers to the removal of calcium ions (or calcium carbonate) from soil by leaching. Leaching generally occurs in humid climates because of the solubilizing action of water-containing carbon dioxide. Leaching increases soil acidity, a condition that is favorable to some plants, because of its ability to reduce infection and make micronutrients more soluble for better plant absorption. Annual soil calcium leaching ranges from 87 to 250 kg/hectare. (See also Calcification.)

Decarbonation

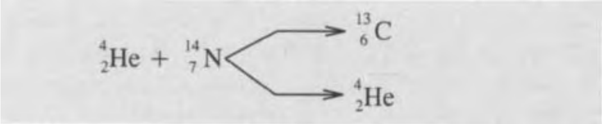
Decarbonation is the decomposition of calcium carbonate, by water containing dissolved carbon dioxide (CO_2) and humus. The general reaction controlling the movement of carbonate is:

$$CaCO_3 + H_2O + CO_2 \underset{1}{\overset{2}{\rightleftharpoons}} Ca(HCO_3)_2$$

If CO_2 and water are present in the above system, the reaction proceeds with the formation of soluble bicarbonate.

Decay

Decay refers to the chemical breakdown of organic material into its elements by the action of micro-organisms or decomposer enzymes. Decay also denotes the rotting and decomposition of organic tissues, which occur during composting. Another form of decay is the spontaneous transformation of a radioactive nuclide into a daughter nuclide, which may or may not be radioactive, with the emission of one or more particles or photons. (See also Decomposition.)



$${}^{4}_{2}He + {}^{14}_{7}N \rightarrow {}^{13}_{6}C \qquad {}^{4}_{2}He + {}^{14}_{7}N \rightarrow {}^{4}_{2}He$$

Deciduous forest

Trees that shed their leaves annually are called **deciduous trees**. Examples of deciduous trees are oak, ash, beech and maple. Forests in temperate zones of both the hemispheres are full of trees that shed leaves in the autumn. These forests are known as deciduous forests (Fig.D.2). Deciduous forests in temperate zones have temperatures of about 10°C and annual rainfall from 75 to 150 cm. These forests are found in North America, middle Europe, Russia, Japan, eastern China, Australia, New Zealand and parts of Chile and Paraguay. Rain forests near the equator also have many deciduous trees. (See also Forest.)

Deciduous trees: See Deciduous forest

Fig.D.2: A deciduous forest.

Declarable content of fertilizer

The declarable content or **guaranteed analysis** of a fertilizer is a statement about the elements or oxides present in that fertilizer. It is displayed on a label or on any other document as per legal requirements.

Decomposer

Soil organic matter, composed of living or dead plant and animal matter, is decomposed by micro-organisms (particularly by bacteria, actinomycetes and fungi) (Fig.D.3). These decomposing agents, mostly bacteria and fungi, are called decomposers. In compost degradation, they act as **biological accelerators**.

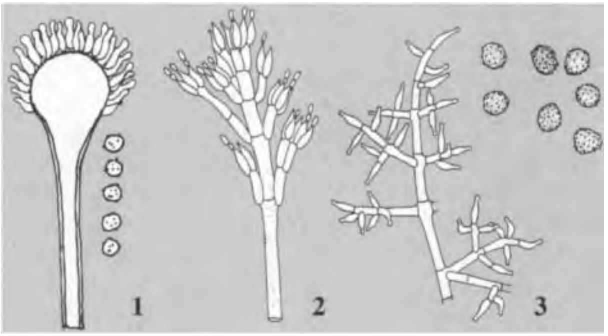


Fig.D.3. Fungi like Aspergillus (1), Paecilomyces (2), and Trichoderma (3) are decomposers which accelerate the process of decomposition.

Decomposition

Decomposition is the decay or breakdown of material. In simple decomposition, one substance breaks down into two or more simpler substances. For example, water yields hydrogen and oxygen. In double decomposition, two compounds break down and may recombine to form different compounds. For example:

$$BaCl_2 + H_2SO_4 \longrightarrow BaSO_4 + 2HCl$$

Chemical reactions that occur during the breakdown of matter are oxidation, reduction, hydrolysis, hydration, etc. These reactions are brought about by temperature, oxygen, light, water, nutrients, micro-organisms, soil moisture, soil pH, and soil texture – either individually or in combination. Decomposition may occur as a result of reaction at room temperature, heating in air, electrolysis, bacterial or enzymatic action (e.g., fermentation), radiation (e.g., photo decomposition) and thermal decomposition (heating in the absence of air). Thermal decomposition is synonymous with **pyrolysis** and **destructive distillation**.

Decomposition of organic matter is very important for healthy plant growth. Warm conditions and moisture facilitate decomposition, whereas cold, dry or waterlogged conditions and lack of nutrients reduce the rate of decomposition. A constant action of micro-organisms changes the ratio of organic carbon and total nitrogen (C: N) in the soil.

Soil organic matter is an active and important portion of the soil. It is a source of nitrogen, phosphorus and sulphur. For maximum benefits, readily decomposable organic matter must continually be replenished with fresh residues. Organic matter is decomposed by micro-organisms like bacteria, actinomycetes and fungi. These are called **decomposers** or **saprobes**. Nutrients like nitrogen and carbon, which are released during decomposition, are used by these micro-organisms for their own growth and reproduction, as well as for further speeding up the rate of decomposition in the soil. If soils are well aerated, decomposition produces carbon dioxide (CO_2), ammonium ion, (NH_4^+) , nitrate ion (NO_3^-), dihydrogen phosphate ($H_2PO_4^-$), sulphate (SO_4^{2-}), water (H_2O) and some other nutrients useful for plant growth.

Decomposers produce enzymes which lower the activation energy necessary to break chemical bonds in organic materials. Most biological processes require a means to reduce this activation energy so that the process can occur in natural conditions. Decomposers bring about this phenomenon by the chemical breakdown of dead organisms or animals or plant wastes. They secrete enzymes on dead matter and then absorb the products created by the breakdown. Many decomposers, like nitrifying bacteria, specialize in breaking down organic materials difficult for other organisms to digest.

Decomposers perform a vital role in the food cycle by returning the constituents of organic matter to the environment (in inorganic form) and helping the plant to assimilate them. The decomposed products are less desirable in anaerobic conditions. The rate of decomposition, speeded up by adding nitrogen, is directly proportional to the number of microbes in that soil, as nitrogen released during decomposition is essential to build proteins in a new microbe population. Hence, bacteria are seen to be heavy users of nitrogen. Plants grown in nitrogen-deficient soil show nitrogen deficiency, because soil microbes use up most of the available nitrogen before allowing it to reach the plant roots. The same is true for other nutrients as well.

Microbes grow well when the soil pH is between 6 and 8. But at pH below 6 or above 8, the decomposition rate slows down. Soil with a high clay content retains more humus, where organic substances adsorb to the clay surfaces and promote decomposition. In highly toxic conditions, or conditions of excessive soluble salts, organic phytotoxins greatly restrict decomposition.

De-electronation

De-electronation is an oxidation process involving the removal of electrons. The process of reduction involving the addition of electrons is known as **electronation**.

Deep banding : See Deep placement

Deep Litter

There are various ways in which fresh manure can be collected and stored (and if required, processed, into **compost**) before use. In the deep litter system of manure making, animals are free to walk around and defecate on to a straw mat. By the action of their walking, the feces get compacted with only the top layer decomposing aerobically. Such manure may be directly applied to the soil.

Deep percolation

Water is held in the soil by hydrogen bonds, and the extent of its strength is known as **water potential**, which is measured in bars.

There are three types of water in the soil. One is gravitational water, the second is plant available water, and finally, there is unavailable water. Excess water, when added to soil by rain or through irrigation, either runs off or moves into deeper layers of the soil. This downward movement of water deep into the soil is called deep percolation. The water penetrating the soil is held in pores and is bonded to the soil surface by its water potential, which determines its availability to plant roots. When the water potential is more than minus 15 bars, it is not available to the roots for absorption.

The amount of water lost to the ground through deep percolation depends on the soil permeability, which in turn depends upon soil texture and structure, the presence of impermeable layers (hardpan or calcium carbonate) in the soil profile, and the exchangeable sodium percentage (ESP). Sandy soils are unsuitable for plant growth.

Deep placement

Deep placement is a method of applying a fluid or solid fertilizer to the subsurface or deeper levels of soil, to ensure that the fertilizer reaches the root zone and does not run-off the surface (Fig.D.4). Nitrogenous fertilizers are supplied to paddy crops in this way.

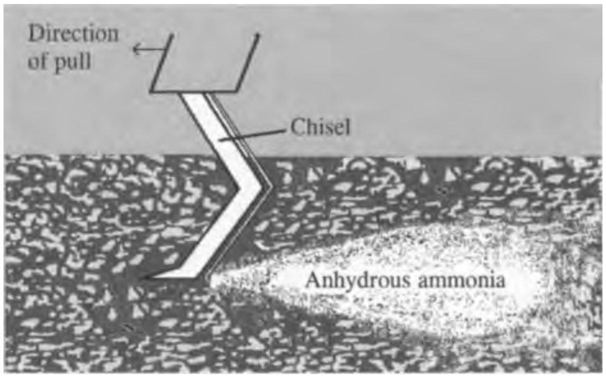


Fig.D.5: Deep placement of anhydrous ammonia in the soil under pressure, at a depth of about 15 cm.

Deep banding is the pre-plant application of solid, liquid or gaseous nutrients 5 to 15 cm below the soil surface. Some applications may be as deep as 40 cm.

Depending on the design of the applicator, nutrients are concentrated in the soil to form streams, sheets or points. Often, the fertilizer is applied in conjunction with a tillage operation, months before the next crop is sown.

Dual application, another term for deep banding, refers to the simultaneous application of anhydrous ammonia (NH_3) as a nitrogen source along with fluid or solid P, K and S fertilizers.

Deep tillage

Deep tillage, also called **chiselling** or **subsoiling** is the process of destroying soil crusts and loosening the soil, by tilling it to a depth of 30 to 40 cm. Deep tillage helps increase soil aeration, root penetration and infiltration of rainfall. **Tillage** or subsoiling means ripping up or physically tearing the hard pan using suitable equipment (Fig.D.5).

A chisel, set at a depth of about 30 cm, can break the tillage pan. Deep tillage results in more water storage in the root zone and permits irrigation before planting. When soil is fertilized after deep tillage, it increases corn yield by up to 30%. Tillage on a clay loam to a depth of 40 cm is beneficial for more than three years.

Tilling up to a depth of 50 cm has the following benefits: (i) The plow sole or the pan just below the plow depth is temporarily eliminated. (ii) Plant root penetration in the tilled layers is increased, especially after fertilization and chiselling. (iii) There is greater movement of water into the soil and larger storage of water in the plant root zone. All these benefits result in increased crop yields.

Deep tillage is more effective when the soil is dry enough to shatter and crack. If deep tillage is performed on wet soil, problems of compaction, non-aeration and permeability increase, adversely affecting the yield. Deep tillage is done prior to planting or during dormant periods when root pruning or root disturbance of permanent crops is less disruptive.

Deep tillage is most useful in soils in which hardpans are formed out of accumulated clay or precipitated calcium carbonate ($CaCO_3$), or where high residual sodium carbonate stops water from percolating to the lower layers.

Tillage practices modify such soil properties as its structure, texture, bulk density, particle density, degree of compaction, percentage of pore space, percentage of organic matter, water infiltration rate, erodibility, water holding capacity, **cation exchange capacity** and pH.

Deferrization

Deferrization means destruction of iron (III) constituents of the soil under the influence of weak acids (mainly organic acids) and a subsequent leaching of the iron in its ferrous form.

Deficiency diseases

The inadequacy of one or more essential nutrients (like vitamins, mineral elements, proteins or amino acids) causes deficiency diseases in animals or plants. Nutrient deficiency results in poor growth. Plants suffering from the deficiency of one or more nutrients show signs of abnormality in color and structure of leaves and shoots; for example, **grey leaf**, **chlorosis** and **brown heart**.

Deficiency of micronutrients: See Micronutrients

Deficiency symptoms

A deficiency in plants may be caused by the non-availability or shortage of a particular nutrient or water, the presence of a disease, insect attacks, adverse weather conditions, etc. The apparent physical sign or expression of a deficiency is a deficiency symptom.

If the symptom is seen early, the problem can be corrected during the growing season by supplying the needed nutrient through a foliar spray. If the deficiency symptoms appear at a later stage of the crop development, it can be corrected only in the next growing season.

Nutrient deficiency can lead to (a) a complete crop failure at the seedling stage, (b) severe stunting of plants, (c) peculiar appearance of leaves at varying times during the season, (d) internal abnormalities, like clogged conducting tissues, (e) delayed or abnormal maturity, (f) drop in the yield with or without leaf symptoms, and (g) poor crop quality with reduced protein, oil or starch content.

Nutrients can show different deficiency symptoms in different plants, affecting their roots, shoots, leaves, flowers or fruits (Table-D.2).

Nutrient deficiency symptoms in leaves are called **foliar symptoms**. These appear as **chlorosis**, necrosis,

Fig.D.5: Deep plowing by a traditional wooden plow (left) and by a tractor-mounted mold board plow (right).

Table-D.2: Common symptoms of nutrient deficiencies.

Nutrient element	Symptoms
Nitrogen	Reduced chlorophyll production, yellow pigments, carotene and xanthophylls appear, dwarf and abnormally light green plants, erect, light green to yellow leaves, fiery appearance in acute deficiency condition.
Phosphorus	Dwarf and abnormally dark green plant, leaves erect, usually narrow. In acute condition leaves turn greenish brown to black, and bronzing occurs on back side of leaves. Retarded tillering and root development.
Potassium	Slow and stunted growth of plants, stalks weak, leaves chlorotic, small dead spots of specks at the leaf tip, rusty appearance of margins, cupping of margins and tips.
Calcium	Decreased development of terminal shoot buds and apical root tips, plant remain dark green, young bud leaves chlorotic, die-back symptom at tips leading to death of terminal but in acute condition.
Magnesium	Chlorotic discoloration of leaves starting from tips and margins, leading to interveinal chlorosis. Veins remain green, leaves exhibit stripy or spotty appearance. Leaf detaches early.
Sulphur	Stunted, thin-stemmed and spindly plants, delayed maturity in cereals, poor nodulation in legumes, leaves light-green, veins still paler, no dead spots.
Boron	Abnormal development of meristematic tissues. Apical meristems become stunted and die. Abortion of fruits and flowers. Quality and yield reduction in some grain and fruit crops.
Chlorine	Chlorosis of younger leaves, wilting.
Copper	Slow growth of plants, stunted growth, distortion of young leaves and death of growing tip of plant.
Iron	Interveinal chlorosis and bleaching of young leaves. In severe cases, the plant turns light green.
Manganese	Only young leaves show interveinal chlorosis; in severe case, the plant remains stunted.
Molybdenum	Middle and older leaves chlorotic. Occasional rolling of leaf margins, restricted growth and flower formation.
Zinc	Interveinal chlorosis or whitening of upper leaves, distortion and rosetting of leaves.

cupping, pigmentation, folding and wrinkles. In the case of **nitrogen deficiency**, chlorophyll production is reduced, and the yellow pigments carotene and xanthophylls appear, resulting in pale green or yellow leaves. Deficiency symptoms in shoots may show up as stunted growth, rosetting of buds, reduced tillering and die-back of twigs. In flowers and fruits, deficiency shows up by immature falling, reduced fertilization or flowering, and by the defective shape of flowers. In practice, a visual symptom may be caused by more than one deficiency or by more than one factor. Similarly, a deficiency due to one nutrient may also relate to an excess of another nutrient. Some nutrient deficiency symptoms look quite similar to those produced by biotic or abiotic factors like diseases, insect attacks, adverse weather conditions, excessive moisture, etc. One has to be very skillful to diagnose a nutrient deficiency symptom visually.

There are instances when a crop shows no obvious nutrient deficiency symptoms although the deficiency exists. This situation is referred to as **hidden hunger** (Fig.D.6). The nutrient addition over a long period, say, a year, helps to enhance the yield and overcome the problem of hidden hunger.

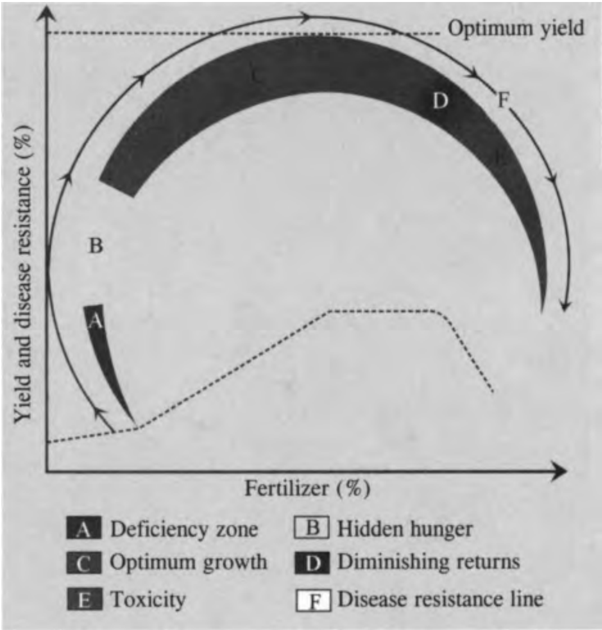


Fig.D.6: A graph (Mitscherlich curve) of yield and disease resistance against nutrient uptake, showing hidden hunger.

Definite proportions, law of: See Chemical combination, laws of

Definitive host

A definitive host is an organism that supports the sexually reproductive form of a parasite. Some parasites require two hosts during their life cycle. The first part of the life cycle (till the sexual maturity of a parasite) is completed on the first host, known as **primary host**. For the second part of the life cycle, i.e. after sexual maturity, parasites need a second host which is known as the definitive host.

Deflocculating agents

Materials used to keep the particles of a substance separate and prevent them from aggregating into lumps are termed deflocculating agents. They may also be called **dispersing agents** as they prevent sedimentation of soils in water when the solid particles are kept suspended in water. Sodium carboxymethyl cellulose, methylcellulose, etc. are good dispersing agents.

Deflocculation

Deflocculation is the process of breaking down soil aggregates into individual particles. Deflocculation of soil is favored by high exchangeable sodium in soil. It is also called dispersion of soil.

During the flocculation of a colloid by an electrolyte, the ions carrying an opposite charge to those on the colloid are adsorbed to a varying degree on the surface. The higher the charge of the ion, the more strongly it is adsorbed. In all cases, the precipitate will be contaminated by surface adsorption.

Upon washing the precipitate with water, a part of the adsorbed electrolyte is removed, causing a drop in the electrolyte concentration in the supernatant liquid. If this falls below the coagulation value, the precipitate may pass into the colloidal solution again.

Defluorinated phosphate rock

Defluorinated phosphate rock or **coronet phosphate** is made and used in Japan as a fertilizer. A high-grade phosphate rock is ground and mixed with small quantities of sodium carbonate or sulphate and wet-process acid. The mixture is calcined at 1350°C in an oil-fired rotary kiln. The product thus obtained contains 38 to 42% phosphorus pentoxide (P_2O_5), of which more than 90% is soluble in neutral ammonium citrate. Almost all fluorine is driven off and recovered as sodium bifluoride ($NaHF_2$). The product is an effective fertilizer when applied in a finely ground form to acid soils. Defluorination has also been demonstrated by the fusion process.

Defoliants

Defoliants are substances that induce defoliation of leaves to facilitate harvesting. **Defoliation** is stripping of leaves from plants, especially by use of chemical sprays.

Defoliants are used in harvesting American cotton. They are used to a lesser extent in soybean, vines and tomato cultivation, and for destroying potato foliage.

Desiccants induce shedding of leaves by accelerating drying of different parts of the plant. Hygroscopic substances, like activated alumina, calcium chloride and silica gel are called desiccants. These absorb water vapor from air and are used to maintain a dry atmosphere in containers, while packaging and transporting food materials.

Defoliants and desiccants are both harvesting aids and are also used as **herbicides**. They may be organic or inorganic. Many are toxic. 2, 4-D, 2, 4, 5-T, sodium chlorate, dimethylarsenic acid and arsenic acid are examples of defoliants, while paraquat, diquat and endothal are examples of desiccants.

The following are some other harvesting aids: (i) **Buminafos** is used as a defoliant in potato and cotton. (ii) **Dimethipin** is a defoliant for cotton plants and a desiccant for potato and vines. (iii) **Merphos** is a defoliant in cotton. (iv) **Thidiazuron** is a substituted urea with cytokinin activity used to defoliate cotton. (v) **Tribufos** is a very effective defoliant for cotton. In the USA about half the cotton plantations are treated with organophorus defoliants 1 to 2 weeks before harvesting. Dimethipin enhances the maturation process and reduces seed moisture in the harvesting of rice, rape seed, flax and sunflower.

Defoliants and desiccants have also been used in war to destroy vegetation.

Defoliation: See Defoliants

Degleification

Degleification, the opposite of gleification, is due to re-oxidation of ferrous salts by aeration of the soil and its improved porous structure. Degleification is brought about by various cultural practices.

Gleification which causes the soil to take on a bluish, greyish or greenish color, happens because of the presence of ferrous salts in poorly aerated soil, the poorly aerated condition being caused by excess water.

Degradable waste

Materials that are "degradable" are susceptible to decomposition. Degradation of waste material generally happens in one of two ways: biodegradation and photodegradation.

Biodegradation is the process of assimilation or consumption of materials by living organisms, such as bacteria and other microbes. Sometimes biodegradation is called "**digestion**". A biodegradable waste is material which is capable of being broken down by micro-organisms into simple, stable compounds such as carbon dioxide and water.

Photodegradation is the process in which material is decomposed by the action of light. In nature, for the most part, photodegradable materials are decomposed via ultra-violet light in sunlight.

Degradation

Degradation is a chemical reaction in which a complex compound is converted into simpler compounds in stages. **Soil degradation** involves the wearing out of the surface by erosion, which makes it agriculturally less productive or generally less useful. It may result from oxidation, heat, sunlight, solvents, bacterial action or from infectious micro-organisms in proteins. The process of breakdown of soil organic matter with the evolution of energy, formation of humic and fulvic acids and conversion of plant nutrients to inorganic form is also known as degradation.

Degraded soil: See Degradation

Degree Baumé solution

The grade or strength of ammonium hydroxide available commercially is 26 degree Baumé which corresponds to 29.4% by weight of ammonia dissolved in water with a density of 0.8974 kg m^{-3} at minus 9.44°C. (See also Aqua ammonia.)

Degree of dissociation

Dissociation is the breakdown of a molecule or an ion into smaller molecules or ions, respectively. The degree of dissociation is the ratio of the amount of dissociated molecules to the original amount of all molecules, and is given by:

$$\alpha = \frac{[\text{Dissociated molecules}]}{[\text{Total initial molecules}]}$$

An example of dissociation is the reversible reaction of ammonia at high temperatures to nitrogen and hydrogen.

$$2NH_3 \rightleftharpoons N_2 + 3H_2$$

The **equilibrium constant** or **dissociation constant** (k) in the above case is given by:

$$k = \frac{[N_2] \cdot [H_2]^3}{[NH_3]^2}$$

As the reaction is dependent on temperature and pressure, the extent to which an ammonia molecule dissociates itself to nitrogen and hydrogen is known as its degree of dissociation. Assuming the degree of dissociation as α, we have at equilibrium $(1-\alpha)$ ammonia, $\alpha/2$ nitrogen and $3\alpha/2$ hydrogen.

Dehulled rice

Dehulled rice is another name for **brown rice**.

Dehydration

Dehydration entails removal of water. In the case of a material like fertilizer, 95% or more is removed by heating. The term dehydration is not applied to loss of water by evaporation or sun-drying.

The primary purpose of dehydration is to reduce the volume of the product, increase its shelf life and lower transportation costs.

Special equipment for dehydration includes tunnel dryers, vacuum dryers, drum dryers, etc. in which the bulk product is exposed to a hot air environment. Another method is spray-drying, in which a liquid product is ejected from a nozzle into hot air. Dried milk and egg-white are prepared in this way.

Dehydration also means the removal of one or more molecules of water from a chemical compound. For example, dehydration of ethyl alcohol gives ethylene.

$$C_2H_5OH \longrightarrow C_2H_4 + H_2O$$

Deliquescent

A substance with a tendency to absorb atmospheric water vapor and dissolve in it or to become liquid is known as deliquescent. The term refers specifically to water soluble chemical salts in the form of powders which dissolve in water absorbed from the air. Such salts should be kept tightly closed.

Ammonium nitrate absorbs moisture from air and becomes a liquid. Hence, it is coated with chemicals like talc, polymers, etc. to impart free flow characteristics to it.

Denitrification

Denitrification refers to the breakdown of nitrates and nitrites by denitrifying bacteria in soil in anaerobic conditions, followed by the release of gaseous nitrogen. Waterlogging of the soil excludes oxygen and promotes conditions for anaerobic denitrification.

Nitrogen is lost from the soil largely owing to its removal by crops and by leaching. Under certain conditions, however, inorganic nitrogen (nitrate and ammonium ions) can be converted into gases that are lost to the atmosphere.

Four conditions are necessary for denitrification, namely, the presence of (a) nitrates, (b) anaerobic environment, (c) soluble carbon, and (d) denitrifying organisms. Chemical denitrification can also occur in acidic soils.

Some micro-organisms get oxygen from nitrite (NO_2^-) and nitrate (NO_3^-) accompanied by the release of energy, nitrogen (N) and nitrous oxide (N_2O). This process happens by the following probable pathway:

$$2HNO_3 \xrightarrow[-2H_2O]{+4H} 2HNO_2 \xrightarrow[-2H_2O]{+2H} 2NO \xrightarrow[-H_2O]{+2H} N_2O \xrightarrow[-H_2O]{+2H} N_2$$

This process takes place mainly in the presence of *Pseudomonas, Acromobacter, Paracoccus* and *Thiobacillus denitrificans*.

In most field soils, there is immense potential for denitrification. However, conditions must change for an organism to shift from aerobic respiration to a denitrifying type metabolism, involving the use of nitrate (NO_3^-) as an electron acceptor in the absence of oxygen. The amount of gaseous nitrogen lost by denitrification varies, along with the proportion of the two major products of denitrification - nitrogen and nitrous oxide (N_2O).

The magnitude and rate of denitrification are strongly influenced by several soil and environmental factors, the most important being (a) the amount and nature of organic matter present, (b) moisture content,

(c) aeration, (d) soil pH and temperature, and (e) concentration and form of inorganic nitrogen (i.e., ammonium or nitrate ions).

In arable soils, estimates of nitrogen losses by denitrification vary from 3 to 62% of the applied nitrogen, with the greatest losses recorded in rice and heavy clay loam soil. The losses subsequently decrease in loam soils and sandy loam soils, in that order. The loss of the nitrate (NO_3^-) by leaching or denitrification can be reduced by blocking the nitrite (NO_2^-) formation and by applying nitrification inhibitors such as **nitrapyrin** (2-chloro-6-trichloromethylpyridine), **AM** (2-amino-4-chloro-6-trimethylpyrimidine) or terrazole (5-ethoxy-3-trichloromethyl-1,2,4-thiadizole).

Some natural compounds, like those found in neem, also inhibit nitrification.

Den process for triple superphosphate production

The Den process for producing triple superphosphate involves four operations namely reaction of phosphate rock with phosphoric acid, the denning step where the reaction solidifies from its liquid phase, the time being 10 to 30 minutes compared to 30 to 120 minutes for single superphosphate, storage/curing in piles for 3 to 6 weeks, and granulation. (See also Triple superphosphate production processes.)

Density

The density of a substance is defined as the mass of the substance per unit of volume.

Three types of density measurements are used in the fertilizer industry: (i) **Bulk density** (ii) **Apparent density** (iii) **True density**. (See Bulk density of fertilizer.)

Deoxyribonucleic acid

Deoxyribonucleic acid (**DNA**) is a complex sugar protein polymer of nucleoprotein, which contains the complete genetic code for every enzyme in the cell.

DNA occurs as a major component of the genes that are located on chromosomes in the cell nucleus. The DNA molecule is a unique and vastly intricate structure first elucidated by Crick and Watson in 1953. It is built from 3000 to several million nucleotide units arranged in a double helix containing phosphoric acid, 2-deoxyribose and nitrogenous bases (adenine, guanine, cytosine and thymine. See Fig.D.7). The spiral consists of two chains of alternating phosphate and deoxyribose units in continuous linkages. The nitrogenous bases project toward the axis of the spiral and are joined to the chains by hydrogen bonds. Adenine always unites with thymine and cytosine with guanine. The complementary nature of the bases on the joined chains allows each chain to act as a template for replication of the other when the new chains are separated, thus producing two new strands of DNA. The sequence on the bases on the chains varies with the individual, and it is this sequence that governs genetic code.

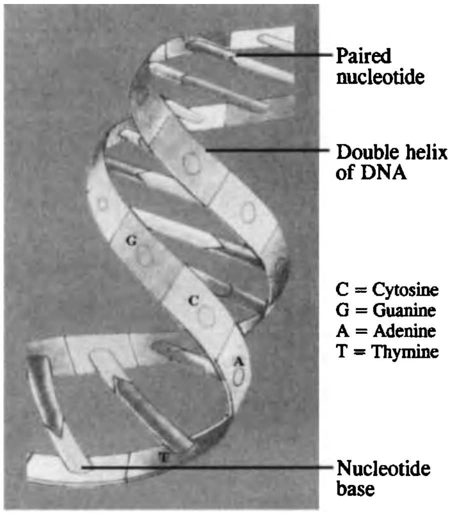


Fig.D.7: Structure of DNA.

DNA works in conjunction with ribonucleic acid (RNA). Synthesis of self-replicating DNA was also reported in 1967. Elucidating the structure of DNA molecule is under continuing research. Recent studies on DNA indicate that the helix may have a left-handed rather than a right-handed form.

The **transgenic plant** is an example of recombinant DNA which is a result of understanding the nature and function of DNA.

Dependent variable: See Regression

Dephosphorated slag

Dephosphorated slag, also called **basic slag** or **Thomas slag**, is a byproduct of the **Bessemer process** for melting iron ores containing phosphorus. It is a good phosphate fertilizer for acid soils and is also valued for its liming effect and micronutrient content.

Iron made from high phosphorus ore in contact with a base (CaO) is converted into steel by oxidation in a **Thomas converter**. The slag mainly contains lime-phosphate-silicate which melts to form calcium silicophosphate. At the end of the blowing process, the slag floats on the molten steel surface. Adding a phosphate rock in place of lime to the converter increases the phosphorus pentoxide (P_2O_5) content. This is not possible, however, with phosphate containing fluorine because the latter reduces the solubility of **basic slag** in 2% citric acid. A typical range of composition of the basic slag is given in Table-D.3.

Table-D.3. Composition of basic slag.

Components	% Weight
P_2O_5	15-20
Al_2O_3	0.5-2.5
CaO	42-50
Fe_2O_3	9-13
SiO_2	4-6
MnO	3-6
MgO	2-4

The slag is applied in a finely-ground state or by granulation with potash. Phosphorus-potassium (P-K) mixed fertilizers have phosphorus pentoxide (P_2O_5) to potassium oxide (K_2O) ratios between 1:1 and 1:3. Addition of fused phosphate or dicalcium phosphate is legally permitted, to allow P_2O_5 content of the slag to be adjusted to maintain a constant P/K ratio.

Depreciation

Depreciation is the reduction in the value of an asset, (like a machine), due to passage of time, and wear and tear. Provision for depreciation can be made in the balance sheet. Depreciation also represents the decrease in the value of a currency.

Depressant

The property of a drug to induce sleep and to numb mental awareness is a depressant. **Alkaloids** present in many plants act as depressants.

Depth per unit time for infiltration

Infiltration rate is measured in terms of the volume per unit time per unit area and is simply estimated as depth per unit time for infiltration.

Derived savannah

Owing to intense human activity on the forest-savannah boundary, the vegetation of savannah has been encroaching rapidly upon tropical rain forests. This creates an ecological zone of transition, commonly known in West Africa as derived savannah.

Desalination

Desalination, also known as **desalting**, is one of the several processes for removing dissolved mineral salts from sea water or other brines. The following are among the most important processes: (i) Distillation with reuse of vapors by compressive distillation or multiple effect evaporation. (ii) Electrodialysis which is an ion-exchange process more efficient for purification of brackish water than sea water. (iii) Reverse osmosis which uses pressure applied to the surface of a saline solution separated from pure water by a semipermeable membrane through which ions cannot easily penetrate. The pressure forces the water component of the solution through the membrane, thus effectively separating the components of the solution. Membranes used are cellulose acetate or graphitic oxide. The method is planned for use in a desalination plant proposed for the brackish waters of the lower Colorado river, and is said to be the world's largest. (iv) Flash distillation which appears to be the most effective method so far developed for sea water desalination, accounting for about 90% of the world production capacity. There are more than 400 desalination plants in the USA. producing over 341 million liters of freshwater a day.

Desalting: See Desalination

Desertic soil

Desertic (arid) soil is a type of soil seen in arid, temperate and tropical climates. They support sparse or sporadic vegetation because of the net deficiency of rainfall leading to a thin or even discontinuous organic layer.

Desertification

Desertification is the process by which good land turns into desert because of drought, deforestation, and disproportionate agricultural or human activity. Thus, environmental degradation arises from human activity and climatic influences under any rainfall regime in arid, semi-arid and sub-humid areas. A reduction in the growth of important plant species or incidence of drought can initiate or accelerate desertification.

Animal grazing leads to the land being stripped off its cover and accentuating the desertification process. If the environment becomes drier and the soil continues its degradation through erosion and compaction, **irreversible desertification** sets in. It is estimated that 60,000 km^2 area of land is lost each year all over the world owing to desertification.

Desert pavement

Desert pavement is a phenomenon in which a coarse residue is left on the surface of the desert after fine particles of the soil have been blown away by the wind. When coarse sand, gravel peds or clods are too large or dense to be swept away by the wind, they cover the wind-eroded soils with fragments generally larger than 1 mm in diameter.

Desiccants

Desiccants are hygroscopic substances such as activated alumina, calcium chloride, silica gel, zinc chloride, etc. They absorb water vapor and maintain a dry atmosphere in the container meant for food packaging, chemical reagents, etc.

Desiccants induce shedding of leaves by accelerated drying of various parts of the plant. Desiccants and **defoliants** facilitate harvesting.

A tightly-closed vessel, usually of glass, containing a desiccant is used in the laboratory for drying test materials, and is known as a **desiccator**. Some types of desiccators maintain partial vacuum.

Desiccator: See Desiccants

Desilication

Desilication is the loss of silica due to hydrolysis and leaching. Weathering of primary minerals occurs to different degrees in all soil environments, releasing highly mobile basic cations, moderately mobile silicic acid [$Si(OH)_4$], and relatively immobile trivalent aluminum (Al^{3+}) and bivalent iron (Fe^{2+}) ions into the soil solution. The fate of these ions depends on the leaching intensity of the soil, the composition of the organic matter, the amount of reactive surface area and the pH. The loss of $Si(OH)_4$ from the soil is known as desilication. In soils with a pH range of 5 to 7, much of the silica is lost by leaching.

Desilting

Periodical removal of finer particles of soil (silt) from a reservoir or canal to maintain its capacity is called desilting.

Desorption

Desorption is the process by which an adsorbed substance is released. Desorption may be achieved by heating, by reduction of pressure, by the presence of another more strongly adsorbed substance or by a combination of all. (See also Adsorption.)

Destructive distillation of coal

The destructive distillation of coal involves heating of complex organic substances in the absence of air to break them down into a mixture of volatile products that are then condensed and collected.

At one time, destructive distillation of coal carried out in a temperature range of 300 to 1000°C (to give coke, coal tar and coal gas) was the principal source of industrial organic chemicals. As the end-product is carbon, other terms used are **carbonization**, **pyrolysis** and **thermal decomposition**.

Crude shale oil may be obtained by destructive distillation of carboniferous shale. Residual oils from petroleum refinery operations are subjected to coking or destructive distillation to reduce their hydrogen content. The main product of the destructive distillation of wood is charcoal which contains sulphur, phosphorus and small quantities of ash.

Detergents

Detergents are synthetic, organic liquids, which are water-soluble cleaning agents. They have wetting and emulsifying properties that remove dirt.

Detergents are common emulsifiers which have lyophobic and lyophilic parts in their molecules to stabilize the emulsion. They, unlike soap, are not manufactured from fats and oils. Linear alkyl sulphonates (LAS) and alkyl benzene sulphonate (ABS) are examples of synthetic detergents. Synthetic detergents are classified into anionic, cationic or nonionic detergents based on the mode of chemical reaction. (See also Emulsion.)

Deuterium

Deuterium is one of the three isotopes of hydrogen, the other two being hydrogen-1 and tritium. Hydrogen-1 and deuterium are naturally occurring stable isotopes, while the radioactive tritium is made artificially.

In nature, the ratio is one part of deuterium to 6500 parts of normal hydrogen. Deuterium is present in water as the oxide HDO from which deuterium is usually obtained by electrolysis or fractional distillation. Its chemical behavior is similar to that of hydrogen, although deuterium compounds react slowly.

Devarda's alloy

Devarda's alloy contains 45% aluminum, 50% copper and 5% zinc. It is used to detect and analyze nitrate groups. It converts nitrate into ammoniacal nitrogen in alkaline solution while analyzing nitrogen fertilizers.

Dextrin

Dextrin is a group of colloidal products, formed by the hydrolysis of starches with dilute acids or by heating dry starch. The yellow or white powder or granules obtained are soluble in boiling water and insoluble in ether or alcohol. Dextrin is used in adhesives, as thickening agents and in penicillin manufacture.

D horizon

D horizon is the geological material situated directly below the parent material of the soil and is lithologically discontinuous from the soil above. The letters C or R designate the D horizon, preceded by the numerical 1. (See also Soil horizons.)

Diagnostic horizon

Diagnostic horizon is a horizon with a set of quantitatively defined properties such as color, hardness and temperature, or values like depth, content, volume and density. It is measured by methods independent of the observer.

To verify diagnostic horizons, some data (percentages of lime and salt) needs to be obtained from the laboratory. Diagnostic horizons help identify soil orders and sub groups which are denoted by a letter code.

Diagnostic horizons found at the soil surface are called **epipedons** and those found below the surface, **endopedons**.

Diagnostic techniques

Diagnostic techniques are used to measure the fertility and nutrient status of the soil. These help the farmer gain knowledge essential for fertilization related practices and issues, which relate to crop requirement, yield goal, weather and soil characteristics.

Interpretation of the following tests depends on the relationship of the test results with the actual crop response: (i) **Field experiments with fertilizers**: These are done both for simple as well as complex fertilizers, the former requiring 4 to 9 plots for experimentation and the latter requiring field and laboratory facilities. Often, experiments are conducted on selected pieces of the government's or the cultivators' own land. (ii) **Pot culture experiments with fertilizers**: These are also called **greenhouse experiments** and are performed under controlled conditions on a small piece of land (Fig.D.8) for relatively quick and inexpensive diagnosis.

Fig.D.8: A greenhouse provides controlled conditions for crop growth.

Soil samples collected from the plow layer depth at different places of the same field are mixed thoroughly and then used for experiment. (iii) **Visual observation of plants**: If a soil is deficient in one or more nutrients, the plants growing there indicate the deficiency. A severe nutrient deficiency or excess reflects on different plant parts, especially leaves. (iv) **Soil analysis methods with fertilizers**: Soil analysis determines the plant nutrient resources of the soil. Farmers can send soil samples for analysis and get a clear picture of the state of their soil for planning the next crop and for determining fertilizer dosage. (v) Method using micro-organisms as extractants: Some micro-organisms exhibit behavior similar to that of higher plants. For example, the growth of *Azotobacter* reflects nutrient deficiency in the soil. Compared to the utilization of higher plants, microbiological methods are rapid, simple and require little space.

Diammonium phosphate

With excess ammonia, the technical grade of diammonium phosphate (DAP) contains 16 to 18% nitrogen and 20 to 21% phosphorus. It is formed by the following reaction:

$$2NH_3 + H_3PO_4 \longrightarrow (NH_4)_2\,HPO_4$$

DAP is an important fertilizer as well as an intermediate in the production of complex fertilizers and bulk blends.

Diazotrophs

Diazotrophs or **biological nitrogen fixers** are micro-organisms which fix atmospheric nitrogen, without the presence of growing plants. They are also called free living micro-organisms. *Azotobacter* is an example of a diazotroph.

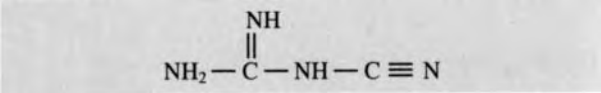
Dicalcium phosphate

Dicalcium phosphate ($CaHPO_4$) is made from calcium carbonate and phosphoric acid. It contains 34% citrate-soluble phosphorus pentoxide (P_2O_5). It is not commonly used as a fertilizer, but is used as a supplement to animal feed.

Dicyandiamide

Dicyandiamide, referred to as **DD** or **DCD**, is used as a nitrification inhibitor and a slow-release nitrogen source.

Dicyandiamide is mixed with fertilizers for nitrification control and the utilization of nitrogen for a longer period. Its chemical structure is given in (Fig.D.9).



$$NH_2-\overset{\overset{\displaystyle NH}{\|}}{C}-NH-C\equiv N$$

Fig.D.9: Chemical structure of dicyandiamide.

Dicyandiamide is a stable compound and its application at the rate of 15 kg/ha inhibits nitrification for up to three months. Urea containing 1.4% DD and urea ammonium nitrate solutions with 0.8% DD are available for increasing the effectiveness of nitrogen fertilizers.

Dicyandiamide, because of its non-volatile character, is easier to handle compared to nitrapyrin.

Diethylenetriaminepentaacetic acid soil test

Diethylenetriaminepentaacetic acid (**DTPA**) is commonly used for extracting the available cations – iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn) – from the soil. The choice of DTPA from among a number of **chelating agents** is because of its stability constants for simultaneous complexing of Fe, Mn, Cu and Zn. The extractant is highly pH dependent and is buffered at pH 7.30 with triethanolamine.

The DTPA method is inexpensive, reproducible, replicable and easily adaptable for routine operations.

Diffusion

Diffusion is defined as the movement of a substance from a region of high concentration to a region of low concentration.

Diffusion occurs most readily in gases, less so in liquids and the least in solids. When nutrient supply in the root vicinity is not sufficient to satisfy the plant demand, a concentration gradient develops and the nutrients move by diffusion. Most of the potassium (K) and the phosphorus (P) move from the soil to the root surface by diffusion, as described by **Fick's first law**:

$$\frac{dc}{dt} = D_e\,A\,\frac{dc}{dx}$$

where dc/dt is the rate of diffusion, dc/dx is the concentration gradient, D_e is the **diffusion coefficient** which describes diffusivity of a homogeneous medium, and A is the cross sectional area. As soil is not homogeneous, the concept of a diffusion rate in soil may be difficult to understand. The diffusion coefficient for the soil medium is given by:

$$D_e = D_w\,\theta\left(\frac{1}{T}\right)\cdot\left(\frac{1}{b}\right)$$

where D_e is the diffusion coefficient in the whole soil medium, D_w is the diffusion coefficient in free water, θ is the volume of the soil water content, T is the tortuosity factor, and b is the soil buffering capacity. This relationship shows that as the soil moisture content (θ) increases, the diffusion coefficient (D_e) increases and results in an increase in the diffusion rate. As the moisture content is lowered, the moisture film around the soil particles becomes thinner and reduces the diffusion of ions through these films.

The distance that a diffusive nutrient moves through soils is usually in the range of 0.1 to 15 mm. Hence, the nutrients within the soil zone alone contribute to the nutrient supply to the roots by way of diffusion. For most ions, diffusion coefficients are in the region of 10^{-6} to 10^{-7} cm^2 S^{-1}. Phosphorus has the slowest diffusion coefficient of 10^{-11} cm^2 S^{-1}. The plant requirement of phosphorus is met mostly during diffusion. Fertilizer applications can improve the mass flow and diffusion of ions to the roots by increasing nutrient concentrations in the soil solution. The increase in the clay content and the lowering of soil moisture temperature slow down diffusion. The addition of P and K increases the diffusion gradient and helps to offset these retarding effects.

Diffusion coefficient: See Diffusion, Fick's law

Digestion: See Degradable waste

Digger

Digger is a type of modern plow.

Dike

Dike or **dyke** is a non-permeable barrier erected around water storage tanks. Dikes are also built around tanks in chemical plants to contain spillage and prevent pollution in the event of a mishap.

Dilatancy

In Newtonian fluids, the velocity gradient is directly proportional to the shear stress. In non-Newtonian fluids, viscosity increases as the velocity gradient increases; that is, the faster the liquid moves, the more viscous it becomes. Such liquids are said to be **dilatants** and the phenomenon they exhibit is called dilatancy. It occurs in some pastes and suspensions containing high concentrations of suspended matter.

Dilatants: See Dilatancy

Diluent

Diluent is a substance that reduces the concentration of an active material for a beneficial effect. Examples: (a) the use of diatomaceous earth (diluent) with extremely impact sensitive and explosive nitroglycerine to form a much less shock-sensitive dynamite, (b) addition of sand to cement to improve workability with no serious loss of strength, (c) addition of an organic liquid having no solvent power to a paint or lacquer to reduce the viscosity and improve application properties. Diluents are also defined as low-gravity materials used primarily to reduce cost; for example, blown asphalt, wood flock, etc. in rubber and plastic mixes.

Diluents, such as calcium carbonate, are added to make a fertilizer formulation. In application, there is no clear difference between a diluent and an extender.

Dilution effect

Dilution effect in nutrient management occurs when the application of one nutrient results in a reduced concentration of another nutrient, leading to a greater uptake of the second nutrient. The application of the first nutrient may be beneficial to the plant and may result in increased yields. But its presence may have a dilutory effect on another nutrient, leading to the greater uptake of the latter.

Dilution effect is distinct from a negative effect since there is no adverse or harmful influence. The addition of sand to urea to get different grades of urea 40-0-0 from 46-0-0 is an example of dilution. Dilution of anhydrous ammonia with water to give aqua ammonia is another example. If the effect of one factor is influenced by the effect of another factor, the two factors are said to interact. The interaction may be positive, negative or neutral.

Dimethipin

Dimethipin is used as a defoliant, to aid harvesting in cotton plants and as a desiccant for potato vines. It enhances the maturation process and reduces seed moisture in the harvesting of rice, rape seed, flax and sunflower.

DIN

DIN is a series of technical standards which originated in Germany and is now used internationally. DIN is used to designate electrical connections, film speeds and paper sizes. In the size analysis of solid powders (like soil or fertilizer), particle size separation is carried out by a series of sieves of different openings. In Germany, DIN sieves are used.

Dinoflagellates

Dinoflagellates are organisms which have rigid cell walls made of cellulose encrusted with silica and two flagella for locomotion. They are classified in a phylum of mostly single-celled organisms, under Protoctista. They are generally photoautotrophs and contain xanthophyll and chlorophyll pigments. Some of the species are bioluminescent.

Dipolemoment: See Liquid

Direct allelopathy

Allelopathy is the chemical inhibition of one plant (or organism) by another, caused by the release of inhibiting substances or toxins into the environment. When a plant harms or kills the other plant by its toxins, it is a direct allelopathy. For example, when the seeds of a weed called dyer's woad fall and rot, they emit a toxin into the soil that kills the roots of nearby grass plants.

Direct fertilizer subsidy

A subsidy is financial assistance granted by a government or by a public body to keep commodity prices at affordable levels. Direct fertilizer subsidy is one of the most common forms of subsidies given to keep fertilizer prices down. Many countries grant direct fertilizer subsidies, mainly for nitrogen fertilizers.

Direct method for recovery of ammonia or ammonium sulphate: See Ammonium sulphate recovery by the direct method

Direct neutralization of ammonia for producing ammonium chloride: See Ammonium chloride production processes

Direct response: See Linear response

Direct slurry granulation process

Direct slurry granulation process is granulation directly from slurry rather than from a powder form. (See also Fertilizer granulation.)

Disaccharides

Low molecular weight condensation polymers of **monosaccharides** are further classified into disaccharides (two monosaccharide units) and **trisaccharides** (three monosaccharide units). Sucrose and maltose are examples of disaccharides.

Disc plow

The disc plow consists of a number of disc blades attached to one axle or gang bolt (Fig.D.10). This plow is used for rapid, shallow plowing.

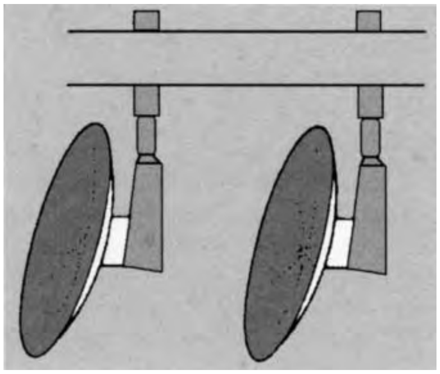


Fig.D.10: Blades of a disc plow.

Numerous rocks and roots are present in fields. The disc plow, which rolls over obstacles, is preferred to the moldboard (another kind of plow). The disc plow is also used for sticky soils that do not scour on a moldboard (Fig.D.11).

Fig.D.11: Disc plow in operation.

Diseases of rice: See Rice, major diseases of

Disinfectant

A disinfectant is a chemical liquid that destroys micro-organisms. Disinfectants are used to destroy harmful micro-organisms or to inhibit their activity.

Disinfectants are either complete or incomplete. **Complete disinfectants** destroy spores as well as vegetative forms of organisms. **Incomplete disinfectants** destroy vegetative forms of organisms but do not injure spores.

Some disinfectants are: (a) mercury compounds (mercuric chloride, phenylmercuric borate), (b) halogen and halogen compounds (chlorine, iodine, fluorine, bromine and calcium and sodium hypochlorites), (c) phenols, including cresol from coal tar and orthophenylphenol, (d) synthetic detergents (anionic, such as sodium alkyl benzene sulphonates and cationic, such as quaternary ammonium compounds), (e) alcohols with low molecular weights, except methanol, (f) natural products (pine oil), and (g) gases (sulphur dioxide, formaldehyde, ethylene oxide, etc.).

Heat and electromagnetic waves are also used as disinfectants.

A number of compounds like mercurous and mercuric chlorides, copper sulphate or carbonate and a mixture of zinc oxide and zinc hydroxide are employed as seed disinfectants. The effectiveness of disinfectants is rated by their phenol coefficient. Phenol is the standard and the corresponding disinfectant measuring system is called phenol coefficient. The disinfectant to be tested is compared with phenol on a standard microbe (usually *Salmonella typhi* or *Staphilococcus*). The disinfectants that are more effective than phenol have a coefficient more than 1. Those that are less effective have a coefficient less than 1.

Disodium tetraborate decahydrate

Disodium tetraborate decahydrate ($Na_2B_4O_7 \cdot 10H_2O$) is the chemical name of borax.

Dispersing agent

A dispersing agent is a surface-active agent added to a suspending medium to promote uniform and maximum separation of extremely fine solid particles, often of colloidal size. True dispersing agents are polymeric electrolytes (polyphosphates) and lignin (derivatives). In nonaqueous media sterols, lecithin and fatty acids are also dispersing agents.

Applications of dispersing agents are used to suspend fine particles in wet-grinding of pigments and sulphur and the preparation of ceramic glazes, oil well drilling muds, insecticidal mixtures, carbon black in rubber and water insoluble dyes.

Dispersion

Dispersion is the phenomenon by which a particulate matter is distributed uniformly throughout a continuous phase. Dispersion also means distributing or spreading a substance over a wide area.

In a two-phase system, with one phase of finely-divided particles distributed throughout a bulk substance, particles are considered to be in the dispersed or internal phase, and the bulk substance is considered to be in the continuous or external phase. Under natural conditions, distribution is seldom uniform, but under controlled conditions, uniformity can be achieved. The various possible systems are: gas/liquid (foam), solid/gas (aerosol), gas/solid (foamed plastic), liquid/gas (fog), liquid/liquid (emulsions), solid/liquid (paint) and solid/solid (carbon black in rubber).

High sodium content in sodic soils disperses clay and humus into individual hydrated particles. This dispersion adversely affects water movement, root growth and nutrient uptake by plants.

In foliar application, solid fertilizers should be dispersed uniformly in a solvent (like water). The spray then has a uniform concentration and there is no salt burn on the leaves or clogging of the spray nozzle. The blended mixture is considered uniform when the fertilizer composition is uniform.

Splitting up of a ray of white light by refraction into its component colors is also known as dispersion.

Dissociation

Dissociation is the reversible decomposition of molecules into two or more simpler fragments, atoms, radicals or ions. It may occur in the gaseous, liquid or solid state or in a solution. For example, the dissociation of water occurs as follows:

$$H_2O \rightleftharpoons H^+ + OH^-$$

Thermal dissociation is induced by applying heat, **photo dissociation** by light, **electrolytic dissociation** by a solvent, or by electric discharge. All electrolytes dissociate to some extent in polar solvents.

Dissociation is quantitatively expressed as the ratio of the number of product molecules (moles) to all initial molecules (moles) and is called the **degree of dissociation**.

Equilibrium, characterized by a **dissociation constant**, may occur during dissociation. For example,

$$NH_4NO_3 \rightleftharpoons NH_4^+ + NO_3^-$$
$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$

The energy necessary for splitting a bond is called **dissociation energy** (the heat of dissociation) and its value depends on the strength of the bonds in a molecule. Molecules with lower dissociation energies split more readily.

Dissociation energy is determined by calorimetry, electron impact, spectroscopy or by kinetic methods.

Dissociation is an endothermic process and its rate increases by increasing the temperature. Since dissociation is accompanied by an increase in the number of particles in the system, increasing the pressure shifts the equilibrium toward undissociated molecules.

Dissociation constant

The equilibrium of a system is characterized by its dissociation constant and is achieved during dissociation. For example,

$$NH_4NO_3 \rightleftharpoons NH_4^+ + NO_3^-$$

The dissociation constant (k) depends on the temperature of the system and is expressed as:

$$k = \frac{[NH_4^+]\ [NO_3^-]}{[NH_4NO_3]}$$

The dissociation constant of a complex compound or a complex ion is the reciprocal of the stability constant of the complex. The dissociation constant, which is a measure of the electrolyte strength, plays an important role in choosing complexing agents like EDTA and EDDHA for complexing micronutrients for foliar application.

Dissociation energy

Dissociation energy or **heat of dissociation** is the energy required to break a bond. Its value depends on the strength of the bonds in a molecule, those with lower dissociation energies breaking more readily.

Dissolution

Dissolution refers to the action or process of dissolving or being dissolved. Dissolution of a solid into a liquid is a heterogeneous process in which the solid (solute) passes into solution because of its interaction with the solvent (for example, ammonium nitrate in water or foliar spray preparation). Dissolution of solids begins at point defects or dislocations of monocrystals and on the surface of grains of polycrystalline compounds. The rate controlling process may be either diffusion or some elementary step of the phase reaction.

The **Nernst equation for dissolution** of a solid in a liquid controlled by diffusion is:

$$\frac{dc}{dt} = kS\ (C_S - C)$$

where dc/dt is the time dependent variation of concentration, S is the surface area of the solid, C is the concentration, C_S is the concentration at the surface determined by the solubility of the compound and k is the rate constant.

The rate constant (k) is determined by the ratio of $D/v\delta$, where D represents the diffusion coefficient, v the solution volume and δ the thickness of the liquid layer adherent to the surface of the solid (in which concentration gradients exist even under vigorous stirring and transport is realized by diffusion). Nernst equation has no general validity, since not only diffusion but also any step other than diffusion of the phase reaction may become the rate determining step.

Dissolved bone

Dissolved bone is another name for **bone superphosphate**.

Dissolved oxygen

Dissolved oxygen content is one of the indicators of the suitability of a water supply for biological, chemical and sanitary investigations. Adequate dissolved oxygen is necessary for the life of fish and other aquatic organisms and is an indicator of corrosivity of water, photosynthetic activity, septicity, etc.

A recent study in Hong Kong found that the lack of oxygen in highly polluted waters can sharply alter the sex ratio among fish, resulting in far more males than females.

Distributional efficiency: See Efficiency

Distribution pattern of fertilizer application

The distribution pattern of fertilizer application through an applicator is a measure of the uniformity of fertilizer distribution in soil. It can be determined accurately on a test stand where boxes with areas of $0.25m^2$ are kept at different places over the whole application width to collect the fertilizer. The collected fertilizer is weighed and the mean is calculated; the smaller the deviation from the mean, the more uniform the distribution pattern.

DNA

DNA is short for **deoxyribonucleic acid**.

Dolomite

Dolomite is a carbonate of calcium and magnesium. It is a mineral of formula $CaMg(CO_3)_2$ with a rhombohedral system. It has a density of 2.8 g/cc and hardness of 4 on the Mohs scale.

Dolomite has a vitreous lustre which is between transparent and translucent. It effervesces with hot concentrated hydrochloric acid (HCl).

A carbonate-rich sedimentary rock of chemical or biological origin contains 50% or more carbonate, of which at least half is in the form of dolomite. The color of dolomite is darker than limestone and does not give any effervescence with cold and dilute HCl.

Dolomite may also contain iron and manganese. Depending on the proportion of dolomite and calcite, there are many transitional phases between calcareous dolomites and dolomitic limestones.

Dolomite has multiple applications. It is used in the manufacture of magnesium and its compounds. It is also used as building material, as a refractory for furnaces, as a fertilizer, for the removal of sulphur dioxide from stack gases and in ceramics. (See also Limestone.)

Dolomitic hydrated lime

A dolomitic limestone, when calcined, forms a mixture of oxides of magnesium and calcium. Upon hydration, the mixture gives dolomitic hydrated lime with 42 to 50% lime and 28 to 32% magnesium oxide. The hydration of the mixed oxides can be carried out in a closed rotating cylinder, with water being introduced as a fine spray or steam.

Dolomitic hydrated lime has good neutralizing power.

Dolomitic limestone

A major source of calcium carbonate is dolomitic limestone. **Limestone** contains 4.4 to 22.6% magnesium carbonate ($MgCO_3$). Pure dolomite, on the other hand, contains 54.3% calcium carbonate ($CaCO_3$). The rest is made up of $MgCO_3$.

Donnan equilibrium

Donnan equilibrium is the dialysis membrane equilibrium. It is set up in the presence of a low molecular mass of colloidal electrolyte.

Donnan equilibrium is an electrochemical equilibrium governed by electrical and diffusion phenomena. A colloidal electrolyte Na^+R^- of concentration C_1 and sodium chloride (NaCl) of concentration C_2 are placed together on one side of a membrane with distilled water placed on the other side. After some time, x moles of NaCl diffuse through the membrane, creating the following situation at equilibrium:

Aqua solution	Distilled water
$R(C_1)$	$Cl^-(x)$
$Cl^-(C_2 - x)$	$Na^+(x)$
$Na^+(C_1 + C_2 - x)$	

Membrane

Only low molecular mass ions are in equilibrium because the colloidal component does not traverse through the membrane. The condition of equality of chemical potential of the electrolyte on both sides of the membrane leads to the following equation for x:

$$x = \frac{C_2(C_1 + C_2)}{C_1 + 2C_2}$$

In the absence of the colloid ($C_1=0$), NaCl is distributed uniformly between both compartments; with an excess of colloid ($C_1 >> C_2$), NaCl passes quantitatively into pure water.

A special case of Donnan equilibrium is seen during **membrane hydrolysis**. Both Donnan equilibrium and membrane hydrolysis lead to the formation of a membrane potential at the dialysis membrane.

Nutrients in the soil solution enter plants through their roots by diffusion, with the cell wall acting as a membrane. In saline soils, NaCl preferentially diffuses through the root, bypassing the phosphate nutrients because of their larger charge and size. This increases the osmotic pressure inside the root, which has to be overcome for diffusion or absorption.

Dormancy

When a plant is said to be dormant, it means the plant is alive but not actively growing. Dormancy is a state in which the growth of a specific plant part is not resumed even though the environment supports germination, seedling growth or development of other (apparently identical) tissues of the same species or plant.

Dosing

Dosing is the practice of mixing waste material in the soil to keep the soil aerated and to reduce clogging.

Dose is also the quantity of a substance administered or the amount of ionizing radiation received by any matter or living organism.

Double decomposition

Double decomposition entails a chemical reaction in which two compounds exchange ions and typically precipitate an insoluble product. For example,

$$AgNO_3(aq) + KCl(aq) \longrightarrow AgCl(s) + KNO_3(aq)$$

The reclamation of sodic soils with gypsum is a classic example of double decomposition, where calcium substitutes sodium and gets leached with water.

$$2NaCl + CaSO_4 \cdot 2H_2O \longrightarrow CaCl_2 + Na_2SO_4 + 2H_2O$$

Double superphosphate

Double superphosphate contains 42 to 45% phosphorus pentoxide (P_2O_5) and less sulphur, unlike **single superphosphate**. To make double superphosphate, a higher ratio of sulphuric acid to rock phosphate is maintained than that needed for single superphosphate.

$$Ca_3(PO_4)_2 + 3H_2SO_4 \longrightarrow 3CaSO_4 + 2H_3PO_4$$
$$4H_3PO_4 + Ca_3(PO_4)_2 \longrightarrow 3Ca(H_2PO_4)_2$$

The phosphoric acid combines with rock phosphate to produce a more concentrated **superphosphate** which is used mainly as an intermediate for phosphopotash products. In the production of double superphosphate, phosphate rock is treated with a mixture of sulphuric acid and dilute phosphoric acid.

Draa

Draa are very large sand dune formations, the dimensions of which are in hundreds of meters and their spacing in kilometers.

Drainage

Drainage refers to the removal of excess gravitational water from soil by natural or artificial means. If the downward gravitational flow of matter is impeded, the result is waterlogging which leads to an anaerobic condition called **impeded drainage**.

Drainage is a limiting factor for most plants. Surplus water may be traced to a pond where the rate of precipitation exceeds the rate of infiltration into the soil. Alternatively, temporary or permanent water tables have to be drained artificially to protect plant roots.

A cultivable land with drainage creates a favorable condition for higher plants and micro-organisms. The main advantages of a drainage system are that it (a) improves soil aggregation, encouraging granulation and better plant root development, (b) improves soil aeration, biological activity, and nutrient uptake, (c) permits satisfactory cultivation, and (d) lowers the specific heat of the soil, reducing the energy requirement to increase the temperature of the drained soil and thus ensuring rapid seed germination.

Most crops grow better when wet soils are drained. Waterlogging results in drooping leaves, decreased stem growth rate, leaf abscission, leaf chlorosis, adventitious root formation, decreased root growth, death of smaller roots, absence of fruits and reduced yields. Rice, which favors submerged and poorly-drained soils, is an exception.

In arid or semi-arid areas, adequate drainage is necessary for removing excess salt from the plant root zone, for which an artificial drainage system is established simultaneously with the irrigation system. Drainage practices in humid regions are different from those in arid regions. In humid areas, drains are made at depths of 75 to 120 cm, while in arid areas they are made at a depth of about 180 cm; the greater depth is meant to leach out the excess salt below the root zone.

Surface drainage and **sub-surface drainage** are among prevalent drainage systems. Surface drainage can be achieved by constructing gently sloping open ditches for water collection, making the soil surface smooth and creating enough slope to facilitate water run-off. Burying conduits on specified slopes is the most commonly found subsurface drainage system. Surface drains can be used on all kinds of soils but are especially preferred in the case of fine-textured clay soils. Subsurface drains require sufficiently porous soils for water to percolate through it to the buried drain tile or porous tubing.

Surface drainage systems are best adapted to drain flat or nearly flat soils. These systems are (a) are slowly permeable, (b) are shallow over rock or fine clay, (c) have surface depression that traps water, (d) receive run-off or seepage from uplands, and (e) require removal of excess irrigation water and/or lowering of the water table.

The three principal surface drainage systems are **open ditch**, **drainage by beds** and **smoothing**. These systems include tile drainage, tube drainage, mole drainage, sump-and-pump drainage and special vertical techniques such as relief wells, pumped wells and inverted or recharged wells. Subsurface drainage systems have become increasingly popular in recent years because the prices of productive crop land make the installation of drainage systems on wet and inexpensive land highly preferable to acquiring better land.

Relative water polluting effects of sub-surface drainage systems are found in high nitrate concentrations in tile drain effluents. Surface drainage water has high sediments and fewer soluble phosphates, pesticides, etc.

Drainage problems are generally uncommon in most of the tropics where soils have high infiltration rates and permeability. Heavy rains cause small accumulations and depressions that drain off easily. In areas where drainage is essential, surface ditches are employed.

Drainage basin

Drainage basin, also called **watershed**, **topographic watershed** or **catchment basin**, is a region or a ridge of land that separates waters flowing to different rivers, basins or seas.

Drainage by beds

Drainage by beds, also known as **bedding**, is a type of a **surface drainage** system. It is similar to an open 'W' shaped drainage with one difference – namely, it has a higher crown and a narrower gap between the drains.

Bedding is generally preferred in areas of high rainfall and fairly level fields.

Drainage classes

The drainage class of a soil depends on the water table and its fluctuations, permeability of the soil and topography of the land. Interactions among these factors determine the drainage classes which are: (a) exclusively drained (dry soil), (b) well-drained (no gleyed spots), (c) moderately well-drained (slight gleying), (d) imperfectly drained (considerable gleying), (e) very poorly drained (highly gleyed), and (f) not drained.

Dravite

Dravite is magnesium-rich **tourmaline**. It is a borosilicate which is the main source of a boron-containing mineral found in soil.

Dried slurry

There are several organic, peat-based and mineral fertilizers available for use. Mixture of two or more are commonly applied to suit each soil type, crop, etc.

Dried slurry is the organic component of such mixtures, which are based on **composted bark** or lignite or other organic materials such as spent mushroom substrate.

Drift retardant

When a liquid is forced through a spray orifice under pressure, a large number of extremely fine spray droplets accompany the normal sized droplets. These 'fines' can easily drift from the target area even by a slight breeze. If the spray is of a herbicide and if it is phytotoxic, the drifted herbicides or the 'fines' can seriously damage non-target plants and crops. A long chain polymer (like anionic polyacrylamide) added to a spray tank to reduce the number of fine spray droplets is known as a drift retardant.

Drill

Seeds can be broadcast, drilled or dibbled. A drill is an implement used for sowing seeds in rows or placing a fertilizer at a certain position on or below the soil surface. This process is known as drilling. Seeds and fertilizers are drilled simultaneously in the soil, using an implement called **combine drill**, usually down the same seed-tube, and not by separate hoppers for seed and fertilizer (Fig.D.12). Combine drill is usually recommended for phosphate fertilizers. Fertilizers inserted below the soil using the drill are called **drilled fertilizers**. The combined drill gives good results with wheat, maize and other cereals capable of withstanding contact with fertilizers. This method is, however, unsuitable when the rate of nitrogen application is higher than 25 kg/ha, as this may lead to the burning of the seed.

Fig.D.12: Seed and fertilizer sowing drills: Modern type, tractor mounted (1) and traditional, wooden type (2).

Drilled fertilizers

Fertilizers embedded below the soil surface using a drill are called drilled fertilizers. This method of fertilizer application is usually recommended for phosphate fertilizers. (See also Drill.)

Drill placement

Drill placement is the method of applying fertilizers close to the seeds and is commonly recommended for pre-plant application. It is also called **contact placement** because here the seeds and the fertilizer are sown together by way of drilling. The major objective is to place the fertilizer in the moist root zone.

Drip irrigation method

Drip irrigation or **micro-irrigation** is a method for delivering a slow and frequent water flow to the soil, using a low-pressure distribution system and special flow-control outlets. Here, water is conveyed through a network of pipes and tubes and discharged through small orifices at the base of the plants at a controlled rate (Fig.D.13). The system economizes on water and is used especially for high value cash crops in water-scarce regions.

Fig.D.13: Drip irrigation method as used in a greenhouse. Inset shows an emitter for controlled droplet application.

Drought

Drought refers to a condition of extremely insufficient rains, which can adversely affect the region's economy. Agricultural drought occurs when plant growth is affected by the prolonged shortage of soil moisture. (Fig.D.14). Moisture deficit results when water available in the soil is not sufficient to meet the needs of potential evapotranspiration of crops. Hydrologic drought is common when reservoirs are depleted. Studies on the incidence and prediction of droughts and measures to combat the effects of droughts are important.

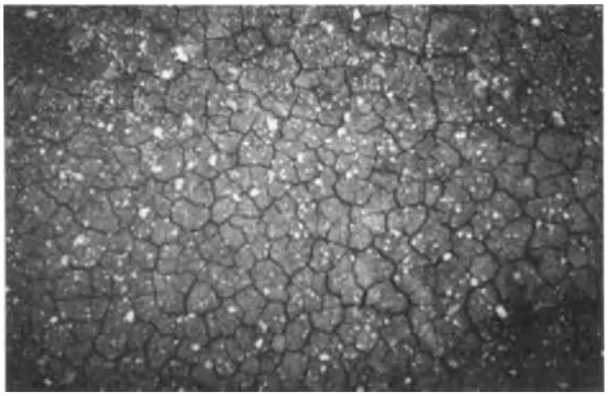


Fig.D.14: Land with clayey soils generally develop cracks owing to drought.

Absolute drought describes a condition when there is either no rainfall or very scanty rainfall (roughly less than 0.25 mm for 15 consecutive days). **Partial drought** is said to have occurred when on at least 29 consecutive days, the mean daily rainfall does not exceed 0.25 mm. Drought is a period when crops need more water than that which is available from rainfall and from water stored in soil. Agriculturists use the **Palmer index** to express drought intensity as a function of rainfall and hydrologic variables. Drought is said to have occurred when available moisture in the root zone is below 30% of the water-holding capacity of the soil.

Drought can be determined in terms of the moisture deficiency or **aridity index**, which is the ratio of annual moisture deficiency to annual water need. Based on the standard deviation (σ) of the aridity index to analyze droughts in arid zones, drought intensities are categorized as follows:

$\frac{1}{2}\sigma$	moderate
$\frac{1}{2}$ to σ	large
σ to 2	severe
$>2\sigma$	disastrous

The intensity and duration of a drought determine its effects. The occurrence of a short period of drought reduces crop yield. Drought causes (a) depletion of water in aquifers, (b) lowering of the water table, (c) an increase in the salinity of water, and (d) scarcity of drinking water. Long-term droughts have more widespread effects. After a drought, water does not penetrate deep into desert soils and the rate of evaporation is high.

Another consequence of drought is the scarcity of grasses and fodder, often leading to famine and migration of human beings and livestock. The impact of drought is reduced by irrigation, water reclamation, use of hybrid seeds, re-afforestation and development of rangeland grazing.

Cereal crops such as sorghum and millet are best suited for cultivation under dry conditions. This feature is known as **drought resistance**. Drought resistance is a characteristic of plants suitable for cultivation in dry conditions, regardless of the mechanism that provides the resistance. There are some 30 factors (like the root to leaf ratio, the reduction of leaf surface, etc.) which affect transpiration and enable drought resistance. Cereals like sorghum have bulliform cells or motor cells that endow drought resistance. Some plants have a greater capacity to survive desiccation, which is known as their **drought hardiness**.

To improve the availability and use of soil moisture in drought-prone areas, the following four techniques are available:

(i) Improving soil moisture intake: The soil moisture intake is improved by (a) planting cover crops which produce ground cover and reduce run-off, (b) leaving crop stubble or debris in place, which slows down the run-off, (c) strip cropping, (d) spreading organic and inorganic material on land to slow down run-off and reduce evaporation, (e) tilling to improve infiltration,

(f) applying chemical wetting agents to speed up infiltration, and (g) constructing run-off bunds and terraces, which physically retard the run-off.

(ii) Reducing evaporation losses: Moisture losses due to evaporation can be reduced by (a) mulches, (b) anti evaporation compounds – spraying of wax, hexadecanol, bitumen, asphalt, etc., (c) removal of weeds by physical extraction or with herbicides, (d) planting hedges or shelter belts, and (e) wind breaks.

(iii) Reducing evapotranspiration losses: Reduction of evapotranspiration is achieved by (a) cultivating crops with low evapotranspiration, (b) removing deep-rooted weeds, (c) spraying crops with suitable compounds to reduce albedo, and (d) spraying with wax, silicone, resin, rubber, latex, etc.

(iv) Reducing percolation losses: Percolation losses can be reduced by (a) addition of hydrophytic material, and (b) insertion of an impermeable film made of plastic, rubber, etc.

Drought is the most serious threat to agriculture because of the frequency with which it occurs in the regions prone to it. Efforts made to control drought range from planting more trees to cloud seeding.

Drought, absolute: See Drought

Drought hardiness: See Drought

Drought resistance: See Drought

Drouinean method for active lime determination

Lime activity is determined by the Drouinean method which is usually applicable to soils containing more than 8% total lime. The lime is treated with excess ammonium oxalate. Calcium oxalate precipitates from active lime and the excess oxalate of ammonium is determined by titration with potassium permanganate after acidification.

Dry ashing

Ashing refers to the phenomenon of burning a plant. It leads to the breaking down of complex compounds into simpler ones, which is an important step in analytical work. When ashing is done by heating the sample, often with sodium carbonate, it is called dry ashing.

Dry combustion method

Dry combustion method is another name for the **Dumas method**.

Dryer

The term "dryer" refers to equipment used for drying food products, textiles, paper, chemicals, fertilizers, etc.

A dryer is a machine or device for drying something. Numerous types of equipment are used in chemical industries to remove water from a product during processing. The major types of dryers include the following:

Belt dryer, Centrifugal dryer, Convection dryer, Conveyor dryer, Flash dryer, Fluid-bed dryer, Freeze dryer, Pan dryer, Rotary drum dryer, Rotary tray dryer, Rotary vacuum dryer, Screw dryer, Spray dryer, Tubular dryer, Tunnel dryer, Truck tray dryer and Vibrating dryer.

A dryer also means a substance that is used to accelerate the drying of paints, varnishes, printing inks, etc. The drying is done by catalyzing the oxidation of drying oils or synthetic resin varnishes, such as alkyds.

Commonly used dryers are salts of metals with a valence of two or more and unsaturated organic acids. The approximate order of effectiveness of the more common metals is cobalt, manganese, cerium, lead, chromium, iron, nickel, uranium and zinc. These are usually prepared as linoleates, naphthenates and resinates of the metals. Paste dryers are commonly metal salts such as acetates, borates or oxalates dispersed in a dry oil.

Dry farming

Dry farming, also called **dry land farming**, is carried out in arid and semi-arid areas without irrigating the land but with techniques to conserve moisture. The technique consists of cultivating a given area on alternate years and allowing moisture to be collected and stored in the fallow year. Moisture losses are reduced by mulching and by removing weeds.

In Siberia, where melting snow provides much of the moisture for spring season crops, the soil is plowed in autumn, providing furrows which can collect snow and prevent it from evaporating or being blown away by winds. Usually, alternate narrow strips are cultivated to reduce erosion in the fallow year. Dry farming methods are also employed in the drier regions of India, Canada, Australia and the erstwhile USSR.

Dry formulation

A dry formulation, also called **dry mixing**, is a mixture of ingredients either in a dry condition or in a slurry which is granulated, prilled or flaked as it dries. The ingredients have to be safe for mixing and storing as well as chemically and physically compatible with each other. The formulations should use uniform particle sizes to reduce segregation and have a high critical relative humidity to spread the formulation at ambient humidity. The granules produced remain stable, hard and dust-free.

The simplest method of producing a micronutrient mixture is to dry-mix it with the primary nutrient materials. This method works well with non-granular materials, when all materials are of fine texture (say, 1 mm or less), and when the segregation is not significant. In countries like the Philippines, farmers turn to dry mixing according to their requirements.

Bulk blending is a form of dry mixing in which all nutrients are granular (1 to 3.3 mm diameter). For example, boron is incorporated in a superphosphate based phosphorus and potassium mixture so that the fertilizer can supply 0.2 to 0.5% boron.

Dry ice

Solid carbon dioxide is known as dry ice. It is produced by cooling gaseous carbon dioxide under pressure.

Dry ice is used in refrigeration, carbonated drinks and fire extinguishers. It is also a constituent of medical gases, as it promotes exhalation.

Drying

Drying entails the removal of about 90 to 95% of water from a material, usually by exposure to heat.

Industrial drying is performed by both continuous and batch methods. The type of equipment and temperatures used depend on the physical state of the material - liquid, solution, slurry or semi liquid (paste), solid or sheet.

Continuous drying: The rotating-drum dryer is used for flaked or powdered products (soap flakes); a heated metal drum revolves slowly in contact with a solution of the material, the dry product being removed with a doctor knife. In paper manufacture, drying is performed by a battery of staggered steam heated revolving drums located at the dry end of the four drinier machine, the paper passing around the drums at high speed. The moisture content is reduced from 60% to about 5%. In spray drying, milk, egg-white and other liquid food products are passed through an atomizing device into a stream of hot air. Ammonium nitrate is prilled in this method by spraying a solution from the top of a tower with hot air blowing upwards.

In **tunnel drying**, the product travels on a conveyor belt through a heated chamber of considerable length.

Batch drying: Steam jacketed pans are used if the material is in a paste or slurry form, or in removable trays placed in an oven, if in solid units (fruits, vegetables, meats, etc). The revolving tube dryer used for granular solids and coarse powders is a long, horizontal cylinder in which a current of warm air runs counter current to the movement of the material.

Freeze-drying is a specialized technique utilizing a high vacuum and low temperatures.

Dry land farming: See Dry farming

Dry land plants

Dry land plants, known as **xerophytes**, grow and survive in unfavorable habitats, such as dry soils (Fig.D.15) or in extremely dry or arid conditions. (See also Xerophytes.)

Dry mixing

Dry mixing is another word for a dry formulation.

Dry season

In tropical regions, especially in south Asia, the year is divided into wet and dry seasons and cropping patterns are designed accordingly. The October to April - period generally comes under the dry season when water deficiency occurs, as stored water level comes down because of evapotranspiration.

Fig.D.15: Various cacti are true dry land plants.

DTPA soil test

DTPA stands for **diethylenetriaminepentaacetic acid**. The DTPA soil test is calibrated for most crops. Its general interpretation for extractable micronutrients has now been documented. The knowledge of chelate stability in the soil provides the basis for developing the DTPA soil test for Fe, Zn, Cu and Mn.

Dual application of anhydrous ammonia

Dual application of anhydrous ammonia means its simultaneous application as a nitrogen source as also with fluid or solid P, K and S fertilizers.

Dual salt process for ammonium chloride

Dual-salt process (**modified solvay process**) is the most important method used for producing ammonium chloride. Here ammonium chloride and sodium carbonate are produced simultaneously using carbon dioxide, common salt and anhydrous ammonia as the principal starting materials. (See also Ammonium chloride.)

Dumas method for analysis of total nitrogen

The analysis of total nitrogen is done by two methods, namely, the Dumas method (also called the **dry combustion method**) and the **Kjeldahl method** (also called the **wet oxidation method**). In the Dumas method, the sample is weighed, mixed with cupric oxide and heated in a tube to 1800 to 2000°C in a stream of oxygen. The oxygen converts any nitrogen present in the compound into oxides of nitrogen which are passed over hot copper (at 650°C) to reduce them to nitrogen gas. The carbon dioxide and water vapor formed are absorbed in chemical traps. The nitrogen gas formed is collected and its volume measured, from which the mass of nitrogen or the total nitrogen content is determined by gas chromatography with a thermal conductivity detector.

The relative molecular mass of volatile liquids is calculated by weighing. An empty thin-glass bulb with a long narrow neck is first weighed at a known temperature. A small amount of the sample is then introduced in the glass bulb, heated (in a bath) to drive out air and vaporize the liquid, after which the tip of the neck is sealed, the bulb cooled and weighed as before. Filling the empty bulb with water and weighing it again gives the volume. The vapor mass is estimated from the air density.

Dune

Dune is a ridge or hillock of sand or other sediment created by the wind. It is formed wherever bare sands are attacked by violent winds - on coasts, riverbeds, glacial margins or deserts. However, it is in the desert that dunes cover the largest area. They can occur in isolation or as fields of many separate or joint dunes (called **erg**) and can be mobile or fixed (Fig.D.16).

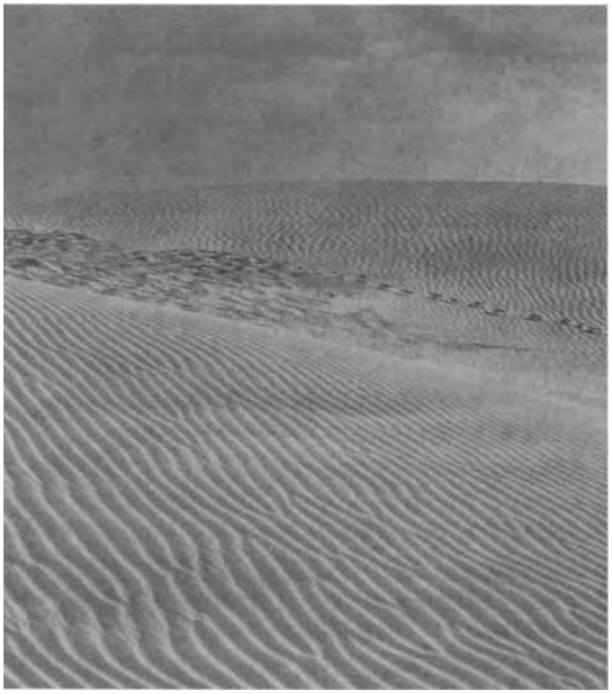


Fig.D.16: Sand dunes cover large areas either as separate or joint dunes.

There is no commonly accepted classification of dunes. This is partly because of their complexity and particularly because numerous intermediates and special forms have to be accommodated in any classification. Nevertheless, some dune types are widely recognized. **Draa** are very large dune formations, the dimensions of which are in hundreds of meters and with hundreds of kilometers between them. Barchans and transverse ridges are two other types of dunes. Parabolic or blow-out dunes are hairpin or spoon shaped. **Longitudinal** or seif-dunes are sometimes hundreds of kilometers long, as can be seen in the Sahara or some Australian deserts.

The **maritime dune** formed on shores is generally asymmetrical in shape because of wind action. The slope facing the wind direction is gentle. The maritime dune is unstable, can move several meters and can rise up to a height of 150 m in a year.

The **continental dune** is formed inland and exhibits near-perfect symmetry, if there are no dominating winds. It can attain a height of several hundred meters.

Dung

Dung, also termed as feces or **excreta**, is the solid waste or undigested material expelled by animals. It contains bacteria and dead cells and is used as manure. It is also used as a soil amendment, soil conditioner, biogas input, domestic fuel, and as the main ingredient of **farmyard manure** (FYM). On a dry weight basis the NPK percentages in dung are approximately 1.57, 0.56 and 1.05, respectively.

The dark-colored liquid that drains from a heap of dung manure and consists of soluble compounds of ammonia and organic matter, is called **dung liquor**.

A pit used for dung or manure is called **dung mere**.

Dung liquor: See Dung

Dung mere: See Dung

Dunnage

Dunnage, a prerequisite for storage, is a platform built on the floor of a godown and used for keeping fertilizer bags, thereby preventing them from coming into contact with the floor. Generally, it is made of wooden planks, bamboo or plastic. (Fig.D.17).

Fig.D.17: Platform of wooden planks used in godowns for storage of goods.

Dust: See Dust, an environment issue

Dust, an environment issue

Dust is made up of finely divided solid particles. Dust may have damaging effects on humans and animals when inhaled. It also constitutes a fire hazard. Dust can thus be an environmental concern.

Dusts are suspensions of particles of 10 microns or less in diameter, though sizes of up to 50 microns may also be present. Such dusts include (a) metallic particles of all types, some being more harmful than others, (b) silica, mica, talc, quartz, sulphur, clays, calcium carbonate, asbestos, etc., and (c) organic materials such as chemicals, pesticides, fertilizers, flours, cellulose, coal, etc. Dust particles ranging from 0.5 to 2 microns size are most damaging to the lungs. Silicosis is caused by chronic exposure to uncombined silica or quartz in mines and quarries. Dust suspensions in enclosed industrial areas pose a fire hazard regardless of the chemical nature of the dust. An explosion may be initiated by a spark or an open flame.

Dust collecting bags, dust collectors or electrostatic precipitators can be used for dust control. A threshold limit value for various dusts is available in literature.

Dustiness

Handling of large quantities of fertilizers and raw materials creates dustiness. The dust can lead to (a) loss of material during the process, (b) environmental pollution, and (c) exposure of employees to dust hazard.

Like many industries, the fertilizer industry generates dust. The most common reasons for dust in granular fertilizers are (a) inefficient screening, (b) poor conditioner adherence, (c) friable granules which abrade easily, and (d) granular surface dust created in the process.

The extent of dustiness of a fertilizer is normally measured by passing the sample through a counter current airflow inside a 'dusting tower' and measuring weight loss. The counter-current airflow is adjusted to entrain a specified particle size (dust) while allowing the granules to fall to the bottom of the tower. The equipment can also be used to evaluate chemical conditioners, such as kaolin's adherence to granular fertilizer.

A dust control treatment involves spraying the fertilizer with a petroleum oil-based liquid so that dust particles adhere to the granules, or agglomerate and do not become air borne. Oils of high paraffin content or amines enhance dust control properties.

Particle collection systems or devices for control of particulate matter may be considered on the basis of structural or application similarities in several principal categories. These are the gravity settling chamber, inertial device, packed bed, cloth collector, scrubber, electrostatic precipitator and air filter.

Dyer's reagent

Dyer's reagent is a 2% solution of citric acid with a pH equal to 2, used for the estimation of available phosphorus in the soil. It corresponds to root action.

Dyke

Dyke or **dike** is a non-permeable barrier erected around tanks or chemical plants to contain spillage and prevent pollution.

Dynamic equilibrium

A chemical reaction in which the forward and the reverse reactions proceed simultaneously at equal rates is said to be in dynamic equilibrium. Each chemical reaction can be understood kinetically as reversible having different rates in the forward and reverse directions. The observed rate of change of concentration is then the difference between these two rates, and this difference, due to the lowered forward rate and increased rate of the reverse reaction, may gradually become zero. Any further movement of the reaction toward the product is thus stopped and the system is in chemical equilibrium. The apparent equilibrium constant K_c is expressed as the ratio of the rate constants of the forward and reverse reactions, such as:

$$A \underset{K_{-1}}{\overset{K_1}{\rightleftharpoons}} P$$

where $K_c = K_1 / K_{-1}$, and A and P are the reactants and products, respectively.

This equation links kinetics to thermodynamics and is followed exactly by elementary sulphur reactions. From the kinetics stand point, the reaction is not at a standstill but occurs at equal rates bi-directionally. The equilibrium between the solution potassium ion (K^+) and the exchangeable K^+ ion in soil is an example of dynamic equilibrium.

$$\text{Fixed Potassium} \rightleftharpoons \text{Exchangeable potassium} \rightleftharpoons \text{Solution potassium}$$

Dyne's rain gauge

Dyne's self-recording rain gauge is used for recording the time of rainfall and determining its intensity and duration. The continuous type of recording rain gauge uses a calibrated spring balance to record the weight of precipitation, on a clock-driven chart.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

E

Early district: See Early soil

Early soil

A soil that warms up rapidly in spring and is more capable of supporting the early growth of a crop than other soils in the area is called an early soil. **Early district** is an area occupied by early soils.

Earthworms

Earthworms are important soil organisms. They aerate and stir the soil, facilitating better water infiltration and easier root penetration. Their presence is useful to agronomists, gardeners and fishermen. Being saprophytes, earthworms live only on dead organic matter. They do not consume living vegetation like destructive cutworms do.

Moist, well aerated, warm soils with a pH between 5 and 8, and low salt concentration are the conditions best suited to earthworms. Earthworms flourish in fairly deep soil with a medium or fine texture and high calcium content, and in soil undisturbed by tillage. Mice, moles, mites, millipedes, ants, strong insecticides and heavy machinery kill earthworms.

Earthworm species such as *Eisenia foetida* and *Uginus ugini* (Fig.E.1) are used for making vermicompost, an **organic manure**.

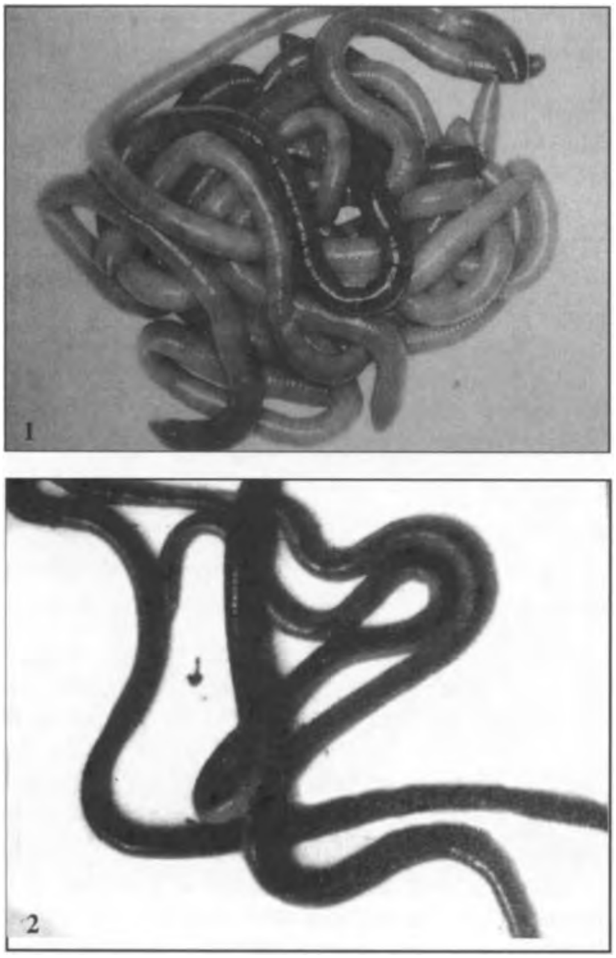


Fig.E.1: Adult earthworms of (1) Eisenia foetida, and (2) Uginus ugini.

Earthworms significantly influence soil structure, fertility and crop productivity. Several methods have been developed to estimate their numbers in soils. These methods are mainly: (a) physical, in which earthworms are removed from the soil for a physical body-count, (b) behavioral, in which earthworms are stimulated to move out of the soil and be counted, and (c) indirect, wherein the number of earthworms are estimated by trap catches or from other physical evidence. There are other methods: hand sorting, washing and sieving, chemical and electrical expulsion, and trapping. (See also Vermicompost.)

Easily accessible water

Easily accessible water (**EAW**) is the fraction of usable water in soil that is easily available to plants. Approximately, two thirds of useful available water is easily accessible. Only when EAW is exhausted, do plants need to be protected against drought.

A precise estimation of EAW is difficult because it is largely dependent on the root system and evaporation conditions. A rough estimate of EAW is obtained from:

$$\mathrm{EAW} = 0.66 \times \frac{\mathrm{BD}}{10}(\mathrm{RC} - \mathrm{PWP})\frac{d_{\text{fine earth}}}{100}$$

where BD is the **bulk density**, RC is the **retention capacity**, PWP is the **permanent wilting point** and d is the rooting depth in cm.

East lothian rotation

East lothian rotation is a **crop rotation** system with six-course rotations (See Crop rotation.)

EAW

EAW is short for **easily accessible water**.

EAY

EAY is short for **equivalent area yield**.

EB horizon

EB or **AB horizon** is a transition soil horizon between **A** or **E** horizon and **B horizon**. It has dominant characteristics of an overlying A or E horizon and subordinate properties of an underlying B horizon.

Ecology

Ecology is the branch of biology dealing with the totality of the interrelationships of living organisms with the external environment. It is concerned with fundamentals common to all living systems. The term **autecology** refers to the study of environmental relations of individuals or species, whereas **synecology** refers to the study of groups and communities of organisms.

Systems ecology is a new branch of ecology in which mathematical concepts are used to explore qualitative and quantitative interrelations of living organisms at a number of levels. Ecology has been subdivided for convenience on the basis of environment or habitat, such as marine ecology, fresh water ecology or terrestrial ecology.

Though ecology deals primarily with biological phenomena, it does involve the chemistry of nutrients, metabolism, photosynthesis, etc. in plants and animals, and the interfering systems or processes. Thus, insecticides, oil spills, chemical waste disposal, air and water pollution, and radioactive contaminants have a direct bearing on the ecology of a given area.

Economic efficiency

Economic **efficiency** is achieved when all economic units operate at their optimum levels.

Economic yield

Economic yield refers to the economically useful parts of a **biological yield**, such as the seed. Economic yield is the proportion of crop yield that has an economic value and that can be traded.

Ecosystem: See Agroecosystem research

ECP

ECP is short for **exchangeable cation percentage**.

Ectomycorrhizae

Ectomycorrhizae is one of the two common types of mycorrhizae. In this type, the mycorrhizal fungi form a mantle or sheath on the root surface of host plants, and the hyphae penetrate only between the cells. (See also Mycorrhizae.)

Ectoparasite

A **parasite** that lives on the exterior of its host is an ectoparasite.

Edaphology

Edaphology is a branch of science that studies the influence of soils on living organisms, especially plants.

Edaphic means something relating to the soil, or produced or influenced by the soil. A very alkaline soil may be the edaphic factor limiting plant growth in a particular location or region.

EDDHA

EDDHA is short for **ethylenediamine di-o-hydroxyphenylacetic acid**. It is a chelating agent ($C_{18}H_{20}O_6N_2$) that forms a chelate, which complexes with metal ions. Fe-EDDHA, which is stable over an entire pH range, is commonly used as an iron fertilizer because of its affinity to iron. The comparison of a soil treated with iron chelates, such as **EDTA** (ethylenediamine tetra-aceticacid), **DTPA** (diethylenetriaminepentaaceticacid) or EDDHA shows that EDDHA is most effective in making iron available to plants. The structural formula of EDDHA is shown in Fig.E.2.

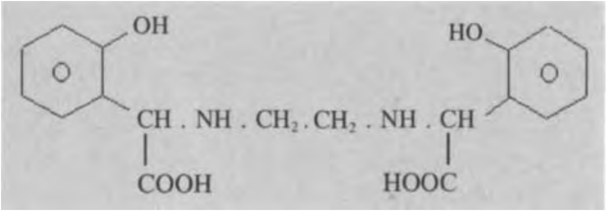


Fig.E.2: Structural formula of EDDHA.

Edible oil

Edible oil is oil that is fit for human consumption. Like any fat or oil, edible oils are glyceryl esters or glycosides of higher fatty acids. Edible oils that are liquids at normal body temperature are called **oils**. Edible oil is used primarily in food-stuffs (salad dressing, margarine, etc) and for cooking. Olive, safflower, cottonseed, coconut, peanut, soybean and corn oils are all edible oils, some of which may be hydrogenated to a solid form. They vary in degree of unsaturation, ranging from 78% for safflower to about 10% for coconut. Castor oil, though technically edible, is not usually considered edible. Medicinal oils are generally not derived from animal sources.

Edible oil cakes

Oil cakes suitable for cattle feed are called edible oil cakes. Coconut and groundnut oil cakes are examples of edible oil cakes. These are also used as fertilizers.

EDTA

EDTA is short for **ethylenediaminetetraacetic acid**, an amino polycarboxylic acid. It is a tetraprotic acid and is represented as H_4Y with four carboxyl groups and two nitrogen atoms (Fig.E.3) acting as **ligand** sites. Thus the compound is a hexadentate ligand. Ligands include ions such as Cl^-, NO_2^- and CN^- or neutral molecules like NH_3 and H_2O, which possess a lone pair of electrons that can be shared with a metal cation in coordinate covalent bonds.

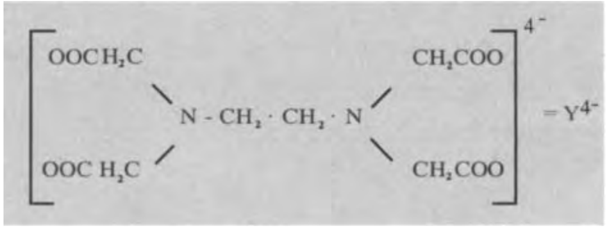


Fig.E.3: Structural formula of EDTA.

The water solubility of EDTA is very low and, therefore, its di-sodium salt $Na_2H_2Y{\cdot}2H_2O$ is commonly used in titrations. The Y^{4-} forms very stable, one-to-one complexes with practically every metal ion in the Periodic Table. The reactions are carried out in a neutral or alkaline medium as the complex decomposes in acidic medium.

EDTA is used (a) as an antidote in lead poisoning because it binds to lead ions (Pb^{2+}) and prevents it from inhibiting important enzyme functions, (b) to bind iron and calcium and as a water softener in products like shampoos, (c) to tie up metal ions that catalyze oxidation (and hence deterioration) of the food product, (d) to increase the storage life of whole blood by removing free calcium ions (Ca^{2+}) to inhibit clotting, and (e) for extracting trace elements, especially copper. EDTA metal complexes, such as NaFeEDTA, MnEDTA, ZnEDTA and CuEDTA are used as fertilizers and foliar sprays.

EF_B

EF_B is short for **biological enrichment factor**. It is the ratio of an element in an organism to that of the same element in a crystal rock.

Biological enrichment factor varies with the ionization potential of elements. It depends on the hydrolysable nature and the oxyanion forming nature of the element. (See also Banin-Navrot plots.)

Effective nodule for nitrogen fixation

Nitrogen-fixing bacteria, like the various strains of *Rhizobium* and *Bradyrhizobium,* fix gaseous nitrogen and convert it into ammonia (NH_3). This activity is carried out after they colonize the roots of legume plants like peas, beans, soybean, alfalfa, clover, etc. The plants react to this infection by producing tumor-like swellings called nodules. This marks the beginning of a biological symbiotic relationship where the plant becomes a host to the bacteria, providing them with energy, in exchange for nitrogen necessary for the production of protein.

All the nodules do not have fixed nitrogen. Root nodules that are large and round (as in the case of soybeans and peanuts) or small, rounded or cylindrical (as in clovers, alfalfa), often clustered on the roots, and always pink or reddish pink are effective nodules. The color is due to the leghemoglobin pigment which indicates nitrogen fixation (Fig.E.4). Greenish color of the nodules indicates ineffective nodules.

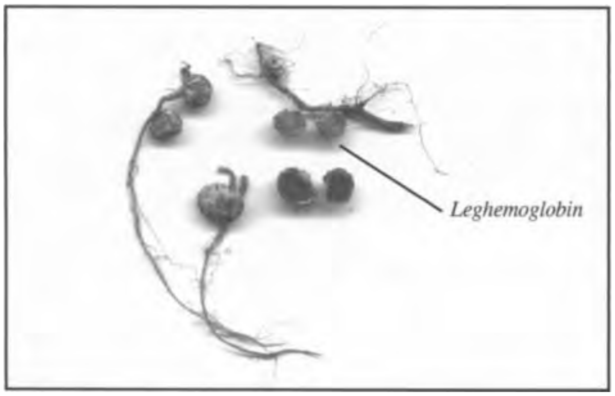


Fig.E.4.: Root nodules of soybean containing pink pigment, leghemoglobin.

The vigorous growth of plants and the green color of grasses in a typical grass-legume pasture are the evidence of effective nodulation.

Effective nodulation depends on the number of bacteria present, the kind of legumes grown, the supply of N fertilizers, soil conditions, and the availability of K, Mg, Ca, Fe, Mo, Cu and B. A constant supply of nitrogen fertilizers discourages N-fixation by bacteria because the plant does not need excess nitrogen. As a logical extension, effective nodulation is observed to be significant in poor soils. The more the supply of phosphorus, the more abundant are the nodules. Generally, magnesium is considered more important for nitrogen fixation than is calcium. Mo, Fe and B are also considered necessary for nitrogen fixation to take place. Care should be taken to ensure the availability of Mo to plants growing in soils rich in Mn and Fe. (Mo may be ideally supplied with the inoculum itself.)

Effective management practices may be evolved with the above indicators in mind, for maximizing the formation of effective nodulation.

Effervescence

Effervescence is the release of carbon dioxide (CO_2) or gas by the action of an acid (like hydrochloric acid) on a carbonate or a salt. For example:

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + CO_2\uparrow + H_2O$$

This reaction is used in soil science to grade the soil carbonate content. For instance, if there is no effervescence, carbonate content is less than 1%. Similarly, the carbonate content of 1 to 10% results in slight effervescence, of 10 to 20% in moderate and more than 20% in brisk effervescence.

Calcium carbonate is used to neutralize acidic soils and the presence of excess carbonate affects the micronutrient availability to plants.

Efficiency

Efficiency is a measure of output. It is the measure of, say, the crop yield or nutrient uptake (which are an outputs) for every unit of fertilizer deployed (which is an input). If one kg of a fertilizer produces 10 kg grain and another produces 8 kg from the same soil and under identical conditions, the first fertilizer is said to be more efficient than the second one.

Efficiency is expressed as a percentage of the output to the input of power, etc. and is expressed as:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100$$

Efficiency is considered under different headings as defined below.

(i) **Mechanical efficiency** deals with how well a machine converts energy from one form to another. For example, an engine converts chemical energy or heat energy from fuel into mechanical power and causes torque and rotation of the engine crankshaft. All energy in the fuel is not converted into torque and shaft rotation, as a majority gets converted into heat and escapes through the radiator and the exhaust. Therefore, engines are not 100% efficient. A typical petrol engine is about 35% efficient; a diesel engine is slightly better. An electric motor, however, has a high efficiency. It converts electrical energy into shaft rotation and torque with an efficiency of around 95%.

(ii) **Performance efficiency** refers to the quality of work done by a machine. For a harvesting machine, the performance efficiency is a measure of the actual performance compared with the ideal or desired performance. If a machine is to perform more than one operation (combine), we could measure the bushels of grain harvested compared with the total baskets of grain in the field. The combines could also be evaluated according to the amount of damaged grain. Other harvesting machines could be evaluated on the basis of the amount of damaged fruits or the number of cracked shells.

(iii) **Field efficiency** compares the amount of work or volume of activity done by a machine with its real capacity. A machine is capable of covering ground at a rate determined by its width and the speed of travel. If the machine is operated with a constant width and speed, it will operate at 100% field efficiency. A machine can operate at 100% field efficiency for short periods, but as soon as the speed changes (slows down for turns, etc.) or the width changes (overlap width of the machine to prevent skips), it operates at less than 100% efficiency. Machine field efficiencies of less than 100% are caused by lost (or unproductive) time and the failure to use the full working width. Some field efficiencies of common agricultural machines compiled from various data are given in Table-E.1.

(iv) **Economic efficiency** refers to a situation in which all the economic units are deemed to operate at their optimum levels, and at the lowest costs. This kind of model demands 3 types of efficiencies which are (a) **productive efficiency**, where the costs of production are kept at a minimum while producing output, (b) **allocative efficiency**, in which only the most essential types of output (goods and services) are produced by an economic unit, thus minimizing wasteful allocation of resources (such as funds, manpower, technical skill, time, etc.), and (c) **distributional efficiency** where the output is equally and proportionately shared among the consumers, again ensuring optimal utilization of resources to the user's satisfaction. This situation is said to operate in the environment of perfect competition. In this hypothetical industrial structure, many small firms (so small that no one firm can singly dominate or monopolize the supply or price situation) compete to sell a single product. Other assumptions are that there is a multitude of buyers; there are no exit or entry barriers and all want to maximize profits.

Although in real life, attainment of economic efficiency is fraught with a barrage of constraints (like transportation difficulties, changes in demands, changes in costs of inputs, loss incurred due to damage caused to output, lack of communication of information, etc.) it forms a strong basis for the comprehension of efficiency, as a concept.

Table-E.1: Efficiency and speed of common agricultural machines.

Type of machine	Field efficiency (%)		Field speed (km/hr)	
	Range	Typical	Range	Typical
Tillage				
Moldboard plow	70–90	80	3.0–6.0	4.5
Heavy duty disk	70–90	85	3.5–6.0	4.5
Tandem disk harrow	70–90	80	3.0–6.0	4.0
Chisel plow	70–90	85	4.0–6.5	4.5
Field cultivator	70–90	85	3.0–8.0	5.5
Spring tooth	70–90	85	3.0–6.0	5.0
Roller packer	70–90	85	4.5–7.8	6.0
Rotary hoe	70–90	80	5.0–10.0	7.0
Row crop cultivator	70–90	80	2.5–5.0	3.5
Rotary tiller	70–90	85	1.0–4.5	3.0
Planting				
No-till planter	50–75	65	2.0–4.0	3.0
Conventional planter	50–75	60	3.0–7.0	4.5
Grain drill	65–85	70	2.5–6.0	4.0
Harvesting				
Corn picker	60–75	65	2.0–4.0	2.5
Combine	65–80	70	2.0–5.0	3.0
Mower	75–85	80	4.0–7.0	5.0
Mower conditioner	55–80	75	3.0–6.0	4.5
Baler, small	60–85	75	2.5–5.0	3.5
Forage harvester, (Pull type)	50–75	65	1.5–5.0	2.5
Self propelled forage harvester	60–85	70	1.5–6.0	3.0
Sugar beet harvester	60–85	70	2.5–5.0	3.0
Potato harvester	55–70	60	1.5–4.0	2.0
Cotton picker or stripper	60–75	70	2.0–4.0	3.0
Miscellaneous				
Fertilizer spreader	60–70	70	3.0–5.0	4.5
Field sprayer	50–80	65	3.0–7.0	6.5
Beet topper	60–80	70	2.0–3.0	2.5

Efficiency of nutrient utilization

Efficiency of nutrient utilization is defined as the ratio of **biomass** to the total amount of nutrient in the biomass. The concentration of mineral nutrients must be above a critical level for optimal functioning of the enzymes, the collective activities of which culminate into growth. The efficiency of nutrient utilization is made of two components – the utilization quotient and biomass production.

Efficiency of water use: See Water use efficiency

Efflorescence

Efflorescence refers to the loss of combined water molecules by a hydrate when exposed to air, resulting in partial decomposition (indicated by the presence of a powdery coating on the material). This occurs commonly with washing soda ($Na_2CO_3 \cdot 10H_2O$) which loses almost all its water constituents spontaneously.

Effluent

Effluents are fluids (including water) discharged from domestic, industrial or municipal waste collection systems or treatment facilities. An effluent can also be a waste product in gaseous or liquid form discharged through a pipe or a similar outlet from a chemical or industrial plant.

Most effluents pollute the surrounding environment with their harmful contents. For example, the alcohol industry uses molasses and malt as raw material. The effluents from this industry have high concentrations of soluble salts, highly acidic pH, high temperatures, high **BODs** (biological oxygen demand) and **CODs** (chemical oxygen demand), all of which are harmful. Besides, most of them have an unpleasant smell and are of a deep yellow to dark brown color due to their lignin content. Paper industry effluents have a medium to high concentration of salts, high BOD and COD, suspended solids and a toxic concentration of silica. The BOD, the COD and the suspended solids decrease if treated in a conventional treatment plant. But even so, lignin often remains undegraded and salinity levels remain unchanged. Such effluents can contaminate ground water.

Waste waters or effluents are increasingly regulated to prevent pollution of ground and surface waters. Although irrigating with effluents does partially clean the water by percolation through soil, not all contaminants can be removed from the effluent water, as soluble salts continue to flow to ground or surface waters.

Effluent disposal on land or into waters is permitted only if it does not cause (a) extensive groundwater pollution and a public health hazard, (b) the accumulation of hazardous substances (for example, mercury, cadmium salt, pesticides, etc.) in the soil or water and thereby into the food chain, (c) the accumulation of pollutants such as odor into the atmosphere, and (d) aesthetic losses.

Eh

Eh is the voltage difference between a reference electrode for hydrogen and a calomel electrode in a solution. It represents differences in the **redox potential** of an oxidation-reduction system. The voltage difference between a hydrogen electrode and calomel electrode is 0.248 V.

$$\mathrm{Eh} = \mathrm{E}_{\text{measured}} + 0.248\ \mathrm{V}$$

Eh is used to study redox potential of a system. Thus, in the soil, there is exchange of electrons between redox systems like Fe^{2+}/Fe^{3+}, Mn^{2+}/Mn^{4+} and the potential difference varies between 900 mV and 300 mV. The variation in Eh depends on several factors such as the concentration of the metal, moisture content, pH, organic matter content and the presence of microflora.

E horizon

E horizon is a soil horizon from which particularly large amounts of material (such as clay and iron) have been removed by leaching. E represents the word eluvial. **Eluviation** means translocation of weathered products from an upper horizon to a lower horizon. E horizons are usually lighter in color than either the overlying A or the underlying B horizons.

EHU

EHU is short for **erosion hazard unit**.

Elbaite

Elbaite, a lithium rich variety of tourmaline, is a borosilicate. Elbite is the main source of a **boron** containing mineral found in soil.

Electrical conductivity

Electrical conductivity of a material is a measure of the ease with which it conducts electricity. The electrical conductivity of a material is the reciprocal of its resistivity and is measured in Siemens per meter in SI units. Electrical conductivity is used to measure the salinity of soil solutions with an instrument called the electrical conductivity bridge.

Electric furnace slag

Electric furnace slag is produced by the reduction of rock phosphate in an electric furnace during the preparation of phosphorus and the manufacture of pig iron and steel. The slag contains 0.9 to 2.3% phosphorus pentoxide and its neutralizing value (**calcium carbonate equivalent, CCE**) is between 65 and 80%.

Electrolysis

Electrolysis refers to decomposition brought about by passing an electric current through a liquid or solution containing ions. When a salt is fused or dissolved in a solvent, the ions become free. In an electric field, the positively charged **cations** move toward the cathode and the negative charged anions toward the anode (Fig.E.5). The process is called electrolysis.

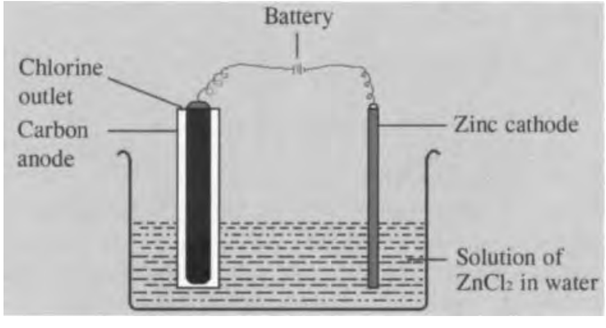


Fig.E.5: Electrolysis of zinc chloride solution.

Electrolysis of acidified water gives hydrogen and oxygen. The electrolytic process is used in the production of a number of chemicals and metals, for electroplating and in the production of electricity from batteries.

Electrolysis for hydrogen production in ammonia synthesis: See Ammonia production processes

Electrolyte

Electrolyte is a liquid or gel which contains ions and can be decomposed by electrolysis.

Electrolytes are salts, usually composed of orderly arrangements of ions, that are not free to move easily in solid. However, they ionize in water to give ions.

Electrolytes are classified as **strong electrolytes** when they dissociate completely in water, and **weak electrolytes** when they dissociate partially. Sodium chloride is a strong electrolyte and acetic acid, a weak electrolyte.

Electrolytic dissociation

Electrolytic dissociation is the process by which electricity is passed through an electrolyte solution which dissociates into its ions. Acidified water, when subjected to electrolysis, dissociates into hydrogen and oxygen ions which are deposited at the anode and cathode, respectively to produce hydrogen and oxygen.

Electronation reaction

A reduction process involving the addition of electrons is known as an electronation reaction.

Electron-dense stains: See Electron stain

Electron stain

Electron stains, used for staining samples for electron microscopy, are described as **electron-dense stains**. Compounds of osmium, uranium, lead, etc. are used for staining as they reflect electrons. Material to be observed under an electron microscope is fixed using glutaraldehyde or a mixture of glutaraldehyde and osmic acid (OsO_4). These act as a fixative and as a stain in lipids.

Electrophos

Electrophos is a trade name for phosphoric acid made from phosphorus which is obtained by heating rock phosphate in an electric furnace. Phosphorus is burned in air to form phosphorus pentoxide (P_2O_5). This is hydrated to give phosphoric acid:

$$Ca_{10}F_2(PO_4)_6 + 15C + 6SiO_2 \rightarrow 1.5P_4 + 15CO + 3(3CaO \cdot 2SiO_2) + CaF_2$$

$$P_4 + 5O_2 + 6H_2O \longrightarrow 4H_3PO_4$$

The phosphoric acid, also called **white acid** or **furnace acid**, is an important intermediate in the production of phosphatic fertilizers. Phosphoric acid thus made is much purer than the wet acid made from rock phosphate and sulphuric acid, and is used in the non-fertilizer segment of the chemical industry.

Electrostatic adsorption: See Adsorption, electrostatic

Electrostatic ULV sprayer

Electrostatic ULV sprayer is short for electrostatic **ultra-low volume sprayer**. It is designed to apply small volumes of liquid (generally less than 5 liters/ha). The drop size of the liquid is 60 to 70 microns so that drops can be carried by the wind to give a thorough crop cover. The spray is prone to drift and so the ULV sprayer is not used for applying herbicides or toxic chemicals. Electrostatic ULV sprayers, which produce positively charged droplets of controlled size (about 50 microns), fall mainly on the target crop area and behave fairly predictably in terms of the area covered.

Electro-ultra filtration

Electro-ultra filtration (**EUF**) is a method that estimates the available nutrient in the soil by the application of electric potential. It is especially used for the estimation of potassium in soils. EUF, a form of electrophoresis, is used in Germany to determine the nitrogen fertilizer requirement for sugar beets.

Electrovalence

The number of electronic charges carried by an ion is called its electrovalence. For example, cupric ion (Cu^{2+}) has a valence of two and nitrate ion has one.

Element

Elements are basic constituents of matter. A chemical substance in its atomic form (which cannot be further broken into simpler substances) is called an element. In an element, all atoms have the same number of protons or electrons, but they may differ in mass. For example, hydrogen (Fig.E.6) has mass numbers of 1, 2 and 3, and are called **hydrogen**, **deuterium** and **tritium**, respectively. The hydrogen atoms with a higher mass are called hydrogen isotopes.

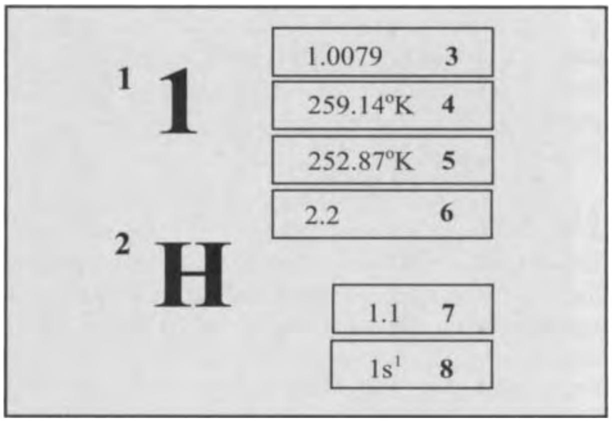


Fig.E.6: Properties of Hydrogen atom: 1. Atomic number, 2. Element symbol, 3. Relative atomic mass, 4. Melting point, 5.Boiling point, 6. Electro-negativity (Allred, Rochow), 7. Oxidation states and 8. Electron configuration.

The atomic number of an element indicates its position in the Periodic Table and represents the number of protons present, which is the same as the number of electrons. All elements above bismuth (Bi) in the Periodic Table are unstable and radioactive.

Elements are classified as metals and non-metals. Approximately 75% of the elements are metals and others are non-metals (Fig.E.7). At room temperature, most elements are solids, whereas mercury and bromine are liquids and the rest are gases.

A few of these elements (O, N, noble gases, S, Cu, Ag and Au) are found in a free state while the rest

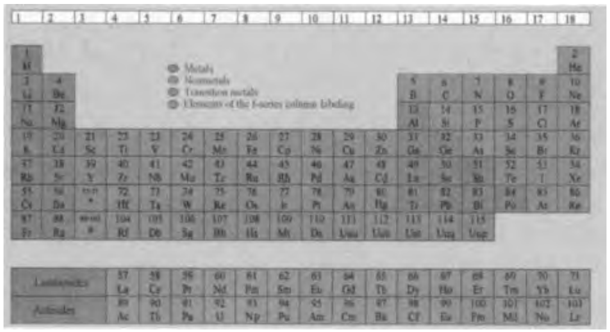


Fig.E.7: Periodic Table showing the position of elements - metals and non-metals.

combine with other elements and occur in the form of compounds.

Among the 92 naturally occurring elements, 20 are essential for plant growth. These are C, H, O, N, P, K, Ca, S, Mg, Fe, B, Cu, Mn, Zn, Mo, Cl, Co, Ni, Va and Na.

Elemental sulphur

Elemental sulphur is a yellow, non-metallic element belonging to Group 16 (formerly VI B) of the Periodic Table (Fig.E.8). Sulphur occurs in many sulphate and sulphide minerals. It has various allotropic forms. Sulphur is an essential element in living organisms and plants, occurring in amino acids, cysteine and methionine, and therefore, in many proteins. It is also a constituent of various cell metabolites, including coenzyme A, biotine and thiamine. Plants absorb sulphur from the soil as sulphate ions. Native sulphur is found in Sicily and the USA. **Flowers of sulphur** are obtained as a fine yellow powder by subliming sulphur.

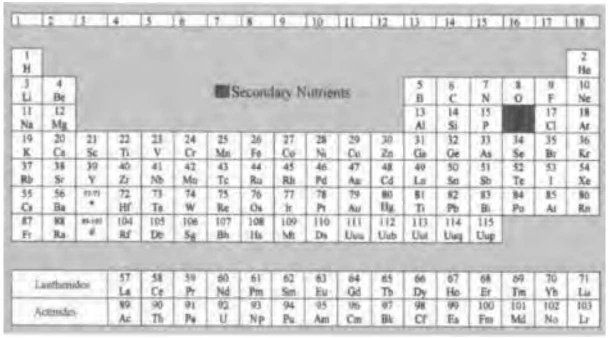


Fig.E.8: Position of sulphur, a secondary nutrient, in the Periodic Table.

Sulphur is an important raw material for fertilizer production (Fig.E.9). It is used in rubber vulcanization, petroleum refining, pharmaceuticals, drugs, explosives, insecticides, fungicides, in the manufacture of sulphuric acid, and as a soil conditioner as well as a coating for controlled release of fertilizers.

When sulphur is applied to soils, it is slowly oxidized by micro-organisms to sulphuric acid in the presence of air and water. Lime in the soil reacts with sulphuric acid to form calcium sulphate. Finely ground sulphur in soil is more reactive than coarsely ground sulphur, but the latter is easier to apply as it is less irritating to the skin and eyes.

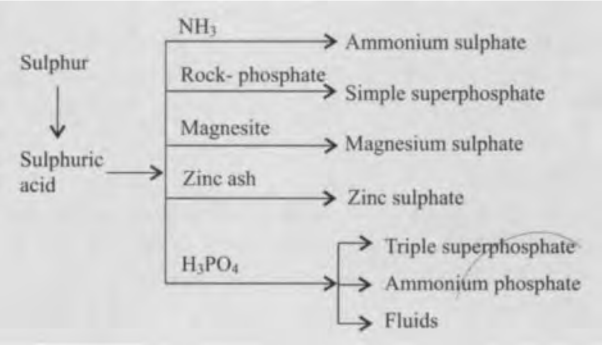


Fig.E.9: Use of sulphur for producing various fertilizers by different processes.

Elongation test

Elongation test is one of the many simple empirical tests used to ascertain the suitability of a given clay. The physical and geotechnical properties of soils are based on their mineralogical composition, grain size, chemical composition and moisture content. In the elongation test, a clay soil cylinder, 300 mm in length and 25 mm in diameter, is held horizontally at its two ends, leaving 100 mm in the middle unsupported. The cylinder is stretched until it breaks. The length of the neck is measured. The longer the neck, the more suitable the clay.

Eluvial horizon

Eluvial horizon is a distinct soil horizon depleted of its dissolved and suspended soil material and soluble salts, by the process of leaching. It is designated by the letter E, though formerly it was designated by the symbol A_2. Eluvial horizon is also called **eluvial layer**, **eluviated horizon**, or **leached layer**.

Eluvial layer

Eluvial layer is also called **eluvial horizon**.

Eluviated horizon

Eluviated horizon is another term for **eluvial horizon**. (See also Eluviation.)

Eluviation

Eluviation is the downward movement of dissolved and suspended soil material through water from one subsoil layer to another. The layer, thus depleted, forms the **eluvial horizon**. The layer of accumulation which receives the dissolved and suspended soil material by the process of eluviation is called **illuvial layer** or **illuvial horizon** and the process is called **illuviation**. Thus, eluviation and illuviation are processes that use percolating water in solution or suspension, to move soil material from one horizon to another within the soil. These processes are similar to **leaching** and occur in areas of excessive rainfall. While eluviation involves movement between the soil layers, illuviation is a deposition process. Eluviation takes place in surface soil horizons and illuviation in subsurface or lower soil horizons. Leaching may involve a total loss of nutrients and other soluble substances from the soil.

The horizon that has lost fine elements and that occurs above an argillic or bulgic horizon or above a cheluvium is called **eluviated horizon**. It is different from an impoverished horizon that has a reducing clay content.

Emery

Emery or **corundum** is a naturally occurring **alumina** (natural aluminum oxide, Al_2O_3) used as an abrasive and polishing material, and in the manufacture of some concrete floors.

Emulsifier: See Emulsion

Emulsifying agents

Emulsifying agents are materials that stabilize the emulsion of two liquids which are not miscible and that tend to separate out from each other. Emulsifying agents maintain the stability of the concentrate within limits. Casein is an emulsifying agent in milk, which is composed of butter fat dispersed in water.

Emulsion

An emulsion is a fine dispersion of very small particles of a liquid in another immiscible liquid. Usually, an emulsion involves dispersion of oil in water or water in oil, which is stabilized by an **emulsifier**.

Emulsifiers enable the formation of an emulsion. They also promote its stability. These substances have lyophobic and lyophilic parts or groups in their molecules to stabilize the emulsion. Soaps and detergents are examples of emulsifiers. Dietary fats are reduced to an emulsion in the duodenum to facilitate their subsequent digestion. Proteins stabilize many naturally occurring emulsions, such as milk or rubber latex. Egg yolk proteins stabilize mayonnaise and salad dressing.

Fertilizers and pesticides that cannot be dissolved directly in water are dissolved in an organic solvent. They can then be mixed with water to form an emulsion using an emulsifier. For example, a sulphur emulsion for foliar spraying is made by dissolving sulphur in carbon disulphide and mixing with water.

The breaking of an emulsion is necessary in many industrial operations. The separation of water-in-oil emulsions in the petroleum industry and product recovery from emulsions produced by steam distillation of organic liquids are examples. Extracting butter from milk or curds is another example of emulsion breaking.

Emulsions may be broken by (a) adding multivalent ions of the charge opposite to the emulsion droplet, (b) chemical action, such as the addition of acids to the emulsion stabilized by soaps, (c) freezing, heating, aging, or centrifuging, (d) high potential electrical fields, and (e) treatment with ultrasonic waves of low intensity.

Encapsulation

Encapsulation means enclosing in, as in a capsule. It is a process in which a material (or an assembly of small, discrete units) is coated with or imbedded in a molten film, sheath or foam, usually of a elastomer. A foam-forming plastic may be used to fill spaces between various electrical and electronic components, so that they are embedded in and supported by the foam. Plastics and other materials used for this purpose are often called **potting compounds**. A specialized use of this technique is in growing crystals for semi conductors in which a coating of liquid boric acid is the encapsulating agent. The use of a glass silicate coating to encapsulate nuclear waste for permanent disposal is under investigation.

The granules of soluble fertilizers are coated with certain substances to control their dissolution rate. The coating of fertilizers is an example of encapsulation.

Endogenous inhibitor

Endogenous inhibitor is a substance produced by an organism which at low concentration inhibits its own growth, the growth of another organism, or some physiological process associated with growth in a relatively specific manner. A characteristic of higher plant growth inhibitors, such as abscisic acid, is that their effects are often antagonized by specific growth promoters like gibberellins and cytokinins.

Endomycorrhizae

Endomycorrhizae or **endomycorrhizal fungi** are one of the main structural types of mycorrhizae. In this type, the hyphae of the endomycorrhizal fungi actually penetrate into the root cells of the host and develop a symbiotic association. **Mycorrhizae** mainly function as phosphate solubilizers. (See also Mycorrhizae.)

Endomycorrhizal fungi: See Endomycorrhizae

Endoparasite

The **parasites** that lodge in the internal organs or tissues of their hosts are termed as endoparasites.

Endopedons

The diagnostic horizons formed below the soil surface (**subsurface horizon**) are called endopedons. Some common endopedons are **calcic horizon**, **gypsic horizon**, **salic horizon** and **sulphuric horizon**.

Endophyte

An organism that completes its life cycle in a plant, showing no external sign of infection, is called an endophyte.

Endophytic micro-organisms are found in virtually every plant on earth. These organisms reside in the living tissues of the host plant and do so in a variety of relationships, ranging from symbiotic to slightly pathogenic. As a contribution to the host plant, endophytes may produce a plethora of substances beneficial to the plant and which may incidentally be useful in modern medicine, agriculture and industry. Novel antibiotics, antimycotics, immunosuppressants and anticancer compounds are a few examples of what has been found after the isolation, culture, purification and characterization of some endophytes. The potential of finding new drugs for treating newly developing tissues in humans, plants and animals is significantly high.

A group of fungi parasitic on grasses are endophytic and are toxic to grazing animals.

Some plants generating bioactive natural products have associated endophytes that produce the same natural products. For instance, paclitaxel, a highly functionalized diterpenoid and famed anticancer agent was found in yew tree species (*Taxus* spp.). *Taxomyces andreanae*, an endophyte of *Taxus brevifolia* was isolated (and characterized) and was found to produce the same paclitaxel.

End point, volumetric analysis: See Volumetric analysis

Energy sources

There are different kinds of energy sources. Some are renewable, some are non-renewable and some others are mechanical.

Non-renewable energy sources are materials of geological origin. Petroleum, natural gas, coal, shale oil, uranium, etc. are non-renewable energy sources. These cannot be replaced or replenished once the existing supply is exhausted.

Renewable sources, on the other hand, can be replenished on a predictable time basis. Biomass, for instance, is a renewable energy source and includes wood, baggase, bark and sawdust, which have a thermal value. Several of these sources have been in use for many years as fuel in industries dealing with sugar cane, plywood, paper and pulp. Another instance is (biogas) methane, obtained from animal manures, which is also a renewable energy source. Mass cultivation of algae and hydrocarbon-producing plants such as guayule and copaiba have been under consideration for use as energy sources for a few years now.

There are also a number of mechanical energy sources the development of which involves the application of engineering (as in thermal and hydroelectric power stations), solar radiation, wind, water flow, tides and thermal gradients in ocean water. Several of these, as also the atomic power, are already in use.

Enriched manure

Chemical fertilizers are added to manure to improve its performance or nutrient content and such manures are called enriched manures. An enriched manure can be a nitrogen-potash fertilizer produced by the addition of chemical fertilizers to organic manure. The conditions are kept generally favorable for microbial decomposition when soil is warm and moist - in which state the manure rapidly releases nutrients. The yield from the soil increases significantly when an enriched manure is applied at about 2 to 4 tons per hectare.

A continuous cultivation of crops leads to an increased nitrogen demand that cannot be fully met by manure. A careful combination of organic manures with chemical fertilizers can give the most optimal returns from the soil without destroying soil fertility.

Enriched rice

Rice is categorized on the basis of the kind of processing done on it, before it reaches the market. Enriched rice represents rice to which various nutrients such as thiamin, niacin and iron have been added to make it more nutritious. The use of enriched rice is widely prevalent in most advanced countries. Hence, enriched rice has more nutrients than **brown rice** or unprocessed rice.

Enriched superphosphate

Enriched superphosphate is essentially a mixture of single superphosphate and triple superphosphate made by acidulation of phosphate rock with a mixture of sulphuric and phosphoric acids.

Entisols

Entisols refer to a soil order consisting of mineral soils that have no characteristic or distinct diagnostic pedogenic horizons. It is one of the 12 recognized soil orders. Entisols occupy about 16.2% of the earth's ice-free land surface. Over two-thirds of entisols are found in the temperate regions of the earth and the remainder is mainly in the tropics.

The mineral soils of this soil order do not exhibit diagnostic subsurface horizons. These soils are within a specified depth of the soil surface, generally 1 to 2 meters. These weakly expressed soils are commonly found on geomorphic surfaces and are unstable because of frequent flooding, erosion, truncation and human impact. Soils formed from resistant mineral parent materials are coarse in texture and subject to very little pedogenic development over time.

Entisols are commonly found along flood plains of rivers, stream valley systems, desert sand dunes and high gradient mountainous terrain. Entisols are associated with recently mined or disturbed lands. Aquents, arents, fluvents, orthents and psamments are suborders of entisols.

Environment

An environment is the physical, chemical or biological condition of a region in which organisms live. Ecologically, environment is defined as the sum total of the influences of external conditions that affect the life and development of organisms.

Biotic and **abiotic** factors are the main components of an environment. Factors such as air, water, trees, lakes, gases, landform, climate, etc. together constitute an environment. All components of the environment and their influences on living organisms have to be considered together for any study on environment.

Important environmental factors influencing plant growth include temperature, moisture supply, radiant energy, soil reaction, biotic factors, atmospheric composition, soil structure, soil-air composition, mineral nutrient supply and growth-restricting substances.

Pesticides used in agriculture represent an important group of materials that can pollute the environment. Some of them are highly toxic, and if misused, can cause harm to many non-target organisms.

The U.S. Environmental Protection Agency requires manufacturers to conduct tests on materials or products that may affect the environment or public health adversely. The agency is also concerned with the effect of other potentially detrimental materials like pesticides, fungicides, herbicides and industrial wastes.

Environmental and pollution laws on tail gas of nitric acid plants: See Nitric acid production processes

Environmental approach of the Norsk hydro nitrophosphate process: See Environmental impact of fertilizer industry

Environmental approach – Uhde closed scrubber system: See Environmental impact of fertilizer industry

Environmental approach – Uhde methodology of pollution control: See Environmental impact of fertilizer industry

Environmental, health and safety issues in the manufacture of phosphoric acid: See Environmental impact of phosphoric acid industry

Environmental impact assessment

An environmental impact assessment (EIA) and an environmental impact statement (EIS) present guidelines on risk management at a regional level. All chemical plants should be subject to periodic environmental impact review. The frequency of the review is established either by law or by company regulations. An EIA becomes an EIS when the company or a plant formally releases the EIA to controlling government organizations.

The objectives of conducting an EIA are to (a) determine the achieved level of protection to man and environment, (b) identify discrepancies and sources relative to established legislation and internal rules, (c) analyze emergency cases and check implementation of recommendations, (d) check implementation of related policies and decisions, (e) determine necessary adjustments and provide information on justification and efficiency, (f) provide a basis for recognizing both good and inadequate performance, (g) demonstrate management's commitment to environmental protection and provide motivation for improvement, (h) provide information on achievements in environmental protection to public authorities and community shareholders, and (i) provide inputs to the company's education and training activities.

The methodology of EIA preparation depends on the company, its size and organizational system. Three basic approaches are used to prepare an EIA, and are as follows: (i) In large companies, a special safety or environmental department assumes the responsibility for preparing a regular EIS. (ii) In medium-sized companies, a task force is formed. This group consists of the operational staff, safety staff and maintenance staff under the responsibility of a technical manager. (iii) In small companies, a specialized auditing company may be given the contract. However, participation of the local staff is also crucial for the success of the implementation of the recommendations.

In all the three cases, the group is given access to all technical documents, environmental reports, regular water and air analysis reports, reports on technical deviations and accidents and a background to the factory operations. Operational hazard studies or similar reviews are also made available.

In an ideal situation, the EIA group acts in the following sequence: (i) Review the documents. (ii) Conduct a detailed physical audit of the installation. (iii) Prepare the questionnaire and discuss it with workers and staff. (iv) Prepare a statistical review document of the crucial parameters. (v) Prepare chapters for normal operation, incidents/accidents. (vi) Review new legislation and identify new industrial obligations. (vii) Prepare recommendations on technology adjustment, training, education, equipment revamping and adjustment of management procedures. (viii) Prepare the economic / financial analysis report containing specifications of costs, penalties and yields, economic efficiency of the adjustments and financial resources, and modalities of implementation. (ix) Discuss the draft report with management. (x) Edit and print the report. (xi) Disseminate and advertise.

As a unified format of the EIA does not exist, any format created should cover the following areas: (i) Review of the legislation and internal company rules. (ii) Review of statistical data. (iii) Review of technological processes, emissions, effluents and disposal, and of the present situation outside the factory area at local control points. (iv) Analyze the economic and financial situation.

From 1997 to 1999, the International Organization for Standards (ISO) brought out a series of '**Environmental Management Standards,**' called the ISO 14000 series. The ISO 14000 series is intended to help companies improve their environmental performance and keep environmental issues from becoming trade barriers. All standards except 14001 are guidance documents.

The aim of the preparation of these standards is to introduce uniform requirements for the operation of industrial plants and establish a framework for managing the environmental impact. The standards feature a wide variety of environmental disciplines like environmental management system, environmental auditing, environmental performance evaluation, environmental labelling, life-cycle assessment and environmental aspects of product standards.

ISO 14000 standards are voluntary. Companies intending to be certified under ISO 14001 should meet the specific requirements of the standard. The basic activities under the environmental management system should be implemented and documented in a special manual. Necessary training should be imparted to all the personnel. It is assumed that a company would prepare the necessary documents by internal auditing or using special consultants. Given below are some of the aspects of production that can impact the environment, and guidelines to avoid harm.

Environmental impact of ammonia industry

Ammonia is made from natural gas, sulphur rich crude oil or from coal via gasification. Water is needed for boilers and cooling.

(a) Wastes and emissions from ammonia production plants: In the production of ammonia, the main emission into the atmosphere comprises carbon dioxide and some oxides of nitrogen and sulphur. Care should be taken to avoid evolving ammonia by way of leakage although any flow containing ammonia is scrubbed and recycled. However, some ammonia is leaked into the atmosphere around the production plant from faulty operations and during maintenance. Ammonia becomes explosive at concentrations of 16 to 25% volume in air, which can occur during loading and unloading operations and by leakages from storage vessels of ammonia. The limit of ammonia leakage in the workplace must be kept below 10 mg/Nm^3.

The partial oxidation and gasification processes produce water containing dissolved and suspended impurities. These impurities must be treated to meet effluent disposal standards.

Catalysts used in steam-reforming, partial oxidation and coal gasification contain hexavalent chromium, nickel, zinc, iron and minerals, and so they have to be replaced every 2 to 6 years. This replaced material, which cannot be disposed as landfills are generally recycled. The potassium carbonate in carbon dioxide absorption contains inorganic and organic additives that could be hazardous when released in large quantities. Small amounts of light hydrocarbons, ammonia, hydrogen, carbon dioxide, etc. are apt to leak out from flanges and joints. Oxides of sulphur and nitrogen contribute to acid rains and carbon dioxide is a green house gas. The concentration of even 1.25 mg/l ammonia in water is harmful to fishes.

(b) Pollution prevention and control in the manufacture of ammonia: Carbon dioxide emissions are lowered by using carbon dioxide (CO_2) in urea and nitro phosphate plants. Spent catalysts are recycled for metal reclamation. Ammonia must be stored, transported and handled in the special tanks. Since ammonia, natural gas and hydrogen, handled in the production process can leak out and form explosive mixtures with air, gas sensors, fire alarms and fire fighting equipments are required to be located in critical places. For instance, as ammonia is stored under low temperature and under pressure, safety equipments like gas masks, eye wash fountains and showers, must be located at work places. Besides trained operators, detailed operation manuals and safety guidelines are necessary for the safe operation of the plant.

For future developments, an ammonia synthesis plant based on desulphurized natural gas and a reforming process requiring a low amount of energy (<28 GJ/ton) and decreased amount of oxides of nitrogen to almost zero concentrations would be in the right direction from an environmental perspective.

Environmental impact of fertilizer industry

Solid fertilizers are produced in two stages: (i) Synthesis of the product by one of the following methods: Reaction of (a) ammonia and carbon dioxide as in the manufacture of urea and ammonium carbonate, (b) sulphuric acid and/or phosphoric acid with phosphate rock as in standard super phosphate and triple super phosphate, and (c) sulphuric, phosphoric and nitric acids with ammonia. (ii) Giving a physical form to the product by crystallization, granulation or prilling.

(a) Wastes and emissions in the manufacture of fertilizers: Phosphate rock contains 3 to 4.5% of fluorine. This, when acidulated, gives out hydrogen fluoride and flurosilisic acid by reaction with silica in the rock. Most of the fluorides are retained in triple super phosphate, whereas about 25% is released from single or standard super phosphate. Phosphate rock bins are equipped with individual bag filters for collection of dust and recycling. An efficient scrubber system allows recovery of fluorosilisic acid which can be converted to synthetic cryolite, aluminum fluoride and other fluorosilicates.

Ammonia and fluorine produced during the ammonia-acid reaction in the manufacture of mono and diammonium phosphates are scrubbed by water and/or acids. During the granulation and prilling stages the gases evolved from the dryers are filtered, when dry, by cyclone separators and bag filters. Water condensation is prevented by insulation and external heating. Most of the materials recovered are recycled.

Acidulation of phosphate rocks with nitric acid produces oxides of nitrogen and fluorine compounds. These compounds after evaporation, prilling and granulation produce gaseous fluorine compounds, ammonia and dust.

The environmental hazard stems from the fact that the main emission from ammonium nitrate, calcium ammonium nitrate and ammonium sulphate is steam which contains ammonia and ammonium nitrate. Even while these are scrubbed with water and the water is recycled, the ammonium nitrate mist from the prilling tower disperses into the atmosphere and can reach soil many kilometers away. The amount of ammonium nitrate emitted even from the best equipped dust collection system is 0.25 to 0.5 kg per ton of the fertilizer.

The main evolution from a urea plant is from the prilling tower. The hot vented air from 10,000 to 15,000 Nm^3/ton of urea contains 500 to 1000 mg/Nm^3 of air.

Liquid effluents originating from urea and ammonium nitrate plants are concentrated solutions from scrubbers. Aqueous effluents can also come from spills, leaking pumps and flanges from fertilizer plants.

The emissions from fertilizer plants can have a negative impact on the environment. For example, ammonia and acid fumes can cause mists and damage the vegetation in the vicinity. The fluoride emissions can harm vegetation and the animals being fed on this vegetation. Similarly, the dust released into the atmosphere can also cause harm to vegetation. When plant nutrients are released to the aquatic environment from the scrubber system or run-off water, they cause eutrophication of water resources especially in lakes and closed reservoirs.

(b) Pollution prevention and control in fertilizer manufacture: The nitrogen dioxide emission from the nitro phosphate process can be controlled by adding urea to the digestion stage. Most emissions are wet scrubbed.

Ammonium nitrate and fertilizers containing a high percentage of ammonium nitrate are oxidizers and hence require special transport and storage facilities and should not be tagged with hydrocarbons or carbohydrates.

To remove ammonium nitrate fumes, low-velocity filters may be necessary. For urea dust, a venturiplate scrubbing unit may be used. The dust thus generated, is passed through cyclones and the larger particles recycled. The finer particles are collected or removed by bag filters or wet scrubbers. The other gases, mists, fumes, etc. may be water scrubbed.

Scrubber liquors may be concentrated and recycled or otherwise treated and returned to the aquatic environment. Radioactive elements from phosphoric acid are removed by the normal industrial processes. As far as possible, fluorides should be transformed into useful industrial products.

The cost of pollution abatement equipment accounts for 10 to 20% of the total cost, and the maintenance and operational costs related to environmental protection accounts for another 10 to 20% of the total production cost.

The principles applied in **pollution abatement** of some major fertilizers are as follows:

(i) Pollution abatement in **urea** process : The major pollutants from a urea plant are ammonia and urea, which occur due to the (a) gland cooling water leakage from reciprocating and centrifugal pumps, (b) process condensate from the concentration section, and (c) effluent air from the prilling tower or granulator.

Toyo Engineering Company and Mitsui Toatsu Company of Japan have developed an **integrated pollution control system for urea plants**. The salient features of the system are the following: (i) The leakage of gland cooling water pumps is controlled by adopting a closed circuit of the gland cooling water system. The lubrication oil in the gland cooling water is removed through an oil separator installed on the cooling water circulation line. The blow down steam containing urea and ammonia is discharged to the process condensate treatment stage. (ii) The process condensate and large liquid pollutants in the urea plant are evaporated under vacuum in an evaporator or concentrator. The evaporated water along with the mist of urea is condensed on the surface condenser. Uncondensed gas is vented to the atmosphere through an absorber for ammonia, carbon dioxide and inerts. The process condensate from the second stage of the surface condenser is stripped at 3 MPa for ammonia and carbon dioxide. The mixture is sent to a low pressure decomposer for the recovery of ammonia, carbon dioxide and heat. (iii) The urea dust from the prilling tower or urea granulator contains fine particles of < 1 micron in diameter and the quantity of air containing these dust particles is about 600,000 Nm^3/hour. The dust scrubber of Toyo Engineering scrubs the air from the prilling tower or granulator with a 20% aqueous urea solution. Any mist in the exit air is captured by a demister. These control measures when implemented, reduce the liquid and gaseous effluent levels as follows: (a) levels of urea and free ammonia in liquid effluents is reduced to 3 to 5 ppmw, and (b) the urea concentration in the gaseous stream is about 30 to 50 mg/Nm^3 of air.

The Foster Wheeler process combines the processes of condensate purification and air dedusting. It involves the steam stripping of raw process condensate from a urea unit, which is further mixed with a circulating stream of urea solution and introduced into an evaporative scrubbing system. The air from the prilling or granulation stages is introduced into the bottom of the evaporative scrubbing system. Particles entrained in the air are dissolved in the urea solution which cools as a result of water evaporation. A portion rich in urea, is sent to the urea plant from the scrubber. The main solution from the scrubber is circulated through the condenser to condense vapors. The amount of heat required for the evaporative scrubbing system comes from the heat generated in the vapor condenser. If additional heat is required it is supplied by the steam heater. The integrated system has certain advantages. It is a small synthesis equipment with low cooling water consumption, and it eliminates medium pressure steam for urea hydrolysis. The system is successful in dedusting of air from the ammonium nitrate prilling or granulation plant.

The **Stamicarbon bv process** water treatment unit processes effluent water containing ammonia (around 6%), carbon dioxide (about 4%) and urea (about 1%). The process has two kinds of units - desorption units and hydrolyzing units. The process waste water enters a desorber where ammonia and carbon dioxide are recovered by heat. The effluent containing urea is then sent to a hydrolyzer where urea is decomposed at 200°C. The liquid is sent to a second desorber and the gaseous part is sent to the first desorber where it serves as a stripping agent. All vapors are condensed in a condensate where carbamate is produced. The gases are vented and the effluent from the absorber after cooling can be used as process water. The design value of the urea and ammonia in the effluent is 5 ppmw each. However, in practice it is below 1 ppmw.

(ii) **Pollution abatement in Ammonium nitrate / calcium ammonium nitrate process**: The Institute of GIAP pollution abatement system has a bell-shaped shroud installed around the spray head in the upper part of the prill tower. This collects the fume-laden air from the part of the tower where fumes are formed. (Fumes are created when air contacts hot ammonium nitrate solution in the prill solidification process). The airflow through this shroud is only about 25% of the total airflow through the tower, and the remaining 75% is practically free of dust and fumes. The air from the shroud is passed through a scrubber and brinks. Fumes and vapor from the neutralizer and evaporators are connected to the same scrubbing system. The system recovers 3 to 7 kg of ammonium nitrate per ton of the product from all sources. The atmospheric emission contains less than 0.5 kg/ton of the product and opacity of less than 10% can be achieved.

(iii) Pollution abatement in **complex fertilizers (NP/NPK)**: The **Uhde methodology of pollution control** considers potential emissions related to the specific equipment and technological parameters. This methodology involves a four step approach, as listed below: (i) Reduce or avoid the formation of pollutants at the source. (ii) Select process conditions and equipment to reduce the emissions to a minimum at the source. (iii) Contain the pollutants in a minimum of carriers. (iv) Recover airborne pollutants.

The Beladune Fertilizers Limited (BFL) Process uses a double mol scrubbing system and a BFL vaporizer to remove the condensate containing 2.5 to 3% ammonia during the diammonium phosphate (DAP) production. The system utilizes waste heat to vaporize ammonia, scrub fluorine and provide hot water for cake washing in the phosphoric acid plant. All condensate water is drained to a sealed tank and recirculated to a single large spray nozzle at the heat exchange inlet. The off-gases flow through the heat exchanger and the gas stream/condensed water enters a separator having a demister. The purified gas is vented out and the acidic water is returned to the plant.

In the **Uhde closed scrubber system**, exhaust gases from the pipe reactor and granulator enter the granulation scrubber for cleaning through recirculated solution. The gas from the solution enters the main scrubber along with exhaust from the drying drum. The off-gases are washed in the final scrubber with water and sulphuric acid. Excess circulating solution is returned to a pipe reactor.

(iv) Pollution abatement in **Nitrophosphate fertilizers** processes: In the Norsk hydro nitrophosphate process, all wash-waters collected in a place are treated with calcium hydroxide or calcium carbonate to precipitate phosphates and fluorides. A flocculent is added to increase the rate of precipitation. The slurry is recycled and water is used as wash-water. The water vapor from the neutralization and evaporation stages are scrubbed with 60% ammonium nitrate. The vapors are condensed and ammonia stripped, and they are returned to the neutralization stage.

The gaseous emissions from the four stages of digestion, crystallization, separation and filtration are scrubbed by wash-water. To take care of excessive oxides of nitrogen, some urea is added to the scrubbing solution. The emissions from the conversion unit are first scrubbed with acidic ammonium nitrate and then with acidic water at the second stage. Conventional cyclones are used to treat emissions from the granulation stage.

In the BASF nitrophosphate method, the emissions are oxides of nitrogen, as also ammonia and dust. Waste air containing oxides of nitrogen (>2000 mg/Nm^3) enters the first scrubber. The gas coming out of the scrubber is mixed with that from the cooling section and from calcium nitrate filters. The second scrubber is fed with ammonia solution and water. The ammonium nitrate formed is decomposed by adding urea. As already mentioned, phosphate rock dust, fluorides, acids, ammonia and radioactive elements are the main health hazards in the production of this fertilizer. Coating materials, such as silica, are hazardous when inhaled.

(v) Pollution abatement in **phosphogypsum production**: The composition of phosphogypsum produced as a byproduct of the phosphoric acid production process depends on the type of phosphate rock used. Most of the phosphogypsum is used in landfills. A small quantity is disposed into the sea.

A large amount of water is required for not only the disposal of phosphogypsum, but also for entire production of phosphoric acid. Water is required for cooling the phosphoric acid processing units and for absorbing gaseous and particulate emissions. This washed water is used to pump the phophogypsum as a slurry in to a storage site which are commonly ponds near the plant. During rains, there is a risk of phophogypsum overflowing from the ponds and polluting the environment. The contaminated water must be treated before discharge. The disposal of phosphogypsum into the sea raises pollution issues relating to the impact of gypsum, trace elements and pH of the discharged water. In an open sea or a sea under good tidal conditions, gypsum quickly dissolves without changing the calcium ion concentration. In addition, all heavy metals present in the phosphogypsum are also present in the seawater and hence the change caused by the effluent disposal is insignificant. The pH change in the same volume is also found to be negligible. Phosphogypsum is used to a small extent as cement retardant and as additives in construction materials, paperboard products and in agricultural applications.

Phosphogypsum is converted into lime and elemental sulphur by reducing agents such as coal. Phosphogypsum is purified by repulping and filtering to remove the traces of phosphorus pentoxide and make it suitable for use in the ammonium sulphate process as is being followed at Gujarat State Fertilizer Company, India. Ammonium carbonate - made from ammonia, water and carbon dioxide – is mixed with washed fine phosphogypsum crystals to get slurry of calcium carbonate and ammonium sulphate liquor. The slurry is filtered and the solution clarified in a settler. The filtered cake is repulped with effluent water and disposed off into chalk ponds. Excess ammonia in the filtrate is removed and evaporated to get ammonium sulphate which is centrifuged. The waste calcium carbonate is used to produce lime, building lime, activated lime, cementation binder, bitumen mastic and flooring tiles.

Environmental impact of nitric acid industry

Major raw materials for the manufacture of nitric acid are anhydrous ammonia, air and process water.

Water is required for steam turbine condensation, for process make up and for cooling. The nitric acid process produces large amount of high pressure steam.

(a) Wastes and emissions from nitric acid plants: The main emissions are oxides of nitrogen, the concentrations of which vary between 75 and 2000 ppmv and depend on the acid concentration, absorption tower pressure, temperature of the cooling water, quality and quantity of process water and the tail gas treatment. The waste water from the blow down of the cooling tower water and the boiler and water treatment plants contain dissolved salts that have low environmental effect. The platinum/ rhodium catalyst needs treatment after a period of time and is sent back to the manufacturer for recovery. Small amounts of nitric acid and ammonia are released during the maintenance operations. The main impact of the release of oxides of nitrogen is acid rain and greenhouse effects.

(b) Pollution prevention and control in the manufacture of nitric acid: When catalyst wastes are recycled, a good plant design and optimal operation can reduce emissions. Nitric acid is stored in closed stainless steel tanks. The plant area should have impermeable flooring and all surface drainages should be connected to a neutralization pit. Small amounts of nitrate salts produced in the neutralization pit should be discharged with a cooling water blow down waste.

The tail gas is treated with sodium hydroxide in a scrubber to achieve concentrations of oxides of nitrogen of less than 200 ppmv. The byproduct of the washing process is low concentrated sodium nitrate/nitrite which is safely disposed of with cooling water blow down. Goodpasture (USA) developed a process to scrub tail gas with ammonium nitrate solution with addition of ammonia in the scrubbing unit to recover ammonium nitrate. Norsk Hydro has developed a scrubbing process where an aqueous urea and nitric acid solution is used for scrubbing.

In many industrialized countries, an extended absorption method is used to control oxides of nitrogen in tail gas. This method increases the efficiency of the absorption system by adding a second absorption tower, adding more solutions to the absorption tower and in some cases reducing the temperature in the absorption stages. Potassium carbonate, hydrogen peroxide, etc. are used to increase the efficiency of the absorption process. A substantial reduction in the concentration of oxides of nitrogen is observed by saturating the scrubbing liquid with oxygen. The extended absorption method has the added advantage of recovering nitrogen as nitric acid.

In the **nonselective catalytic reduction (NSCR) process** hydrogen or hydrocarbons are burned in tail gas over platinum/rhodium catalysts to remove oxides of nitrogen in excess oxygen. This burning requires a 1:1 to 1:1.25 excess fuel component compared to the amounts in oxides of nitrogen. Natural gas is used as a fuel in this method. The following reactions illustrate the process:

$$2O_2 + CH_4 \longrightarrow CO_2 + 2H_2O$$
$$2NO_2 + CH_4 \longrightarrow CO_2 + 2H_2O + N_2$$
$$4NO + CH_4 \longrightarrow 2N_2 + CO_2 + 2H_2O$$

These reactions are highly exothermic. This method is designed with two or more catalyst beds in series with intercooling to remove excess heat. The nitrogen industry uses a catalyst containing Al_2O_3 with 2% palladium in the first bed and Al_2O_3 in the second bed. The temperature of the gas leaving the reactor ranges from 680 to 800 °C.

The selective catalytic reduction (SCR) process uses ammonia to reduce the oxides of nitrogen to nitrogen in the presence of a catalyst and to bring down the tail gas content to 100 ppmv of the oxides of nitrogen. The following reactions occur during this process:

$$4NH_3 + 6NO \longrightarrow 5N_2 + 6H_2O$$
$$8NH_3 + 6NO_2 \longrightarrow 7N_2 + 12H_2O$$

The reaction temperature is usually between 200 and 450 °C. In the Russian process two different catalysts are used ie alumina-vanadium and alumina-copper-zinc. The process has been successfully used in several commercial plants in Japan, USA and western Europe.

In the absorption process, absorption by silica gel or molecular sieves is attempted. The oxides of nitrogen from the absorbate are then returned to the process. The Compagnie Francaise de l'Azote process is a version of the wet absorption scrubbing method to remove oxides of nitrogen. Two processes that combine the high efficiency absorption columns and the selective catalytic reduction are the Rhone Poulenc process and Institute of Mineral Fertilizers (INS Poland) process.

The principle of the high efficiency absorption columns is based on liquid-phase oxidation and absorption. The product is dilute acid which is recycled. The non-absorbed gases are passed over a catalytic reactor where the reduction of the oxides of nitrogen takes place with ammonia. The tail gas passes through the turbine and out of the stack.

The **Institute of Mineral Fertilizers Process** is a double pressure process where a high efficiency absorption tower ensures 99.9% efficiency. After treatment, the gas contains oxides of nitrogen to the concentration of 40 ppmv which is then passed over a double catalyst system (the first step uses platinum-rhodium and the second step uses palladium).

Oxides of nitrogen fumes are toxic and the threshold limit value for an 8 hour period is 3 ppmv. Wearing a breathing apparatus is necessary. Nitric acid is highly corrosive and its handling is always done with a protective suit, goggles, face shields, PVC gloves and boots. Also, eye wash fountains are required to be provided at strategic places throughout the plant. Trained operators and operating manuals and guidelines are essential for the safe operation of plants. Also, continuous monitoring of the concentration of oxides of nitrogen in the stack gases needs to be carried out.

Environmental impact of phosphoric acid industry

Phosphoric acid is made from sulphuric acid and rock phosphate. Phosphate rocks, depending on their origin, can contain radioactive elements like uranium, thorium and radon or heavy metals such as cadmium, nickel and copper. The crystalline nature of phosphate rock influences the process efficiency and byproducts. Hence, choosing the source of phosphate rock is important. The production of one ton of phosphoric acid needs 7.1 tons of make-up water. Additional water is necessary to pump the **phosphogypsum** slurry to the dumping site or into the sea. Two kinds of water are essential for phosphoric acid plant, namely, cooling water and process water.

(a) Wastes and pollutants in the manufacture of phosphoric acid: Hydrogen fluoride is released from the acidulation of phosphate rock, which combines with silica to form fluorosilicates. Phosphate rocks with low silicate content also produce hydrogen fluoride. Both fluorides are harmful emissions. In most cases water used to transport gypsum to storage is recirculated. Other aqueous effluents from a phosphoric plant originate from spills and leakages from pumps and flanges. Around 5 tons of dry phosphogypsum is produced per ton of phosphorus pentoxide. This waste gypsum contains 40% water, heavy elements like cadmium and radioactive elements, and some phosphoric acid. These impurities in phosphate rocks are partitioned between the ore beneficiation process waste, acid process waste and the final product.

The increasing cadmium level in fertilizers is a cause for concern. While igneous phosphate rock contains very little cadmium (<1 mg cadmium/kg of phosphorus) sedimentary sources contain much higher levels of cadmium (43 to 380 mg/kg of phosphorus). However, the amount of cadmium entering the ecosystem from fertilizers is 6% of the total cadmium present in the phosphate rock. As cadmium sulphate is water soluble and cadmium phosphate is acid soluble, most of the cadmium remains in the acid while phosphates are made out of the acid.

The phosphogypsum produced during phosphoric acid manufacture requires a large surface of land for disposal or a transportation system for disposal into the deep sea. Sea disposal has to follow many guidelines. The land disposal of phosphogypsum calls for specially lined surfaces for the stacks to prevent leakage and contamination of the ground water. The excess water from the stacks should be drained and neutralized before release.

(b) Pollution prevention and control in the manufacture of phosphoric acid: The emission of hydrogen fluoride can be reduced by efficient absorption systems. The wastewater released from phosphogypsm slurry must be carefully circulated. Though the hemihydrate process produces smaller quantities of phosphogypsum and a higher concentration of phosphoric acid, the pollution problems are similar. Phosphogypsum, after processing, can be used as construction material or may be converted into cement and sulphuric acid. Fluorides are converted into useful industrial products, or the process water is discharged with phosphogypsum. Phosphoric acid is highly corrosive to mild steel and hence rubberlined mild steel tanks are used along with plastic pipes and valves. All storage tanks should be kept in controlled conditions. Plant areas should have impermeable flooring with the surface drainages connected to a neutralization pit. Complete recovery of uranium from phosphoric acid is being attempted. However, complete removal of cadmium from the acid is difficult. Fluorides are removed by scrubbing.

(c) Health and safety issues in the manufacture of phosphoric acid: Phosphate rock dust and radioactive elements are the main health hazards of this process. A reasonable level of fluoride in food and drinking water is 2 mg/day of fluoride ingestion. The first signs of chronic fluorosis in man is mottling of teeth followed by ossification of ligaments. Animals are affected by concentration of fluorides in excess of 30 mg/Nm^3. Vegetation is more sensitive to exposure of fluorides than animals or human beings.

The concentration of radio nuclides in phosphate rock varies according to the location from where it is mined. About 40% of the radio nuclide concentration in phosphate rock is present in phosphoric acid and 2% is present in phosphogypsum. The long-term effects of phosphate fertilization have not shown any concentration change of uranium, thorium and radon. The soil conditions facilitating the uptake of radio nuclides by crops have not been studied in detail though these elements in soil are absorbed by the plants. To avoid ingestion of radioactive elements, a high level of cleanliness and hygiene should be observed in these chemical plants. Acids should be handled by trained operators with fully protective suits, using detailed manuals and guidelines for the safe operation of the plant. A daily monitoring of the fluoride level is obligatory.

Environmental impact of sulphuric acid industry

Sulphuric acid is made from any one of the basic raw materials - sulphur, pyrites or tail gases from metallurgical industries. The production of 1 ton of sulphuric acid (of 100% concentration) requires 0.33 ton of sulphur and produces 1.8 tons of high pressure steam. The manufacture of sulphuric acid requires three qualities of water, namely, demineralized water for boiler feed, process water to absorb sulphur trioxide and cooling water.

(a) Wastes and emissions from sulphuric acid manufacture: Sulphur dioxide and acid mist are released from waste gas from the final absorber tower. Apart from boiler blow downs and water treatment plant regeneration, aqueous effluent from sulphuric acid plant originates from spills, leakages from pumps and flanges. The vanadium catalyst used for the oxidation process is returned to the catalyst manufacturer for vanadium recovery or safe disposal. Small amounts of sulphur dust are produced when sulphur is stored in open air. Sulphur dioxide and acid mist released into the atmosphere may contribute to acid rain.

(b) Pollution prevention and control in the manufacture of sulphuric acid: Sulphur with low ash content reduces catalyst requirement and produces less solid waste. Yellow sulphur is preferred to other colors of sulphur that have organic impurities. The catalyst is recycled. Sulphuric acid of more than 96% can be stored in mild steel tanks. Plant areas have impermeable flooring with the surface drainages connected to a neutralization pit. Emission levels of sulphur dioxide and acid mist is reduced by using a double conversion / double absorption system. Fiber mist eliminators having low gas velocities are used to remove all particles with more than 9 microns and 99% of all the smaller sized particles. Electrostatic precipitators are effective. In specific cases, final tail-gases are scrubbed with ammonia or caustic soda solutions. The existing single absorption facilities are upgraded with one of the following options: (i) Conversion to double absorption. (ii) Switching to cesium type catalyst. (iii) Additional alkaline tail-gas scrubbing. These installations are costly and they generate liquid effluents that need to be disposed of.

(c) Safety issues and occupational health hazards in the sulphuric acid production process: Any sulphur dioxide concentration in excess of 27 mg/Nm^3 is known to be a strong irritant and the allowable maximum safe and industrially accepted concentration is half this value. The maximum safe concentration for sulphuric acid mist for a 24 hour period is 0.14 ppmv. The acid should be handled by skilled workers with full safety protection appliances such as eye wash fountains at strategic points, detailed operation manuals and safety guidelines. Continuous monitoring of sulphur dioxide levels in the stack and of acid mist and sulphur trioxide concentration in the gas after passing through the final absorber must be measured weekly.

Environmental impact of wastes and emissions from ammonia production plants: See Environmental impact of ammonia industry

Environmental impact of wastes and emissions from nitric acid plants: See Environmental impact of nitric acid industry

Environmental impact of wastes and emissions from sulphuric acid: See Environmental impact of sulphuric acid industry

Environmental impact of wastes and emissions in the manufacture of fertilizers: See Environmental impact of fertilizer industry

Environmental impact of wastes and pollutants in the manufacture of phosphoric acid: See Environmental impact of phosphoric acid industry

Environmental issue, dust: See Dust, an environment issue

Environmental issues related to fertilizer use

Though there are concerns that soil fertility management practices of modern, high yielding cropping systems are harmful to the environment, results from long term fertilizer experiments designed to assess the influence of fertilization tend to dispel some of these concerns. Some Japanese research tends to show that NPK fertilization does not negatively affect the physical, chemical and biological properties of soil as much as some times suspected. It also shows that yields stood at twice the levels as those of unfertilized soils.

(a) Soil protection by nutrient balance: Nitrogen forms a part of chlorophyll, and is in DNA and RNA for storing and processing genetic information. Nitrogen is also needed in amino acids that make all proteins and in enzymes that control transformations occurring in the living world. Phosphorus is involved in plant processes ranging from cell division to the development of a good root system for timely and uniform ripening of the crop. Young and fast growing tissues need phosphorus for functions related to growth, development, photosynthesis and the use of carbohydrates. It is a constituent of ATP and ADP, the two most important substances in the life processes.

The gains and losses of nutrients often roughly balance out. This means that biological growth depends on the cycling of nutrients between the biomass and the organic and inorganic stores. Removing or harvesting portions of the biomass without replacing nutrients in the biomass, depletes one or more of the nutrients. Hence, subsequent yields are reduced. Nutrients are also lost in the ecosystem through leaching, denitrification, volatilization and erosion. Erosion is the single largest factor responsible for soil degradation, which includes the loss of phosphorus.

Nutrient loss and soil fertility can result in environmental degradation. Soil nutrient depletion is a worldwide concern. In Africa, there is a large annual deficit; in Brazil applied nutrients meet 35% of the nutrient needs and in India only 24%. Potassium and phosphorus are deficient on a large scale in China. Almost all countries show deficient nutrient budgets.

The application of fertilizers to soil to protect it from the depletion of nutrients and to enhance the environment requires several conditions to be satisfied. These relate to the (a) nutrient ratio, (b) ratio of biomass to fertilizers, and (c) time of nutrient application. Mismanagement of plant nutrients can cause harmful modifications to the prevailing conditions of the ecosystem. Nitrogen in the surface water brings down the quality of drinking water and leads to **eutrophication**. Nitrogen in groundwater also affects the quality of drinking water. Phosphorus in surface water produces eutrophication.

(a) **Nutrient ratio**: Thirteen essential nutrients are provided to the soil from its own resources as well as from added fertilizers and manures. All these nutrients are needed in the right proportion. Nitrogen, the most widely deficient nutrient, when added to the soil results in a large yield but it does not contribute to soil fertility build up. Unbalanced use of nitrogen causes depletion of other soil nutrients.

In one experiment, application of nitrogen (~ 175 kg/ha) not only increased rice yield by 2.9 times but also increased the removal of phosphorus, potassium and sulphur by a factor of 2.6, 3.7 and 4.6, respectively. On the other hand, phosphorus deficiency reduces the efficiency of nitrogen. An inadequate phosphorus supply leads to nitrate leaching into groundwater. There is no response to potassium application in the absence of phosphorus, which at high levels reduces zinc availability. Hence, the balance of all nutrients is essential and good soil management achieves this.

(b) **Ratio of biomass to mineral fertilizers**: The sources of natural nutrients are soil, water, atmosphere, biomass and farmyard manures. Soils are the source of multiple nutrients. The atmosphere supplies nitrogen, sulphur dioxide, carbon dioxide and chlorides. Water supplies calcium, magnesium and potassium. Biomass and farmyard manure supply nutrients and have complex effects on soils and plant growth by improving the soil's physical and chemical properties and biological activity. Since the amount of biomass and farmyard manure is generally limited, the substitution of mineral fertilizers with farmyard manure to be effective as source of nutrients would need a fourfold increase of livestock, which is impracticable. The use of organic matter as fertilizer has the following disadvantages: (i) Continuous use of organic products under reducing conditions may retard plant growth. (ii) City compost and sewage may be contaminated by organic toxic compounds and heavy metals. (iii) Farmyard manure is a source of cadmium. (iv) A large use of farmyard manure may cause bacterial pollution of ground water and eutrophication of surface waters. (v) The application of biomass because of its large volume operations are labor and energy intensive.

(c) **Time of fertilizer application**: Plants require different nutrients in varying quantities during their life cycle. In cases of over-supply, the unused part of the nutrients may pollute the environment. The plant nutrient supply from various sources should cover the immediate needs of the plant. If the risks from leaching, volatilization, denitrification or fixation are high, which can happen in rainy, tropical climates, it is important to respond to a supply or demand situation rather than think in terms of total nutrient doses.

The daily uptake of nitrogen increases between tillering and jointing. The second critical period is between panicle initiation and flowering. Phosphorus demand grows after sucker settlement; however, to produce rich roots, phosphorus is necessary from the very beginning. Between half-time tillering, jointing and the preparatory phase of the panicle initiation, the demand of phosphorus is about 1 kg/ha/day. After flowering, initiation and grain growth, the demand of phosphorus is 0.2 to 0.3 kg/ha/day.

Potassium consumption takes place during the first two weeks and the nutrient supply must reach 15 kg/ha/day.

Environmental management standards: See Environmental impact assessment

Environmental optimum

An environmental optimum refers to the optimum return within the framework of environmental guidelines. If, for example, the application of nitrate fertilizer ensures that leached nitrate does not contaminate or pollute drinking water, the environmental optimum is reached. The World Health Organization recommends that drinking water should contain less than 50 mg nitrate per liter. If this stipulation is met, the environmental optimum is reached. (However, in the case of crops, whatever the rate used, the nitrate addition should be justified by the need of crop.)

Environmental perspective of the Institute of Mineral Fertilizers Process in nitric acid production: See Environmental impact of nitric acid industry

Environmental perspective on fertilizer nitrogen: See Fertilizer nitrogen, an environmental perspective

Environmental perspective on human intervention in agriculture systems: See Human intervention in agriculture systems, an environmental perspective

Environmental perspective on pollution prevention and control in fertilizer manufacture: See Environmental impact of fertilizer industry

Environmental perspective on pollution prevention and control in manufacture of ammonia: See Environmental impact of ammonia industry

Environmental perspective on pollution prevention and control in manufacture of nitric acid: See Environmental impact of nitric acid industry

Environmental perspective on pollution prevention and control in manufacture of

phosphoric acid: See Environmental impact of phosphoric acid industry

Environmental perspective on soil protection by nutrient balance: See Environment impact related to fertilizer use

Environmental perspective on the non-selective catalytic reduction (NSCR) process of nitric acid production: See Environmental impact of nitric acid industry

Environmental pollution abatement: See Environmental impact of fertilizer industry

Environmental pollution abatement in nitrophosphate fertilizers: See Environmental impact of fertilizer industry

Environmental pollution abatement in phosphogypsum production process: See Environmental impact of fertilizer industry

Environmental pollution prevention and control in the manufacture of sulphuric acid: See Environmental impact of sulphuric acid industry

Environmental problems, global: See Environmental protection and pollution prevention

Environmental Protection Agency of the USA

The Environmental Protection Agency (EPA) of the USA, which President Nixon created in December 1970, came in existence as a result of intense concern about environmental pollution. It was created to enable coordinated and effective governmental action to be taken for the betterment of the environment.

The EPA was established to consolidate, in a single agency structure, appropriate integration of federal research policies, monitoring, standard-setting and enforcement activities to ensure environmental protection. EPA's mission is to protect human health and to safeguard the natural environment - air, water and land - upon which life depends.

As a complement to its other activities, EPA coordinates and supports research and antipollution activities by state and local governments, private and public groups, individuals, and educational institutions. The EPA also strengthens efforts among other Federal agencies with respect to the impact of their operations on the environment. In all, EPA is designed to serve as the public's advocate for a livable environment.

The EPA has been working for a cleaner, healthier environment for the American people. From regulating auto emissions to banning the use of DDT, from cleaning up toxic waste to protecting the ozone layer, from increasing recycling to revitalizing inner-city brownfields, EPA's achievements have resulted in cleaner air, purer water and better-protected land.

Environmental protection agencies of other countries work on similar lines.

Environmental protection and pollution prevention

Production of fertilizers includes steps concerning mining, mechanical and chemical processing, material handling and transport. Fertilizers are ultimately for soils. Hence, fertilizer producers and users have to be concerned with fertilizer impact on the environment. Fertilizer production processes release emissions containing potential pollutants that may lead to acid rain, ground water contamination, water acidification, and eutrophication. All these may contribute to global environmental problems.

Adverse environmental effects from fertilizer production, distribution and application are not easy to generalize. It is worth recalling that the fertilizer industry has evolved over more than 100 years to meet the changing demands of the farmers. Besides, (a) environmental awareness has evolved and come to the forefront only in the last three decades, (b) the fertilizer industry operates at different levels of safety, depending on the complexity of different processes, and (c) fertilizer application practices have evolved over a long period of time and with different crop production patterns. In order that fertilizer processes and uses minimize adverse environmental impact, it is important that measures for pollution prevention be fully used with the highest standards of operation and maintenance.

Eco-friendly technologies are now available for basic fertilizer production. These technologies, however, for varying socio-economic reasons and a lack of full appreciation for the environment have not always got totally implemented. Fortunately, environmental awareness and sensitivity are on the rise and the emphasis is on minimizing the total adverse environmental impact of fertilizers, which calls for environmental protection at all stages of industrial development. Local standards and regulations are increasingly complying with internationally adopted standards and guidelines. The net effect is that all producers and users of fertilizers are under increasing pressure to develop and implement environmentally sensitive fertilizer production technologies and more efficient pollution abatement processes and installations. Existing facilities are also attempted to be retrofitted to bring them closer to the latest in fertilizer technology.

Environmental significance of time of fertilizer application: See Environment impact related to fertilizer use

Environmental significance on plant nutrient ratio: See Environment impact related to fertilizer use

Environmental significance on the ratio of biomass to mineral fertilizers: See Environment impact related to fertilizer use

Environment pollution abatement in ammonium nitrate/calcium ammonium nitrate production: See Environmental impact of fertilizer industry

Environment pollution abatement in the production of complex fertilizers: See Environmental impact of fertilizer industry

Environment, pollution to: See Environment

Environment, safety issues and occupational health hazards in sulphuric acid production: See Environmental impact of sulphuric acid industry

Environment, Stamicarbon bv process of effluent water treatment for: See Environmental impact of fertilizer industry

Environment, the phosphorus fertilizer industry and use of phosphorus: See Phosphate industry, an environmental perspective

Enzyme

Enzyme is a complex organic substance formed in the cells of plants and animals. Enzymes serve as catalysts for chemical reactions of biological processes such as digestion. They are highly specific in their catalytic behavior. A given enzyme is effective for only one particular reaction. The first synthesis of an enzyme (ribonuclease) was reported in 1969.

Enzymes are classified by the kind of substrate consumed in the reactions catalyzed. Enzymes that breakdown proteins by hydrolytic cleavage are called **proteolytic enzymes**. Some of the enzymes and their actions are listed in Table-E.2.

Table-E.2: Enzymes and their actions.

Enzyme	Action
Amylase	Hydrolyzes starch
Carboxylase	Converts cellulose to glucose
Cholinesterase	Inactivates acetylcholine
Invertase	Converts sucrose to glucose and fructose
Lipase	Hydrolyzes fats
Maltase	Converts maltose to glucose
Nitrogenase	Helps convert nitrogen into ammonia; also reduces ethelyne to acetylene.
Pepsin	Hydrolyzes proteins
Protease	Hydrolyzes proteins and peptide linkages
Rennin	Hydrolyzes proteins
Ribonuclease	Decomposes RNA
Trypsin	Splits proteins to amino acids
Urease	Decomposes urea to NH_3 and CO_2
Zymase	Converts sugars to alcohol and Co_2

Enzymes are identified by four numbers. The first indicates the group of enzymes to which the enzyme belongs. The second number represents the subclass. The third figure indicates sub-sub class. The fourth is simply the serial number of the enzyme in the sub-sub class. The major groups are (a) oxido reductases, (b) transferases, (c) hydrolases, (d) lyases, (e) esomerases, and (f) ligases.

EPA

EPA is short for **Environmental Protection Agency**.

EPIC

EPIC is short for **erosion productivity impact calculator**. (See Erosion prediction.)

Epidermis

Epidermis is the outer cellular layer of the skin or the outer layer of cells of leaves, stems, roots, etc. Leaves, herbaceous stems and floral organs usually retain the epidermis throughout their life. Most woody stems retain the epidermis until it is replaced by the bark.

The epidermis of the leaf has apertures called **stomata** which are surrounded by two specialized guard cells. The opening and closing of the stomata is caused by relative changes in the turgor between the guard cells and the surrounding epidermal cells (Fig.E.10).

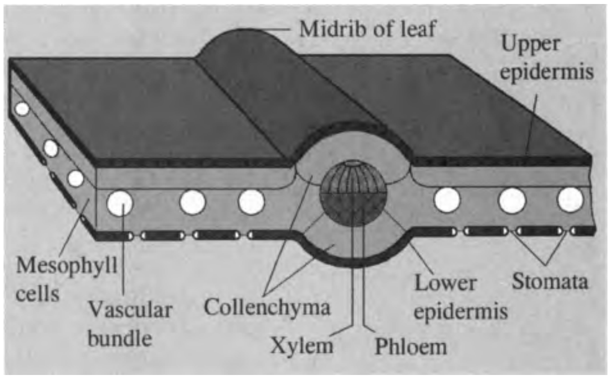


Fig.E.10: A diagrammatic representation of a section of leaf showing the epidermis and other primary components.

Cotton and kapok fibers are unicellular epidermal hairs from the seed and inner fruit wall respectively. Root hairs are thin-walled extensions of certain root epidermal cells. They develop only on growing root tips and may arise from an epidermal cell or from specialized cells known as **trichoblasts**. The life of a given root hair is usually no more than a few days.

Epinasty

Epinasty refers to a tendency in plant organs to grow more rapidly on the upper side. For example, the presence of a low ethylene concentration causes epinasty in tomato petioles.

Epinasty is characterized by the elongation of the petiole, making it bend downwards. This affects the orientation of the lamina which may become vertical. But epinasty is different from wilting, in that the leaf and the petiole remain puffed out.

Epipedons

The horizons at the uppermost soil surface are called epipedons. They are thinner (generally, 20 to 30 cm thick) than A horizons.

Epiphyte

An epiphyte is a plant that grows on another plant, but is not parasitic. Epiphytes only seek physical support to grow and are not otherwise dependent on their hosts. They can grow equally well on poles, roofs, buildings, walls, etc. Some epiphytes have aerial roots.

Epiphytes grow in humid regions, obtaining carbon dioxide from the air and producing their own food. Their aerial roots additionally absorb the moisture that settles on them; they also absorb nutrients from the bark and leaf cavities of the host trees. Occasionally, an epiphyte becomes very large and dense (like in the case of Spanish moss) and can cause physical injury to the host, robbing the tree of sunshine and moisture. Epiphytes include many mosses and lichens and some tropical orchids.

Epsomite

Epsomite ($MgSO_4 \cdot 7H_2O$), a naturally occurring mineral, has needle-like, orthorhombic crystals. It may be found in the saline efflorescence of the surface of some soils of arid regions. It is soluble in water, which makes magnesium easily available to plants. It is used as a source of magnesium in many chemical industries like paper, sugar refining, etc.

Epsom salt, $MgSO_4 \cdot 7H_2O$ (rhombic), is the commonest hydrate of magnesium sulphate. Used as a plant nutrient to overcome magnesium deficiency, epsom salt finds application in fertilizer manufacture besides being used in fireproofing cotton and in tanning leather. Epsom salt is also known to be a laxative.

Epsom salt: See Epsomite

Equation for dissolution of solid in liquid

Dissolution of a solid in a liquid is a heterogeneous process in which the solid (solute) passes into solution because of its interaction with the solvent. William **Nernst equation for dissolution** of a solid in a liquid controlled by diffusion is:

$$\frac{dc}{dt} = kS\,(C_s\text{-}C)$$

where dc/dt is the time dependence of concentration, S is the surface area of the solid, C is the concentration, C_s is the concentration at the surface determined by the solubility of the compound and k is the rate constant.

Equatorial forests

Equatorial forests, also called **tropical rain forests,** are found in equatorial regions. The region has temperatures of over 27°C all the year round, an average annual rainfall of about 2000 mm or more and an abundant growth of dense, luxuriant and evergreen vegetation. The trees of equatorial forests usually have **epiphytes** growing on them. Such forests are found in Congo, Amazon basins and South East Asia.

Tropical rain forests, which produce high biomass, use soil efficiently. Due to rich and highly competitive plant growth, the plant **biomass** contains many nutrients. However, felling of trees leaves the soil in poor condition.

The primary products from tropical rain forests are derived from wood. A large number of minor forest products includes gum arabic, tannin, honey, fruits, nuts, wild palms, medicinal herbs and mushrooms.

Equatorial zone

The equatorial zone is the region between 28.5°N and 18.5°S on both the sides of the equator. It is also called **torrid zone**.

Equilibrium

Chemical equilibrium is a condition in which a reaction and its opposite or reverse reaction occur at the same rate, resulting in a constant concentration of reactants. For example, ammonia synthesis is at equilibrium when ammonia molecules form and decompose at equal velocities.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

Physical equilibrium is exhibited when two or more phases of a system are changing at the same rate, so that the net change in the system is zero. An example is the liquid to vapor or vapor to liquid interchange in an enclosed system, which reaches equilibrium when the number of molecules leaving the liquid is equal to the number entering it.

Equilibrium constant

The equilibrium constant is a number that relates concentrations of the starting materials and products of a reversible chemical reaction to one another. For example, in a chemical reaction represented by the equation

$$a\,AB + b\,CD \rightleftharpoons c\,AD + d\,BC$$

the equilibrium constant (K) would be

$$K = \frac{[AD]^c\,[BC]^d}{[AB]^a\,[CD]^b}$$

where a,b,c and d are the number of molecules of AB, CD, AD and BC in the balanced equation and [AD], [BC], [AB] and [CD] are the molecular concentrations of AD, BC, AB and CD in the equilibrium mixture. At any one temperature, K is usually at least approximately constant regardless of the relative quantities of several substances. So when K is known, it is often possible to predict the concentrations of the products when those of the starting materials are known. The constant (K) changes markedly with temperature. The constant can be calculated from the relations of thermodynamics if the free energy for the chemical reaction is known or can be calculated by measuring all concentrations in one or more carefully conducted experiments.

Equivalent acidity

Equivalent acidity is the amount (weight) of calcium carbonate needed to neutralize the acidity caused by a certain amount of an acid forming fertilizer.

Equivalent area yield

The equivalent area yield is a criterion used for comparing mixed culture and monocultures of crops. The equivalents represent production of mixed crops in terms of the total area of pure stands of the component crops which would have been required to give the same yield. A value less than one indicates that the mixed crop was less productive than the pure stands. The equivalent area yield (**EAY**) is given by

$$\text{EAY} = \frac{\text{Yield of cereal in a mixture}}{\text{Yield of cereal in solid stand}} + \frac{\text{Yield of legume in a mixture}}{\text{Yield of legume in solid stand}}$$

Equivalent point: See Volumetric analysis

Equivalent proportions, law of: See Chemical combination, laws of

Equivalent spherical diameter

In particle size analysis by sedimentation principle, the equivalent spherical diameter refers to the diameter of a non-spherical particle that is equal to the diameter of a spherical particle of the same density and the same rate of fall.

Erg

Dunes, especially desert dunes, which occur in isolation or in fields of many separate or joint dunes are called erg. They can be mobile or fixed.

Erg is also a CGS unit of work and is defined as the amount of work done by a force of one dyne in moving the point of application through one centimeter. Since erg is a small unit, a more commonly used unit is a joule which is 10^7 ergs.

Erodibility

The relative ease with which a soil is eroded under specified conditions of slope as compared to another soil under similar conditions of slope is known as erodibility. Erodibility depends on soil properties (particle size, clod forming properties, cohesiveness, aggregates and infiltration capacity), vegetation, topography and land use practices.

Erodibility index of soil: See Erosion prediction

Erosion

A gradual destruction or wearing away of the earth's surface by natural agents such as wind and water, is called erosion. **Soil erosion** is a subject of serious study.

Erosion control

The process of eroding or being eroded by wind, water or any other natural agent is called erosion. The detachment and movement of soil or rock fragments by water, wind, ice or gravity is known as **soil erosion**. It can be controlled to some extent by taking measures to reduce soil detachment or soil sediment transport or both.

By far the best and most common method of reducing the soil detachment is to cover the soil surface with crops. (Fig.E.11). Such a cover on the soil surface intercepts raindrops, reduces the speed of wind and water and reduces soil erosion rate. The roots of plants create pores in the soil, to increase soil permeability, which further helps prevent erosion. Furthermore, the root exudates help the aggregation of soil particles. Other materials (like mulch, straw, papers and wood chips) also intercept raindrops and retard run-off. The **stubble mulch farming** practice is an effective wind and water erosion control technique for semi-arid lands.

Soil erosion by water can be reduced by obstructing steep slopes with barriers like terraces, brush wood dams, **contour cultivation** and **contour strip cropping**. Constructing **terraces**, in particular, reduces the average land slope and hence erosion (Fig.E.12). But if terraces are not properly designed and maintained, they could collect water and the overflow thereon can do more damage than good. The practice of **zero tillage** also reduces soil erosion by encouraging wild vegetation.

Fig.E.11: (Top) Exposed soil surface is prone to erosion. (Bottom) Vegetative cover reduces erosion.

Fig.E.12: Terracing is an effective erosion control method on steep slopes.

To reduce erosion, the collection of water in restricted areas and its movement into narrow channels is avoided. In general, any method that increases the infiltration rate and absorptive capacity of the soil (such as surface tillage, organic residue incorporation, and stubble mulches) reduces the run-off of water over the surface. Permanent pastures or grassed waterways are used to check **gully erosion** of medium intensity. Similarly, in situations leading to mild erosion, roughening the soil surface may help to keep erosion in check.

Wind erosion is most common in arid and semi-arid climates. It is a very serious problem during dry seasons in most countries, especially when the soil is less cohesive, the loose particles are small, vegetative cover is sparse and wind speeds are high.

Factors like climate and **soil erodibility index** influence wind erosion and these are not readily controllable. Wind erosion can be controlled by mulching, windbreaks, wetting the soil, creating soil roughness and minimum tillage. For severe wind erosion conditions, barriers like tree shelter-belts can very effectively check wind velocity (at least for short distances) and trap the drifting sand.

It may not always be possible to prevent the loss of large masses of soil (**mass wasting**) caused by natural forces, like landslides. But some measures can reduce mass wasting. For example, **contour cultivation** restricts erosion during a low-intensity rainfall on moderate slopes. Ridges made during contour tillage, combined with terracing or **contour strip cropping** (See Fig.E.12) are quite effective in controlling erosion.

Uncontrolled soil erosion affects human beings but many times they are also themselves responsible for erosion when they allow overgrazing, lumbering, massive urbanization especially on continental land slopes and coastal topographic features.

Erosion hazard units

The **universal soil loss equation** predicts the expected soil loss. The **soil loss estimator for Southern Africa (SLESA)** is a more refined equation for estimating universal soil loss and addressing the soil loss problems peculiar to South Africa. This model yields the **erosion hazard units (EHU)** on a scale of approximately 0 to 1000. A number of monograms and graphs are available to simplify the calculation of EHU (See Erosion prediction.)

Erosion prediction

The **universal soil loss equation (USLE)** given below, is widely used to predict the extent of erosion from farms. The equation, first proposed in 1965 in the USA with six variables, is considered universal because it can totally describe the soil erosion process:

$$A = RKLSCP$$

where A is the long term average soil loss, R is the long term average rainfall run-off erosivity factor, K is the soil erodibility index, L is the slope length factor, S is the slope angle factor, C is the soil cover factor and P is the erosion control practice factor.

Soil loss estimator for Southern Africa (SLESA) is a refined form of USLE. SLESA depends on (a) physical systems like crop, climate, soil topography, (b) control variables such as energy interception, rainfall energy, soil erodibility, slope steepness and slope length, and (c) crop ratio, soil loss from bare soil and topographic ratio. This model yields **erosion hazard units (EHU)** on a scale of approximately 1 to 1000.

Erosion productivity impact calculator (EPIC) is a computer simulation model used for the prediction of consequences of soil erosion on productivity. This model takes into account the parameters relating to

(a) hydrology (surface run-off, percolation, subsurface flow, drainage, evapotranspiration, irrigation, etc.), (b) weather (precipitation, temperature, radiation and wind), (c) erosion by wind and water, (d) nutrients, (e) soil temperature, and (f) tillage. Analogous to the universal soil loss equation is the wind erosion equation as given below:

$$E = f(I' K' C' L' V')$$

where E is the erosion per hectare per annum, I' is the **soil erodibility index**, (with I' representing the potential loss from a wide, unsheltered, isolated field with a bare, smooth, non-crusted surface, and the **knoll erodibility index** (I_s) which is erodibility of windward slopes expressed as percentage slope), K' is the soil ridge roughness factor (which is a measure of natural or artificial roughness other than that caused by clods and vegetation), C' is the local wind climatic factor; L' is the field length or its equivalent along the prevailing wind erosion direction and the sheltered distance in the same direction, V' is the equivalent quantity of vegetal cover and vegetal roughness. These parameters give rise to some sub-relations; for example, V' is related to other parameters, the values of which are available from appropriate tables. The soil erodibility index ranges from 0 (stony) to 300 (very fine sand); the soil roughness ranges from 1.0 (smooth soil surfaces) to 0.5 (rough surface); the field size (L') ranges from 0 to 1.0.

Erosion productivity impact calculator

Erosion productivity impact calculator (**EPIC**) is a computer simulation model used for the prediction of consequences of soil erosion on productivity. (See also Erosion prediction.)

ERT Espindesa processes for non-granular monoammonium phosphate

ERT Espindesa, Nissan Scottish Agricultural Industries, Fison's Ltd. and Swift Agricultural Chemicals have developed processes for the manufacture of non-granular monoammonium phosphate which is used as an intermediate in the production of compound fertilizers.

The most important feature of the ERT Espindesa process is that unlike in other processes, the reaction to MAP or DAP is completed within the pipe reactor and further ammoniation is avoided. Hence, powdered or granular product can be easily made.

Pure monoammonium phosphate is completely water-soluble and contains 12% nitrogen and 21% phosphorus (52% as P_2O_5). (See also Monoammonium and diammonium phosphate production processes.)

ESP

ESP is short for **exchangeable sodium percentage**.

ESR

ESR is short for exchangeable sodium ratio. (See Water quality.)

Essential chemical elements

Besides the carbon, hydrogen and oxygen found in organic compounds, all plants, animals and micro-organisms require a range of elements in inorganic forms in varying amounts. Essential chemical elements are those that are required by living organisms like plants for their normal growth, development and maintenance. These elements are so critical in the metabolic functions of the plant that without these elements, plants cannot complete its life cycle.

Sixteen elements are considered essential for plant growth. Their relative concentrations range from 1.5% for nitrogen to 0.1 ppm for molybdenum. Of these sixteen elements, carbon, hydrogen and oxygen are the most abundant elements and are not considered as mineral nutrients. The remaining 13 elements are grouped into macronutrients (N, P and K), secondary nutrients (Ca, Mg and S) and micronutrients (Fe, Zn, Mn, Cu, B, Cl and Mo) (See Fig.E.13).

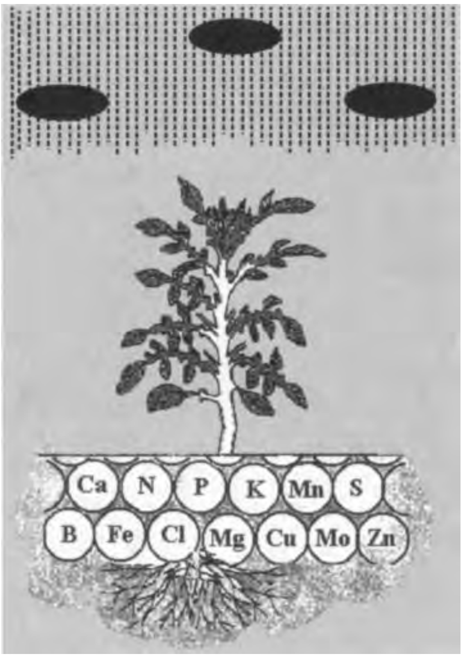


Fig.E.13: Essential chemical elements.

Plant nutritionists and soil scientists are increasingly using a less restrictive definition of essentiality of nutrients for plants. Accordingly, they have added five more elements to the list of essential elements. These are Na, Si, Co, V and Ni.

The essentiality of sodium has been established for plants with C_4 photosynthetic pathway and for the optimum growth of celery, spinach, sugar beet and turnip. Scientists from Japan, China and Korea have established the essentiality of silicon for rice. Cobalt is required for the microbial fixation of atmospheric nitrogen. Vanadium is required for the functioning of some micro-organisms. Nickel is present in the enzyme urease and is required for the hydrolysis of urea.

Sodium, potassium and chlorine ions are the chief electrolytic components of cells and body fluid. They determine the body's electrical and osmotic status.

Calcium, phosphorus and magnesium are all present in bones. Calcium is essential for the activities of nerves and muscles. Phosphorus is a key constituent of the chemical energy carriers (e.g., **ATP**) and of the plasma membrane and nucleic acids. Magnesium is the constituent of chlorophyll and it activates certain enzymes. Sulphur is a constituent of some amino acids, such as cysteine and methionine synthesis (in plants and micro-organisms). The trace elements serve as cofactors or constituents of complex molecules; for example, iron in haem and cytochromes, and cobalt in vitamin B_{12}.

When a plant nutrient is present in insufficient quantities, deficiency symptoms develop in plants. Similarly, when the nutrients are present in excessive amounts, they may become toxic to plants. The margin between the critical deficiency and toxicity is quite narrow for micronutrients, especially for Cu, B and Fe.

Esters

Esters are a class of organic compounds formed by an acid reacting with alcohol. Methyl acetate (CH_3COOCH_3) is an example of an ester formed by acetic acid reacting with methyl alcohol. Esters containing simple hydrocarbons are volatile and fragrant substances that are used as flavorings in the food industry. Triesters occur in nature as oils and fats, which are esters of glycerol and long chain fatty acids.

Ester sulphate

Ester sulphate is formed by the reaction of sulphuric acid with an organic alcohol. Ethyl sulphate, which contains the C-O-S bonds, is an example. Most of the sulphur in surface horizons in a well-drained agricultural soil is present in an organic form. The nature and properties of these compounds, which govern the release of plant available sulphur, fall under (a) hydroiodic acid (HI) reducible, non-carbon bonded sulphur (such as ester sulphates, phenolic sulphates and sulphated polysaccharides), (b) carbon-bonded sulphur, and (c) residual or inert sulphur.

In the hydroiodic acid reducible sulphur compounds, sulphur is present mostly as sulphate esters and ethers with C-O-S linkages. A mixture of hydroiodic acid, formic acid, and hypo phosphorus acid in different proportions gives hydrogen which reduces the sulphate esters and ethers. The carbon-sulphur (C-S) bonds are not ruptured under these conditions. Aryl and alkyl sulphates, phenolic sulphates, sulphated polysaccharides and sulphated lipids are examples of this class of organic sulphur compounds. About 50% of the organic sulphur belongs to this class.

Ethylenediamine di-o-hydroxyphenylacetic acid

Ethylenediamine di-o-hydroxyphenylacetic acid (**EDDHA**) is a chelating agent used for micronutrients like iron and manganese.

Ethylenediamine tetra-acetic acid

Ethylenediamine tetra-acetic acid $[(HOOC{\cdot}CH_2)_2NCH_2{\cdot}CH_2{\cdot}N(CH_2{\cdot}COOH)_2]$ (**EDTA**) is a chelating agent which reversibly binds with iron, magnesium and other metal ions. It is used in the estimation of calcium, magnesium and some other metal ions.

Ethylene glycol method for treating clay minerals

Ethylene glycol method is a way of treating clay mineral samples. The latter are mixed with ethylene glycol prior to subjecting them to X-ray diffraction which distinguishes the clay mineral layers with the expanding lattice. Ethylene glycol, because of its polar nature, penetrates between the layers and changes the basal spacing. Thus, montmorillonite treated with ethylene glycol increases its basal spacing from 10 to 17Å, while in illite the basal spacing remains at 10Å.

If ethylene glycol is adsorbed as a very thin film to a soil or clay, forming a monomolecular layer, the retention of ethylene glycol is taken to be the measure of the surface soil area.

$$\text{The total surface area } (m^2/g) = \frac{\text{Weight in grams of ethylene glycol retained by unheated soil}}{\text{Weight in grams of vacuum-dried unheated soil sample}} \times 0.00031$$

Eubacteria

Eubacteria is a subgroup of bacteria. They have rigid cell walls which give the cells a fixed form. Eubacteria cells have different shapes - spherical, rod-like or helical. Most are immotile but some have flagella. They are unicellular and divide by binary fission.

Eucaryote

Eucaryote is an organism comprising a cell (or cells) which contains genetic material (DNA) within a distinct nucleus.

All organisms are eucaryotes, except bacteria. Eucaryotes are mostly multi-cellular but there are some unicellular eucaryotes. Fungi, slime moulds, protozoa, algae, nematodes and higher plants and animals are eucaryotic organisms.

Eucaryotes (also spelled as **eukaryote**) are also called eucaryotic organisms.

EUF

EUF is short for **electro-ultra filtration**.

Eukaryote: See Eucaryote

Eutectic point: See Eutectic solutions

Eutectic solutions

A eutectic solution consists of two or more substances, usually metals, and has the lowest melting point that any mixture of these components can possibly have. The minimum melting point for a set of components is called the **eutectic point**.

Alloys with a low melting point are usually eutectic solutions. An alloy usually containing bismuth, lead, tin, cadmium or indium and with a melting point in the range of about 51 to 260°C, is a **fusible alloy**. For example, the Pb-Sn-Cd-Bi alloy (called **wood's metal**) has an eutectic temperature of 70°C. The In-Pb-Sn-Bi alloy has an eutectic temperature of 57°C. Some eutectic fusible alloys are used for punch and die moulds and for pattern application. They are also used as solders and as heat transport media.

The most important non-pressure nitrogen liquid is the urea-ammonium nitrate-water solution. This system, which has a freezing point of minus 26.5°C, forms a eutectic solution and contains 39.5% NH_4NO_3, 30.5% urea and the rest, water.

Eutrophication

Eutrophication means excessive richness of nutrients in a lake or other water body, causing a dense growth of plant life. The phenomenon is unintentional and results in uncontrolled growth of algae and flowering water plants. Eutrophication is frequently caused due to run-off from the land. Very often, it can also be caused by an increased amount of phosphorus, nitrogen and silicon.

Phosphorus and nitrogen help algal growth, whereas silicon determines the composition of the algal community. Algae with silicate skeletons provide food for organisms higher in the food chain (such as fish). The algae utilize N, P and Si in the ratio of 7:1:7 by weight. A low nitrogen to phosphorus ratio in fresh water favors the production of nitrogen-fixing **cyanobacteria**. A high nitrogen to phosphorus ratio with low silicon favors the production of **dinoflagellates**, the toxic algal species that forms 'red tides' in water, discoloring it.

This unwanted growth of water plants eventually leads to the accumulation of a considerable mass of dead, decomposing organic material. As decomposition requires oxygen, the decomposing matter uses up a large portion of dissolved oxygen in water, leading to the creation of near-anaerobic conditions and death of aquatic life in that water. The unwanted growth of water plants and weeds also clogs waterways. Eutrophication affects rivers, lakes and estuaries as well as coastal areas and enclosed water bodies.

Bacteria, especially **autotrophic bacteria**, oxidize ammonium to toxic nitrites, and then to nitrates. The percolating water makes the nitrate flow into ground waters which can be a health hazard for animals and human babies.

Eutrophication also contributes to creating additional sources of carbon. In earlier geological ages, eutrophication was said to have caused an enormous growth of water plants and swamp plants. These plants on their death have contributed to form vast deposits of gas, oil and coal. Farmland drainage that carries nitrates from fertilizers encourages the growth of micro-organisms, particularly algae, in drainage water.

The phosphate removal process involves the addition of a metal ion source to waste effluents, to insolubilize dissolved phosphates. This process is later agglomerated by anionic polymers.

E value

E value is the amount of isotopically exchangeable phosphorus or labile phosphorus present in the soil. The total amount of ammonium (NH_4^+) and nitrate (NO_3^-) ions, as also the readily mineralizable organic nitrogen, is necessary to get the quantity factor Q which gives both labile and non-labile forms of soil phosphorus. In the case of nitrogen and phosphorus, a stable isotope (^{15}N) or radioisotope (^{32}P) has been used to measure Q. For example, the amount of isotopically exchangeable phosphorus (called the E value or **L value**) is calculated from the quantity of the tracer added (^{32}P soil) and the specific activity of the soil solution after isotopic exchange between the solution and the soil surfaces has taken place, using the following equation:

$$\text{E value} = \frac{^{32}\text{P (in soil)} \times {}^{32}\text{P (in solution)}}{^{32}\text{P (in solution)}}$$

The quantity of isotopically exchangeable phosphorus, utilized by a growing plant over the span of a growing season, is called the E value. This value is the laboratory equivalent of the L value, measured over a shorter but specified period of equilibration. Basically, labile phosphorus is the fraction of soil P that is isotopically exchangeable with ^{32}P within a specified time.

The quantity of phosphorus present in a soil solution at a given time is the measure of its intensity. When phosphorus intensity is diminished by the withdrawal of phosphorus from the solution, the solid phase phosphorus goes into solution to replenish the loss. The solid phase of phosphorus (or of any nutrient) that acts as a resource is called the **quantity factor** or **capacity factor of the nutrient**. The quantity factor or reserves of soil phosphorus includes both the labile and non-labile forms of phosphorus. The labile phosphorus is directly linked with solution phosphorus (intensity factor) with a high dissociation rate, while the non-labile phosphorus is indirectly linked with the solution phosphorus with a low dissociation rate.

Evaporation pans

The estimation of potential evaporation or evapotranspiration in a field is done in many ways. Using evaporation pans is one of the methods for the direct measurement of water loss. It provides a very useful field method for measuring or estimating evapotranspiration. Usually the pan values are converted into the corresponding open water evaporation values by applying a pan coefficient or correction factor which varies with the type of the pan, site and climate.

Evapotranspiration

The sum total of evaporation and transpiration is evapotranspiration. (See Evapotranspiration loss.)

Evapotranspiration loss

Large quantities of water are lost by evaporation from the soil surface and by transpiration through plants. The sum total of the effects of evaporation and transpiration is **evapotranspiration**; the water thus lost by the two mechanisms is called the evapotranspiration loss. The loss of water due to evapotranspiration is nearly equal in amount to the consumptive use, which is the quantity of water lost by evapotranspiration, plus that contained in the plant tissues.

Evapotranspiration increases when the air is dry, warm or windy and the soil water is near the field capacity to be absorbed by the roots from the soil surface or vegetation. Evapotranspiration decreases under the opposite conditions, namely, high humidity, cool temperatures, wet soils and no winds. Potential evapotranspiration is the maximum transpiration possible under conditions of a slow-growing crop, adequate water supply and completely shaded soil.

Most of the water absorbed by the plant eventually escapes as vapor from the leaves. Though it is not always easy to calculate, an estimate of the seasonal evapotranspiration is valuable. It helps in designing irrigation systems and in determining the amount of water to be supplied or the number of crops that can be grown with the available water. For this purpose, the knowledge of both short-term (daily or weekly) evapotranspiration and of soil water storage is necessary. Evapotranspiration varies with the season, depending on the total radiation received from the sun and the quantity of heat that converts liquid water into vapor.

It is necessary to reduce evapotranspiration. Mulches are highly effective as they act as barriers to the escaping moisture, and cover the soil to decrease soil temperature.

The estimation of potential evapotranspiration is carried out by the following methods: (i) Direct measurement using evaporation pans, atmometers, lysimeters or evapotranspirometers. (ii) Moisture and water-budget methods. (iii) Meteorological formulae using the (a) aerodynamic approach based on the physics of vapor transfer process, (b) energy budget approach, and (c) a combination method using the aerodynamic and energy budget approaches.

Excessively drained soil

Excessively drained soil (dry soil) is one of various **soil drainage classes**.

Exchangeable acidity

Exchangeable acidity, which is another term for **reserve acidity**, is the acidity produced when soil is treated with a neutral salt solution.

Exchangeable aluminum

Exchangeable aluminum is the trivalent positive ion of aluminum retained on the negative charge of clay minerals or humus. Exchangeable aluminum, along with hydrogen, forms a group of acid-forming exchangeable cations. The exchangeable acidity is mostly due to the aluminum ions, though generally exchangeable hydrogen is considered responsible for the acidity.

$$Al^{3+} + H_2O \longrightarrow Al(OH)^{2+} + H^+$$

Leaching with an unbuffered salt solution, such as 1.0N potassium chloride (KCl), can help estimate the quantity of exchangeable aluminum. The aluminum content is then determined in the extract by titration or by spectrophotometry. If the exchangeable aluminum occupies more than 60% of the cation exchange capacity, the soil medium becomes toxic to plants. The knowledge of the exchangeable aluminum content is, therefore, important in the studies of plant nutrition and of pedogenesis.

Exchangeable base: See Exchangeable cation percentage

Exchangeable cation percentage

Cations that are adsorbed to the surface of the soil colloidal particles and exchanged by cations in the solution are known as **exchangeable cations** or **exchangeable bases**. For example, if a soil saturated with potassium ions is brought in contact with a solution rich in calcium ions, the solution gradually becomes poorer in calcium ions and richer in potassium ions. Determination of the content of exchangeable bases implies taking out the ions from the colloidal complex and then estimating concentration. The ratio (expressed in percentage) of the quantity of exchangeable cations held on the negative colloidal complex of the soil to the cations existing in the soil solution is called exchangeable cation percentage (**ECP**).

$$ECP = \frac{\text{Exchangeable cation (meq per 100 g soil)}}{\text{Cation-exchange capacity (meq per 100 g soil)}} \times 100$$

The **exchangeable sodium percentage (ESP)** is an important parameter as sodium is toxic to most plants and affects the physical properties of the soil, like permeability.

Exchangeable cations: See Exchangeable cation percentage

Exchangeable elements

Cationic elements that are held by electrostatic attraction on soil colloids can be exchanged easily when the soil is brought in contact with neutral salt solutions. These easily exchangeable elemental ions are known as exchangeable elements. The positively charged cations are held on the surface by the negatively charged soil colloids or due to charge imbalance arising from isomorphous substitution. The replacement of one metallic ion by another without breaking or changing the structure is known as **isomorphous substitution**. The replacement of Al^{3+} for Si^{4+} in the tetrahedral coordination of clay minerals, or of Mg^{2+} for Al^{3+} in the octahedral coordination, are examples. These replacements are responsible for the deficit in the positive charge, which will be compensated by the retention of exchangeable cations.

Positive ions are adsorbed at the negatively charged sites by electrostatic or coulombic attraction. These adsorbed cations resist removal by **leaching** water, and can be replaced by other cations in solution by mass action. The exchange of one cation by another is called **cation exchange**. Cations are held on the exchange sites with different adsorption strengths and hence the ease with which these elemental ions can be replaced or exchanged also varies in the following order. $Al^{3+} > Ca^{2+} > Mg^{2+} > K^+ = NH_4^+ > Na^+$. This series is known as the **lyotropic series**. This order depends on the strength of adsorption or desorption of cations. The adsorption depends on the size and the charge of the cation. The complementary cation effect occurs when the exchange of one cation for another becomes easier as the adsorption strength of the third or complementary cation increases. For example, ammonium (NH_4^+) exchange for divalent calcium (Ca^{2+}) occurs more easily when trivalent aluminum (Al^{3+}) is more predominant than the sodium ion (Na^+).

Exchangeable potassium

Most potassium ions absorbed by plants in a given season come from the exchangeable potassium and soluble potassium often in about equal proportions. In neutral and basic soils, soluble potassium is a major plant potassium source and in acid soils, the soluble potassium alone may be adequate to fulfill plant needs. The exchangeable potassium accumulates as mica and feldspars weather and as potassium in plant residues is released to the soil solution. Like other exchangeable cations, potassium ions are held around negatively charged soil colloids by electrostatic attraction on the exchange complex of 2:1 layer silicates.

The amount of exchangeable potassium in a soil may vary from 40 to 600 mg potassium per kg of the soil. Soils containing smectite have more exchangeable potassium than those containing illite these in turn have more exchangeable potassium than soils containing kaolinite. The cations held are easily exchangeable when the soil is brought into contact with neutral salt solutions. The distribution of potassium between negatively charged sites on the soil colloids and the soil solution is a function of the kinds and amounts of complementary cations, the anion concentration and the properties of the soil cation exchange materials.

Calcium is commonly present as a major cation in the soil and on the exchange complex. The exchangeable potassium on soil colloids of 2:1 clay minerals such as illite, vermiculite, etc. is held at three types of exchange sites or binding positions (Fig.E.14). The planar position (p) on the outside surfaces of some clay minerals, such as mica, is rather unspecific for potassium. By contrast, the edge position (e) and the inner position (i) in particular have a rather high specificity for potassium.

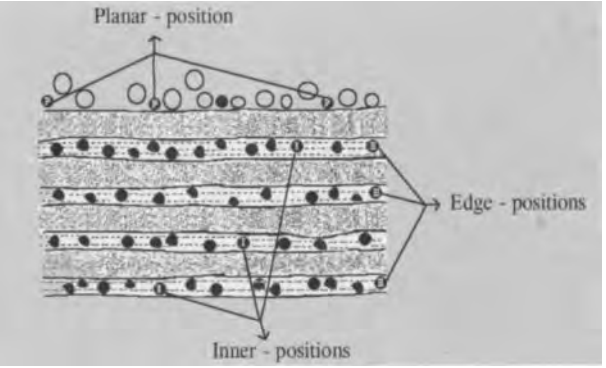


Fig.E.14: Binding positions of exchangeable potassium.

Exchangeable potassium in soils is generally determined by extracting the soil with neutral 1N ammonium acetate and hence includes water soluble potassium also. The entire quantity is known as **available potassium in soils**. The level of exchangeable potassium in soil is an important factor in determining the responsiveness of any crop to the application of potassic fertilizers.

Exchangeable sodium

Exchangeable sodium is defined by the sodium ions exchanged or adsorbed on soil particle exchange sites. The percentage of these exchangeable sodium ions to the total soil exchangeable cations of all types in the soil is called the **exchangeable sodium percentage (ESP)**. **Sodium adsorption ratio (SAR)** is, however, preferred to ESP since measuring the ESP is time consuming. SAR helps in classifying salt affected soils as saline, sodic and saline-sodic soils. Saline soils have an SAR <13 to 15 and electrical conductivity (EC >4 dS/m), sodic soils have an SAR >13 to 15 and EC <4 dS/m and saline-sodic soils have an SAR >13 to 15 and EC ≥ 4 dS/m.

Exchangeable sodium percentage

The percentage of exchangeable sodium ions to the total exchangeable soil **cations** in a soil is called exchangeable sodium percentage (**ESP**). It is the degree of saturation of soil exchange complex with sodium.

Exchange acidity ratio of litter

Exchange acidity ratio of litter is given by the ratio of exchange acidity of humus to that of the top horizon.

Excreta

Excreta is another term used for **feces** or **dung**.

Expanding lattice clays

Sticky swelling clays are referred to as 2:1 type or expanding lattice clays. The ratio 2:1 shows the number of silica sheets per alumina sheet per clay layer. Water penetrates between the layers and makes each clay particle swell. **Montmorillonite** and smectite are the examples of expanding lattice clays.

Extensibility index

Extensibility index is the relative increase in the volume of a clayey material following hydration. A clayey soil may, under certain conditions, increase its volume by half. For example, the montmorillonite in vertisols have an index of 35, which means the volume increase is 35 percent.

Extensive farming

Extensive farming is a method of farming in which large stretches of land are used to raise livestock and produce crops, the yields usually being below average compared to those from intensive farming. In extensive farming, external inputs are applied at a minimum. In intensive farming, crop yields are raised through increased (a) mechanization (b) inputs of labor, (c) use of nutrients, (d) protection against pests, and (e) irrigation. The difference between the intensive and extensive systems is one of economy rather than principle, the preferred system being guided by the local conditions.

External coating of granular fertilizer

External coating of a fertilizer involves applying a thin layer of powder or surfactant to the surface of the granules. Granular coating helps reduce the caking tendency of a fertilizer. Coating agents such as kieselguhr, talcum, kaolin, waxes and fatty amines are commonly used. These are called **external conditioners**.

External coating is also called **external conditioning** or **surface treatment** of a fertilizer.

External conditioners: See External coating of granular fertilizer

External conditioning: See External coating of granular fertilizer

External respiration

The exchange of oxygen and carbon dioxide between body tissues and the environment is called an external respiration.

Extraction

Extraction is the process of separation of a desired constituent from a mixture by selective solubility in a suitable solvent. For example, oil is extracted from groundnut or dried coconuts by solvents like hexane - the process being named as **solvent extraction. Leaching** involves the extraction of soluble constituents from a solid mixture by downward movement with a percolating solvent. Leaching is closely related to solvent extraction, in which a soluble substance is extracted from one liquid by another immiscible liquid. Both leaching and solvent extraction are often called extraction.

Exudate

Exudate is a material that passes from within a plant structure to the outer surface or into the surrounding medium, usually by diffusion (and not through an aperture), as in **root exudates**, leaf exudates, etc.

Exudations

Exudations are secretions or modified excretory products from epidermal glands. They are such substances as oil (from oil beetles), wax (from bees), silk (from caterpillars), nutrient or sugary secretions (from termite and aphids), or scents to attract other insects (from butterflies), unpleasant scents and irritant fluids to ward off undesirable organisms and for self-defense (from earwigs, sting bugs, bed bugs, caterpillars, etc.). Some of these substances exude through pores in the cuticle; others are discharged from special openings or tubes, as wax in greenfly and whitefly.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

F

FA

FA is short for **fulvic acid**. It is a component of soil humus, the other two being **humic acid (HA)** and **humin**. When soil organic matter is extracted with an alkali to study its components, the fulvic acid fraction gets separated. (See also Fulvic acid.)

Facultative anaerobes

Facultative anaerobes are micro-organisms which can grow either in the absence or presence of oxygen.

Facultative bacteria

Facultative bacteria are those which utilize atmospheric oxygen but can also function in an **anaerobic condition**, as found in waterlogged or poorly drained soils.

Facultative parasite

A facultative parasite is an organism that can live either on organic matter from dead or decaying tissues of plants or animals (as saprophyte) or as a parasite on a live host.

Fallow crop: See Fallow land

Fallowing

Fallowing is the technique of keeping land free of cultivation for a certain period, to restore its productivity through the accumulation of nutrients and moisture. In wheat growing areas with limited rainfall, Indian farmers use fallowing in the *kharif* season (wet season).

Fallow land

Fallow land is an area left unsown during a growing season. Such land is plowed and harrowed from time to time (to control weeds) but not cultivated. In this way, soil moisture is saved. The accumulation of water in soil, though very little, helps crops grow in the next season. Periodic plowing and harrowing help improve infiltration and restore soil fertility. Fallowing is advantageous in several ways, especially in rain-fed farming (Fig.F.1).

A fallow crop or **cleaning crop** refers to crops like potato or turnip grown in well-spaced rows, such that weeds between the rows can be controlled by hoeing and cultivating.

False fruit: See Fruit

Family, soil: See Soil taxonomy

FAO guidelines for irrigation water

The FAO (Food and Agricultural Organization) has established guidelines for the quality of irrigation water, which consider the following factors to determine the suitability of any particular water for irrigation: (a) chemical composition of water, (b) crops to be irrigated, (c) soils to be irrigated, (d) management practices for irrigation and drainage, and (e) climate. The interaction of all these factors can lead to the modification of irrigation water for its successful utilization.

Farm

A farm is an area of land used for growing crops and for rearing animals (Fig.F.2). A person who runs a farm or cultivates it, is called a **farmer**. Any service building like a tool shed or poultry shed located on a farm is known as a **farm building**.

Farm building: See Farm

Farm bureau: See Farm service center

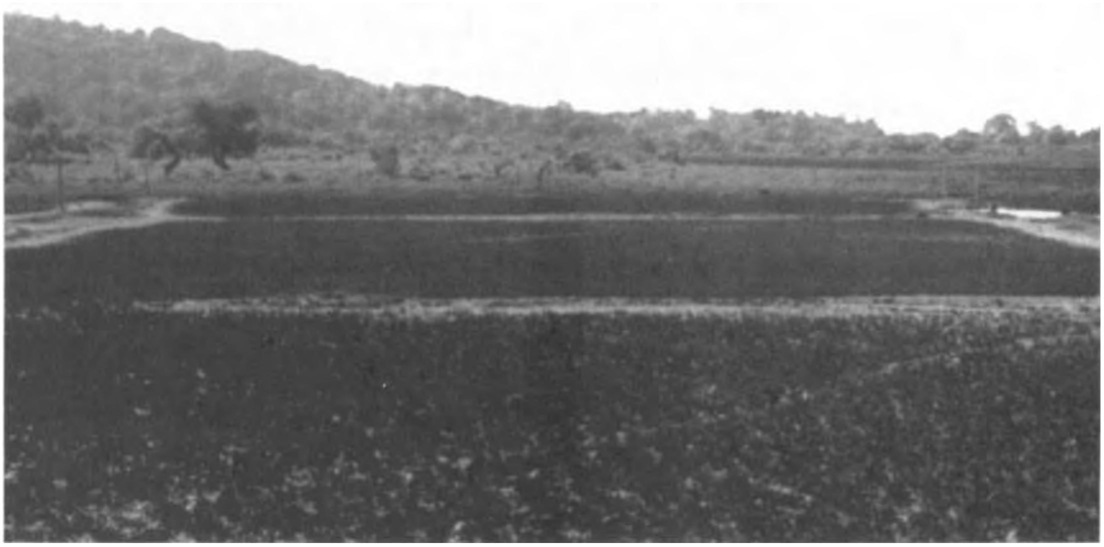


Fig.F.1: Fallow land is left unsown during a growing season and is advantageous in rain-fed farming.

Fig.F.2: A typical farm showing vegetable cultivation, perennials, a greenhouse and a farm building.

Farmer

A farmer is a person who runs a farm or cultivates it. A **farm laborer** is a person employed by the farm operator for assistance in farm operations.

Farm forestry

Farm forestry is another term for **agroforestry**.

Farm laborer: See Farmer

Farm service center

A farm service center or an **agro-service center** is a place where information on farm inputs like seeds, fertilizers, pesticides, agricultural implements and other services is available. A **farm bureau** is an organization of farmers and others interested in agriculture, rural life and agricultural improvement.

Farmyard manure

Farmyard manure (**FYM**) refers to the decomposed mixture of organic matter consisting of the dung and urine of farm animals, and litter and left-over material from roughage or fodder. It is a two-component mixture of solid and liquid in the ratio of 3:1. The solid portion is made up of dung and straw. The dung portion of FYM contains 0.55% nitrogen, 0.40% phosphorus and 0.30% potassium while the urine portion contains 1.02% nitrogen, traces of phosphorus and 1.3% potassium. The mixture is also called **long dung**.

Farmyard manure is usually stored in heaps where bacterial activity releases ammonia and the material degrades into a simpler liquid called **short dung**. All crops do not respond to these manures in the same measure. Crops like potato, tomato, sweet potato, watermelon, radish, carrot, cauliflower, onion, garlic, sugar cane, rice, jute, orange, banana, grape, apple, guava, mango, etc. respond to FYM very well. In contrast, cereals like sorghum, pearl millet, wheat, foxtail millet, finger millet, barley, oats, oilseeds like groundnut, linseed, sesame, castor, coconut, and cash crops like cotton are less responsive to FYM.

Farmyard manure improves the physical properties of soil by increasing its humus content and water holding capacity. FYM also improves clayey soils. The organic matter and the carbonic acid produced flocculates heavy soils, thereby enabling them to absorb rainwater more easily.

On average, farmyard manure contains 0.5% nitrogen, 0.2% phosphorus (as P_2O_5), and 0.5% potassium (as K_2O). Thus, an average dressing of 25 tons of farmyard manure per hectare supplies about 45 kg nitrogen, 18 kg phosphorus (as P_2O_5) and 45 kg potassium (as K_2O). However, the first crop only partially uses the nutrients; the subsequent crop utilizes the remaining. Generally, 30% of nitrogen, 30% of phosphorus and 50% of the potassium contained in the manure are recoverable by plants.

The manure value of fresh poultry droppings is twice that of FYM, as poultry droppings are richer in phosphorus and potassium. In addition, micro-organisms decompose uric acid in fresh droppings and give ammonia. However, this ammonia is easily lost. The evolution of ammonia can be controlled by adding one ton of quickly dried fresh poultry droppings to 50 kg of superphosphate.

For centuries, farmers have been using farmyard manure as a fertilizer. The amount and quality of dung produced by different animals depend upon the animal's age and the fodder consumed. However, even in a country with significant animal population, all the dung and urine may not be converted into manure. Sometimes half of it is converted into fuel cakes (Fig.F.3). As animals are not always kept in confinement, some of the excreta are lost during grazing. If the stable-floors are not

Fig.F.3: Pile of dried dung cakes.

cemented, animal urine is absorbed by the soil and much of the excreta are lost by leaching in the rain. Nitrogen from the dung and urine is lost by exposure to the sun. Ammonia formed during the rotting of the farmyard manure is lost to the atmosphere.

New environmental laws have generated renewed interest and awareness in the old practice of adding animal manure to cultivated soils.

Biomull is the organic manure derived from the kitchen midden and transformed into compost.

Fast-growing *Rhizobium* bacteria

Rhizobium is an example of Gram-negative bacteria. Gram-negative bacteria are bacteria which lose the initial color of the Gram stain and then take on the light pink color of the final stain. Rhizobia demonstrate two different growth patterns. The first one is fast growing and the other, slow growing.

The fast-growing strains of rhizobia utilize the Entner-Meyerhoff-Parnas pathway. They are capable of catabolizing glucose, galactose, sucrose, trehalose and dulcitol, and produce acid on the medium (yeast manitol agar). These strains have the genes for nodulation and nitrogen fixation on large plasmids that are larger than the entire chromosomes of other bacteria. Some examples of strains are **clover rhizobia**, **pea rhizobia**, **medic rhizobia** and **bean rhizobia**. The names indicate the specific group of legume that they inoculate. These are generally characterized by a much slower uptake of both ketoglutaric acid and glutamic acid in the medium.

The fast-growing variety doubles every 2 to 4 hours.

Fats and oils

Fats and oils are **glyceryl esters** or **glycerides** of higher fatty acids. Substances that, at normal body temperatures, are liquids or solids are called oils or fats respectively. Oils have a larger proportion of unsaturated fatty acids than fats do. Fats and oils, being triesters, are commonly called **triglycerides** or simply glycerides.

Fats are esters of carboxylic acids (such as stearic and palmitic acids) with glycerol, which are produced by animals and plants from natural storage material. Such esters and their mixtures exhibit a crystalline structure at room temperature. Lard and tallow are examples.

Fats are insoluble in water. They are the most concentrated sources of energy in human diet and give more than twice the energy provided by starches. Diets having high fat levels are proven to be unhealthy to human beings.

Fats and oils, particularly of fish and plant origins, are commercially important; cottonseed, rapeseed, coconut, soybean, sunflower, palm and peanut oils, olive and fish oils, etc. are examples.

Oils and fats may be of animal, vegetable or plant origin. For example, whale oil, tallow, butterfat and ghee are of animal origin. Linseed oil and coconut oil are examples of a vegetable origin. The plant sources of oils and fats are nuts or seeds. Nearly all terrestrial animal fats are from adipose tissue. Fats differ from mineral oils (like kerosene) and essential oils (e.g., clove oil and lemon grass oil).

Physical and chemical properties of oils and fats depend on the type of fatty acids present in the glycerides. Two or even three different acids are esterified for each glycerol molecule. While most fats and oils are based on C_{16} and C_{18} acids, with 0 to 3 double bonds, there are exceptions like coconut oil which is rich in short chain acids.

Fats and oils have a calorific value twice as high as of carbohydrates and they store this energy in plants and animals. Fats and oils in soils, however, hamper water infiltration.

Fatty acid

Fatty acid is a carboxylic acid derived from or contained in an animal or vegetable oil or fat. All fatty acids contain groups with usually 4 to 22 carbon atoms with carboxyl terminals. The generic formula for all acids is $CH_3(CH_2)_n\,COOH$. Fatty acids, which may be saturated or unsaturated, exist as solids, liquids or semisolids.

A saturated fatty acid contains carbon atoms of alkyl groups which are connected by single bonds. The important ones are butyric (C_4), lauric (C_{12}), palmitic (C_{10}) and stearic (C_{18}) acids. They have a number of uses. Stearic acid is primarily used as a dispersing agent and an accelerator in rubber products and soaps.

An unsaturated fatty acid is one in which one or more double bonds between the carbon atoms are in the alkyl chain. These acids are usually of vegetable origin and consist of alkyl chains containing 18 or more carbon atoms with a characteristic end of a carboxyl (COOH) group.

Most vegetable oils are mixtures of several fatty acids or their glycerides. The most common unsaturated acids are oleic, linoleic and linolenic (all C_{18}). Safflower oil has around 60 to 80% linoleic acid, peanut oil contains 21% linoleic acid and olive oil is 83% oleic acid. Palmitoleic acid is abundant in fish oils.

Fauna

Fauna is the animal life distributed over a particular region, habitat or geological period. All soil-inhabiting animals, whether large or small, together constitute fauna (Fig.F.4). **Microfauna** are microscopic animals living in a microhabitat. **Protozoa** and **nematodes** are examples of microfauna. Soil fauna such as earthworms, anthropods, mites, centipedes and millipedes have a significant effect on the structural and functional properties of soil.

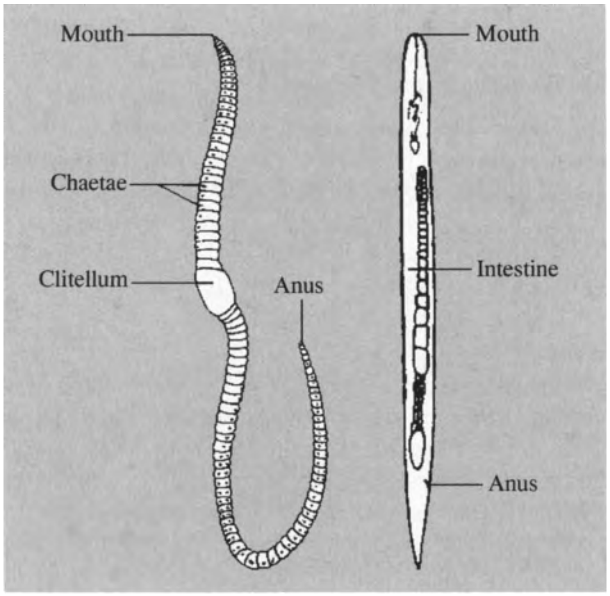


Fig.F.4: Organisms like earthworms (left) and nematodes contribute to soil fauna and microfauna, respectively.

Feather meal

Feather meal is a fertilizer made up of feathers. It is a slow nitrogen-releasing fertilizer with a nitrogen content of around 13%.

Feces

Feces or **excreta** are solid wastes or undigested material expelled by animals and human beings. **Dung** refers specifically to the solid excreta of bovines and equines. Feces contain bacteria and dead cells and have a manure value.

More than 50% of the organic matter in feces is in the form of complex products, consisting of lignin and protein. This organic matter is resistant to further decay and thus the nutrients in it are liberated slowly. On a dry weight basis, the N, P and K percentages in feces are 1.57, 0.56 and 1.05, respectively.

Fe-EDDHA

Fe-EDDHA is an iron chelate of ethylenediamine di-o-hydroxyphenylacetic acid (**EDDHA**). It is commonly used as an iron fertilizer because of its affinity to iron.

Feed-grade urea

Feed-grade urea is sometimes referred to by the number 262 which is arrived at by multiplying its nitrogen content (42%) by 6.25, the latter being the conversion factor used by chemists to convert nitrogen content to its protein equivalent.

Feekes' scale

The development and growth of cereal grains, especially of wheat, has always been a subject of interest to agriculturists. A study of these aspects is crucial to the proper management of crops. Several growth stages have been identified, quantified and converted into scales for wider use. Some scales have evolved, namely the Feekes', Zadoks' and Haun scales. Feekes' scale is the most widely used numerical staging scale.

Feekes' scale is classified into four major stages, namely tillering, stem extension, heading and ripening. This scale has eleven stages to describe the changes in a plant's physical form. The scale tracks development of the cereal plant from the first-leaf stage up to the grain-ripening stage. For example, the one shoot stage is the first stage. The beginning of tillering is the second stage. The period when tillers are formed is the third stage. The tenth stage, called the heading, is subdivided into five sub-divisions. The eleventh stage is the flowering stage which is also subdivided, for further study.

The knowledge of precise growth stages of wheat is crucial for effective fertilization, herbicide programes and other procedures.

Feel method for determination of soil texture

The feel method is a rough and quick method to determine the *in-situ* texture of the soil.

Feldspars

Feldspars, a group of silicate materials, are the most abundant minerals in the earth's crust. Feldspars have a structure in which (SiAl)O_4 tetrahedral is linked together with potassium, sodium and calcium. Occasionally, barium ions also occupy large spaces in the same framework. Commercially, feldspar usually refers to potassium feldspar with the formula $KAlSi_3O_8$. This feldspar has little sodium.

The chemical composition of feldspars may be expressed as combinations of (a) anorthite ($CaAl_2Si_2O_8$), (b) albite ($NaAlSi_3O_8$), (c) orthoclase ($KAlSi_3O_8$), and (d) celcian ($BaAl_2Si_2O_8$).

Feldspars form colorless, white or pink crystals with a hardness of 6 on the Mho's scale. They are used in pottery, cement and concrete, insulating compositions, fertilizers and glass.

Feldspars are subdivided into two groups. One of them is **alkali feldspar** (including microcline, orthoclase and sanidine) which has a significant amount of potassium, a smaller proportion of sodium and negligible calcium. The other group, namely **plagioclase feldspar**, varies in composition from pure sodium feldspar (albite) to pure calcium feldspar (anorthite) with negligible amounts of potassium.

Fenland rotation

Fenland rotation is a kind of crop rotation system that follows a three-course system and includes root crops, peas, celery, bulbs, etc.

Fen: See Fen peat

Fen peat

Fen peat is the **peat** that develops in low and marshy area of land called fens. Fen peat has an alkaline to slightly acidic character. Fens were at one time low lying extensive areas in eastern England and were the largest swamplands in England. These areas were collectively called Fenland. With modern drainage systems, these lands have now been brought under intensive cultivation.

Fermentation

Fermentation is a process in which a chemical change is induced by organisms like bacteria, yeasts or fungi, or by the enzymes produced by them. The fermentation process involves (a) breaking down of organic substances by the action of organisms, and (b) evolution of heat and gases such as carbon dioxide. During fermentation, organic matter is decomposed in the absence of air (oxygen) and hence there is always accumulation of the reduction products or products of incomplete oxidation. The period for fermentation may vary depending on the temperature. The cooler the temperature, the longer the time required for fermentation.

The making of wine, vinegar, etc. is possible because of fermentation. Alcoholic fermentation comprises a series of biochemical reactions by which pyruvate is converted into ethanol and carbon dioxide.

$$C_6H_{12}O_6 \xrightarrow[\text{Enzyme}]{\text{Catalyst}} 2C_2H_5OH + 2CO_2$$

Several fermentation products are of great importance to human beings, and hence, the process of fermentation is carried out on a large scale.

Many microbiological processes involving fermentation occur in the presence of air and yield incomplete oxidation products, like acetic acid from alcohol, and citric acid from sugar. These processes are used industrially.

Micro-organisms like fungi, bacteria and actinomycetes produce antibiotics. The activated sludge process for sewage digestion is a form of fermentation. Edible protein can be produced from petroleum by a continuous fermentation process. Fermentation is also used for producing synthetic amino acids.

Fermenter

A fermenter is a large vessel in which physical parameters such as pH, temperature, dissolved oxygen concentration and substrate concentration can be adjusted to create optimum conditions for the growth of micro-organisms. Thus, it is an important equipment used for the production of ***Rhizobium, Azotobacter, Azospirillum*** and several other important micro-organisms. It is also used for the production of by-products of the fermentation process, which are the basis of activities like baking and wine and beer making.

For any fermenter, the basic requirements are an air inlet port, an air outlet port and an inoculation port. Fermenters are available in different sizes. For a batch of 5 to 10 liters, a glass fermenter with a compressor for aeration is suitable. An autoclavable polycarbonate bottle is used for a 30 to 50 liter batch whereas metal fermenters (Fig.F.5) are employed for 50 to 100 liter batches. There are medium sized fermenters for 100 liters and large ones for 1000 liters. Industrial fermenters have a device to separate the steam supply for sterilization *in situ*.

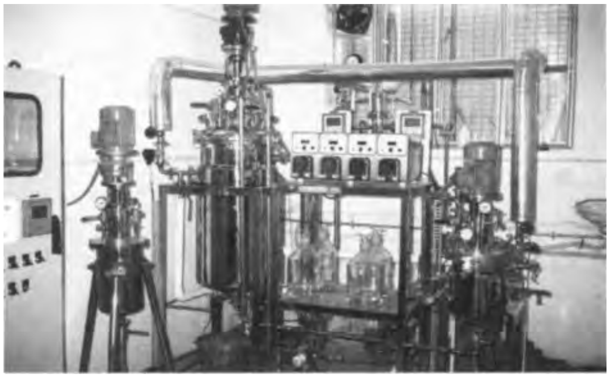


Fig.F.5: A fermenter unit for large scale production of micro-organisms like fungi or bacteria.

A fermenter for *Rhizobium* production must have a container made of stainless steel (SS) as it is non-toxic to bacteria. It must also have an accurate thermal control system, a pressure gauge and a safety valve. It should withstand direct heating and internal steam pressures in excess of 2 kg/cm². Sterile air is supplied for aerating the medium and supplying oxygen to the rhizobia. The fermenter is provided with appropriate facilities for regulating aeration (like an air exhaust tube) and for removing the broth culture.

Fern leaf, potato

Fern leaf refers to the zinc deficiency symptoms in potato.

Ferro phosphorus

Ferro phosphorus is an alloy of iron and phosphorus. It is produced in two grades – with 18% phosphorus and 25% phosphorus. It is used in the steel industry for adjusting the phosphorus content of special steels, and for preventing the thin sheets from sticking when rolled and annealed in bundles.

Ferrous sulphate

Ferrous sulphate heptahydrate ($FeSO_4 \cdot 7H_2O$), also called **green vitriol** or **copperas**, is a blue-green water-soluble crystal and is the best known ferrous salt. It is obtained by the action of dilute sulphuric acid on iron in a reducing atmosphere. The anhydrous compound is very hygroscopic. It gets oxidized gradually in an aqueous solution. On heating, the solid decomposes to give red ferric oxide, sulphur trioxide (SO_3) and sulphur dioxide (SO_2).

Ferrous sulphate contains about 19% iron and is used as a fertilizer. Iron deficiencies in plants are corrected mainly by foliar applications of an iron salt, generally 2% ferrous sulphate. Such foliar applications are repeated 2 to 3 times if the deficiency is severe.

Ferrous sulphate solution of 1 to 2% concentration is used to correct iron deficiency in orchards. Apart from ferrous sulphate, the most widely used iron source in a fertilizer is a synthetic chelate like **Fe-EDDHA**. (See also Iron.)

Ferrous sulphate heptahydrate

Ferrous sulphate heptahydrate ($FeSO_4 \cdot 7H_2O$), also known as **green vitriol**, contains 19% iron and is a common iron fertilizer.

Fertigation

Fertigation is a method of applying fertilizers through irrigation water. It is a part of **chemigation**, and is carried out in open ditches, sprinklers, splitters, etc. (Fig.F.6). It can supply nutrients to crops at the most beneficial time.

Fig.F.6: 1. Fertigation through sprinklers and drip irrigation. 2. Balanced fertilization in polyhouses.

Fertigation is usually resorted to when a higher dosage of fertilizer is required. The process is most effective in sands and sandy soils, although nutrient retention is low in such soils. Fertigation is useful for mobile nutrients like nitrate and sulphate. In sands, nutrients like potassium, magnesium and boron also become mobile. Fertigation is an economical way of dispersing nutrients in deserts where irrigation is indispensable.

But it cannot always replace the old techniques of fertilizer application like band placement and broadcasting. A well-spread water supply facilitates a uniform distribution of fertilizers. However, fertigation is not as beneficial if the supply system is poorly designed, or there is too much of wind leading to an uneven water supply.

Fertigation by a sprinkler system can cause leaf salt burn, especially if saline water is used and there is rapid evaporation between the wetting cycles.

Nitrogen and sulphur via urea and ammonium sulphate are the principal nutrients applied through fertigation. Phosphorus fertigation is less common because of its possible precipitation in high calcium or magnesium waters. Sulphur application is generally done by sprinkler irrigation. The application of nutrients through irrigation water is generally uniform for soluble nutrients.

In order to prevent nutrients from leaching beyond the crop root zone, or from accumulating near the soil surface and making them inaccessible to the crop, they should be introduced toward the middle of the irrigation period and the supply terminated shortly before the completion of irrigation.

The following are the advantages of fertigation: (i) Nutrients can be applied at the time of maximum need. (ii) Field operations are reduced. (iii) There is saving of labor. For instance, corn needs application of nitrogen twice which can be provided by fertigation with less labor. The efficiency of nitrogen application by fertigation method is around 95% while that of potassium is about 80% and of phosphorus around 45%. (See also Chemigation; Liquid fertilizers.)

Fertile land

A fertile land or fertile soil is land that is rich in nutrients and capable of producing good crops (Fig.F.7). The

Fig.F.7: A fertile land produces a healthy crop.

quality of the soil to provide essential nutrients in a balanced manner to the crop is called fertility. Fertility of soil is influenced by important factors like humidity, temperature, physical conditions and acidity. Non-fertile land is called a **sterile land**.

Fertile soil material is also known as **topsoil** or soil layer moved in cultivation. It is that part of soil which contains nutrients in appropriate amount for the growth of plants when other factors such as light, temperature, humidity, etc. are favorable. It is used for top dressing gardens.

The term fertile is also used for plants or animals that are able to reproduce successfully.

Fertile soil material: See Fertile land

Fertility index

Fertility index expresses the relative sufficiency as a percentage of the amount of nutrients adequate for optimum yields. The lower the fertility index, the higher the crop response to fertilization.

Fertility, numerical estimation of

Storie's classification for numerical estimation of fertility (NF) is evaluated as:

$$NF = a\,b\,c\,x$$

where a is the profile character of the soil, b is the grain size distribution of the surface soil and c is the slope of the soil - all three parameters being in comparison with a maximum value of 100 for NF; x covers miscellaneous factors such as drainage, chemical reaction, erodibility, etc.

Storie considered the productivity of the land to be dependent on 32 properties concerning soil, climate and vegetation. To avoid unwieldiness, only nine properties are used in evaluating the **Storie Index Rating of fertility (SIR)**. The nine factors are soil morphology (A), surface texture (B), slope (C) and six variables (X_i) - the drainage class, sodicity, acidity, erosion, micro relief and fertility, rated from 1 to 100%. These are converted into their decimal values and multiplied :

$$SIR = \left[ABC \overset{i=6}{\underset{i=1}{\pi}} X_i\right] \times 100$$

Poor soil, average soil and **good soil** are represented by the NF values of 10, 50 and 70, respectively. Soils that are deep, have no restricting subsoil horizons, and hold water well, have the greatest potential for the widest range of crops.

The fertility of an area is estimated by multiplying the SIR index of each part of land by its area. (See also Storie index rating of fertilizers.)

Fertilization

The enrichment of soil by organic or chemical fertilizers is called fertilization. Fertilization increases and maintains land productivity.

Fertilization also means the formation of zygote during the process of sexual reproduction or the union of male and female reproductive cells. Fertilization can be **self-fertilization** or **autogamy** as found in wheat (Fig.F.8) and oats, or **cross-fertilization** or **allogamy** as found in rye, sorghum, triticale and pearl millet.

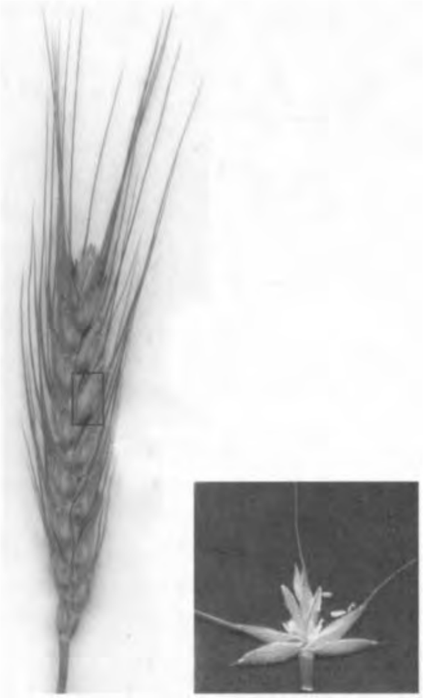


Fig.F.8: Picture of wheat panicle. (Inset) close-up view of spikelet containing male and female reproductive organs for autogamy in wheat.

Fertilizer

Any natural or manufactured solid or liquid material, added to the soil to supply one or more nutrients essential for the proper development and growth of a plant is called a fertilizer. Fertilizers, in the broadest sense, are products that improve the levels of the available plant nutrients and/or the chemical and physical properties of the soil, thereby directly or indirectly enhancing the growth, yield and quality of the plant. The term is generally applied to commercially manufactured materials other than lime or gypsum.

Fertilizers sold on a large scale are called **commercial fertilizers**. They have a specific ratio of nutrients, known as **fertilizer ratio**, also called plant food ratio. The fertilizer ratio is the ratio of the number of fertilizer units in a given mass of fertilizer expressed in the order N, P and K. Thus, it is the ratio of two or more nutrient percentages to one another (Fig.F.9). For instance, a fertilizer with a 5-10-15 grade has a 1-2-3 ratio, whereas a fertilizer with a 10-20-20 grade has a 1-2-2 ratio. Fertilizer ratio is also defined as the relative proportion of primary nutrients in a fertilizer grade divided by the highest common denominator for the grade. For example, the grade 20-12-8 has a ratio of 5-3-2 of N, P and K, respectively.

Based on their chemical composition, fertilizers are classified as (a) mineral fertilizers containing inorganic

Fig.F.9: A fertilizer of grade 8:8:6 for lawn and garden.

or synthetically produced organic compounds, (b) organic products that are produced out of wastes of animal husbandry (stable manure, slurry manure, etc.), plant decomposition products (compost, peat, etc.), or products from waste treatment (composted garbage, sewage sludge, etc.), and (c) synthetic soil conditioners whose main function is to improve the physical properties of the soil.

Based on their nutrient content, fertilizers are classified as (a) **straight fertilizers**, generally containing one primary nutrient, (b) **compound** or **complex** or multinutrient fertilizers, containing several primary nutrients and sometimes micronutrients, and (c) **micronutrient** fertilizers, containing nutrients required in small quantities by plants.

Finally, fertilizers can be classified as solid or **liquid fertilizers** and as soil or foliar fertilizers. Solid fertilizers come in bags as shown in Fig.F.10, while liquid fertilizers (used for spraying on an existing plant population) are sold in containers as shown in Fig.F.11.

There are five types of manufactured chemical fertilizers consumed on a large scale, especially in developing countries. These types are nitrogenous, phosphatic, potassic, complex or those supplying more than one major plant nutrient, and **fertilizer mixtures**.

Fig.F.10: A water-soluble fertilizer of grade 19:19:19 for foliar application.

Fig.F.11: A liquid fertilizer, used as plant tonic.

Natural materials like manures and other organic materials are also used as fertilizers and are called **bulky organic manures**. These have to be used in bulk, with appropriate precautions to prevent the spread of diseases among plants. **Biofertilizers** are materials of biological origin that are sold as fertilizers. These are commercially reared micro-organisms that fix nitrogen or solubilize phosphorus and are multiplied under special conditions. While biofertilizers are economical and ecologically safe, they supply only two nutrients (nitrogen and phosphorus), and are usually used as a supplement to chemical fertilizers.

Nutritional or fertilizer requirements vary with the crop and the soil composition. Ideal doses of fertilizers are available for a number of agriculturally important crop plants.

Fertilizer requirement can be defined as the quantity of additional nutrients required by a particular crop to increase its growth to the optimal level in a given soil.

Fertilizer benefits to the human environment

The misuse or overuse of fertilizers cannot be held against their use. Following are a few, generally accepted positive contributions of fertilizers:

(i) Farming efficiency improvement: The farmer's income can be increased by the application of fertilizers. If the use of economic optimum levels of fertilizer is consistent, negative consequences are minimized.

(ii) Improvement of soil quality with adequate fertilization: The aggregating action from enhanced root proliferation and a greater amount of decaying residues have reportedly made the soil more friable, tillable and water retentive.

(iii) Crop quality improvement: The mineral, protein and vitamin contents of crops can be improved by balanced fertilization.

(iv) Water conservation: Plants, well nourished by fertilizers, use water efficiently through their expanded root system, thereby reducing water evaporation losses, and conserving this natural resource.

Efficient fertilizer use is the key to sustained productivity. A well-fertilized soil gives a dense canopy, which protects the soil from erosion, absorbs more carbon dioxide and gives out more oxygen. Future agricultural strategies should aim at minimizing leaching, erosion, volatilization losses of chemical fertilizers and organic manures, and prevention of over-fertilization.

Fertilizer burn

When concentrated amounts of a soluble salt come in contact with plant roots or germinating seeds, the salt causes injury to plant parts. This is called fertilizer burn. This happens through a process known as **plasmolysis**, resulting in limited moisture availability and toxicity.

Fertilizer, carryover effect of

A carryover effect or **residual effect of fertilizer** refers to the continuing action of a fertilizer (or manure) in providing nutrients to the plant, in one or more seasons after its application.

Fertilizer conditioner

A fertilizer conditioner is the material added to a fertilizer for maintaining its free flow. The use of conditioners is essential to avoid caking during storage, transportation and field applications, essentially when good drying is either uneconomical or ineffective.

Caking or **hardening** of a fertilizer results from the crystallization of water-soluble salts and the formation of bridges between granular surfaces during storage. The surface also suffers plastic deformation under pressure and undergoes reduction in water vapor pressure between the new contact surfaces, which causes the particles to adhere to one another. The following reaction during storage may also affect storage qualities:

$$NH_4NO_3 + KCl \longrightarrow NH_4Cl + KNO_3$$

Internal conditioning of a fertilizer involves the incorporation of additives before or during granulation to improve its physical and anti-caking properties. An internal conditioner usually acts as a hardener or as a crystal modifier to improve storage properties, for instance, of ammonium nitrate fertilizers.

Internal conditioners inhibit or modify the effects of crystal phase inversions caused by temperature changes during storage. For example, inversion at 32°C can cause uninhibited ammonium nitrate granules and prills to shatter and cake. In the case of urea prills and granules, 0.2 to 0.5% of formaldehyde or urea-formaldehyde is added to the urea-melt as a hardener and anti-caking agent. Adding 1.8% magnesium nitrate protects ammonium nitrate from caking and the destructive phase change effects at 32°C.

External conditioning, or **coating** or **surface treatment** of a fertilizer granule involves applying a thin layer of powders or surfactants to the granule surface to reduce the caking tendency of the fertilizer. Adding wax and/or oil in a rotating drum or a fluid bed enhances anti-caking action by suppressing dust formation. Coating with a fine, inert powder (like kieselguhr, talc, lime or kaolin) is a long standing practice as an external form (inorganic) of conditioning. The practice of surface treatment with surfactants (fatty acids and sulphonates) and the use of non-ionic organic sealants (like polythene waxes, paraffins or urea-aldehyde resins) to make the fertilizer surface hydrophobic are also common.

The **intentional aging of the fertilizer** in a storage pile prior to bagging or shipping is referred to as **fertilizer curing**. There are certain chemical reactions which cause caking or bonding and once these are completed, there is no further caking. During curing, chemical reactions that cause caking come to near completion. The heat of reaction retained in the curing pile speeds up completion of the reactions. Pile curing for 30 days is frequently resorted to in the manufacture of superphosphate to improve its physical properties.

Fertilizer-crop price ratio: See Marginal rate of return

Fertilizer curing: See Fertilizer conditioner

Fertilizer efficiency

Fertilizer efficiency or **response rate** indicates the increase in the crop output in response to a nutrient input, as determined by the plant root system, fertilizer-water interaction and fertilizer management techniques. From the standpoint of soil science, fertilizer efficiency is the percentage of applied nutrient recovered in the form of a crop. What matters is the value of the crop produced per unit of investment in fertilizers. (See also Response rate.)

Fertilizer formulation

Most solid fertilizers are mixtures of two or three of the following nutrients – nitrogen, phosphorus and potassium. Many of such fertilizer formulations also contain sulphur.

A fertilizer formulation contains five types of ingredients, namely (a) N, P_2O_5, K_2O and any other ingredient such as sulphur as sulphate, (b) conditioners to reduce caking, (c) acidity neutralizers, (d) fillers such as sand to make up the required weight to bring the nutrient percentage to the desired value, and (e) additional materials such as insecticides, pesticides, herbicides or speciality fertilizers like micronutrients.

Generally, a fertilizer formulation is designated by a set of numbers separated by a hyphen. These numbers represent the **fertilizer grade**. Each number indicates the amount of the nutrient guaranteed by the manufacturer to be present in the fertilizer if subjected to the standard analytical evaluation. The nutrient content is expressed as a percentage by weight of the nutrient per 100 kg of the fertilizer product.

Usually, three numbers are used to indicate the fertilizer grade. These sequentially refer to the content of the primary nutrients - nitrogen, phosphorus and potassium. If other nutrients are present, their content is also indicated along with their chemical symbols. Many countries indicate phosphorus and potassium not in the elemental form but in the oxide form, namely, phosphorus pentoxide (P_2O_5) and potassium oxide (K_2O).

A fertilizer with grade 18-46-0 contains:

18% N or 18 kg of N in every 100 kg fertilizer
46% P_2O_5 or 46 kg of P_2O_5 in every 100 kg fertilizer
0% K_2O or no K_2O in the fertilizer

A fertilizer product with a grade 12-6-22-2 MgO is guaranteed to contain:

12% N or 12 kg of N in every 100 kg fertilizer
6% P_2O_5 or 6 kg of P_2O_5 in every 100 kg fertilizer
22% K_2O or 22 kg of K_2O in every 100 kg fertilizer
2% MgO or 2 kg of MgO in every 100 kg fertilizer

The grade confirms that the consumer is purchasing a specific combination of nutrients. For example, a single superphosphate may be known by different trade names but the commercial product always assures that its P_2O_5 content ranges from 14 to 20%.

Phosphorus containing fertilizers mostly contain phosphates and are, therefore, commonly known as phosphates.

Fertilizer grade

A set of numbers separated by hyphens that represent a fertilizer formulation is designated its fertilizer grade. The grade tells the user what nutrient content is available in the product, in terms of percentages of nitrogen, phosphorus (as P_2O_5) and potassium (as K_2O) in that order.

The fertilizer grade 27-3-9 contains 27% nitrogen (N), 3% phosphorus pentoxide (P_2O_5) and 9% potassium oxide (K_2O). Most nitrogen and potassium are water-soluble. Phosphorus must be sufficiently soluble in neutral ammonium citrate. Comparison between fertilizers can be made only on the basis of their nutrient content, not according to the kinds of compounds in the fertilizer.

Fertilizer granulation

A fertilizer in a powdered or finely divided state readily cakes during storage. Since caking is less in granules because of their lower surface area, it is advantageous to use fertilizers in a granular or pelletized form.

A fertilizer in the form of particles between the two screen sizes of 1 and 5 mm is called a **granular fertilizer**. Such fertilizers produce less dust and lead to smaller product losses.

Fertilizers in granular form facilitate their uniform spreading over the soil when appropriate field equipment is used. The granules produced from various feed-stocks (solids, slurries, and melts) do not segregate, which is an advantage.

Fertilizer granulation is considered a significant advance in fertilizer technology and provides considerable advantages to both the manufacturer and the user. Today, granulation size is a part of fertilizer specifications. A granular fertilizer requires lesser storage space because of its greater bulk density and can be stored and transported more economically than its powdered form.

The granules must disintegrate completely for the nutrients to reach the plant roots. Because of their longer disintegration time, granular fertilizers take longer to reach the plant than powdered fertilizers do, which reduces leaching losses. In the case of some controlled-release fertilizers, the larger granules release nitrogen more slowly. Field studies in some Swedish soils have shown that a granular superphosphate with a grain diameter of 1 to 3.5 mm is twice as effective as the finely divided fertilizer because the granular form retards phosphate fixation in the soil. However, in the case of mineral fertilizers (N, NK, and NMg fertilizers) which do not contain P_2O_5, the grain size does not affect nutrient release significantly.

The most important types of equipment for fertilizer granulation are: (a) pug-mill (blunger), (b) rotary drum, (c) spherodizer, (d) inclined pan granulator, (e) fluidised-bed granulator/dryer, (f) air-cooled prilling tower, (g) TVA ammoniator-granulator drum, and (h) SAI-R drum granulator. Some types are shown in Fig.F.12.

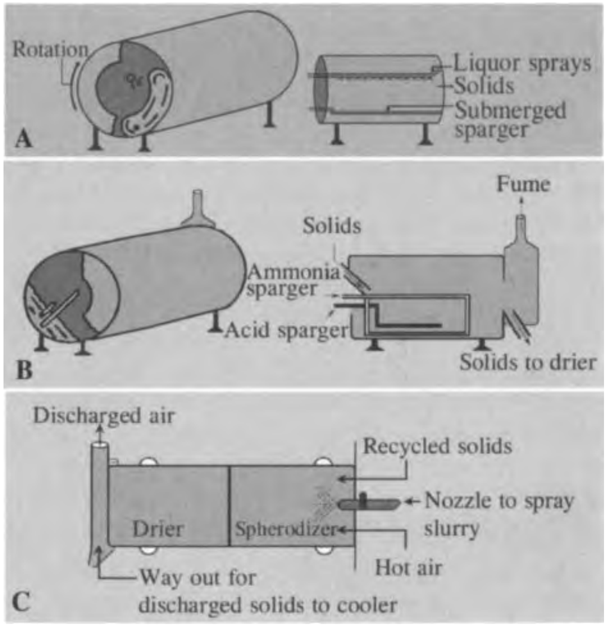


Fig.F.12: Schematic drawing of granulator drums. A. Rotary drum, B. TVA ammoniator drum, and C. Spherodizer.

The drum granulator is an inclined rotating type cylinder most widely used for fertilizers. The rotation speed is adjustable. An inclination of up to 10° from the horizontal usually ensures adequate movement of the product toward the discharge end. The current length to diameter ratio is ≥1 and may reach 6:1. The powdered feed material (mixed and wetted if necessary to provide the granule with the nuclei) can be granulated in the drum by water sprays, solutions, suspensions or highly concentrated slurries or by blowing steam. The volume of the feed is 20 to 30% of the cylinder capacity. The cylinder may be either open ended or fitted with ring clamps at the ends to prevent feed overflow, and to control the bed depth and the residence time. Fixed or movable scrapers inside the drum, or hammers or other rapping devices outside the drum are used to remove or reduce excessive product caking inside the drum.

The condition for granulation is that a bed of particles in the solid phase moves with intensive mixing in the presence of particles in the liquid phase. This facilitates the particles to collide and bond, enabling granules to form and grow.

There are many types and models of **granulation equipment**, most of which use one of the following basic intensive-mixing mechanisms: (a) rotation of one or more shafts carrying staggered paddles in a fixed trough (pug-mill, blunger), (b) rotating the whole device, such as a drum or pan, and (c) movement of particles by a third phase, as blown by air in a fluid-bed granulator. In slurry granulation, the third phase is usually hot air or gas which, apart from mixing, also does the drying. In this way, the two processing steps in the granulation loop can be carried out in a single apparatus. Fig.F.13 shows the flow sheet for granulating ammonium nitrate using a pug-mill.

The granulating devices used most often in the fertilizer industry are drums, pans and pug-mills. Although fluid bed granulation does also find use, mixer-granulators and compactors are more frequently employed to form fertilizer granules. Spray drying and extrusion processes are used only for specific fertilizer products.

For granulation of solids with water or aqueous solutions, a solid phase and a liquid phase or steam (as a granulation aid) are required. For each mixture, there is a percentage of the liquid phase at which the granulation efficiency is optimum.

Materials to be granulated can be in the form of slurry, usually derived from the reaction of sulphuric, nitric or phosphoric acid with ammonia or phosphate rock (or their combination). **Slurry granulation**, which is affected by various impurities, is controlled in the liquid-phase. Usually, a thin film of slurry having the fertilizer composition is sprayed onto small solid particles. The granules are built up in layers (layering process). The process is mainly controlled through the recycle and the water content of slurry (the recycle ratio may be 5:1 or more).

Slurry granulation is widely praticed in Europe for the production of N, NP and NPK fertilizers. Granulation with solutions or slurries is made in fluid-bed spray granulators or spray drying and spherodisers. Spherical agglomerates produced from the melt (urea and ammonium nitrate for example) are called **prills**. These are usually obtained by spraying a salt melt or a highly concentrated solution into the top of the tower. The melt has a very low viscosity, less than 5 centipoises, but a high surface tension at temperatures just a few degrees above the melting point. The prills can be removed with scrapers or belt conveyers, or can be in a fluid bed cooler located at the bottom end of the prilling tower. Multi-nutrient fertilizers have high melting points and are highly viscous.

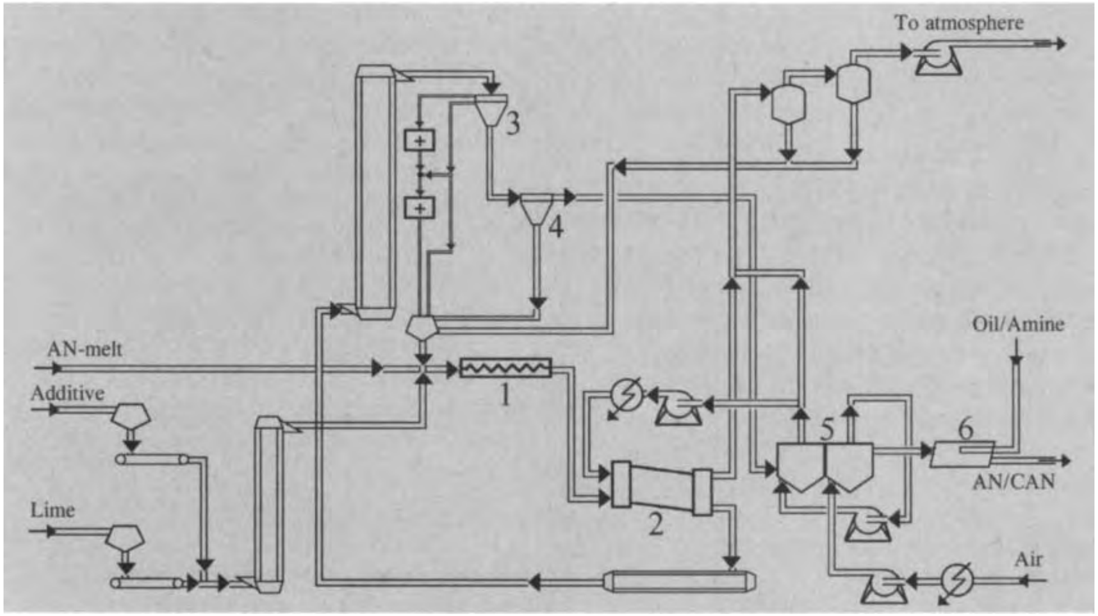


Fig.F.13: Granulation process. Pug-mill granulator used for granulating ammonium nitrate. 1. Pug-mill granulator, 2. Dryer, 3. and 4. Screens, 5. Fluid-bed cooler and 6. Conditioning drum. (Source: "Fertilizer Manual", 1998, UNIDO, IFDC and Kluwer Academic Publishers. With permission.)

As with the manufacture of ammoniated triple superphosphate, granulation can be coupled either with one of the production steps or it can be a separate step in the production process, as in the case of granulation in the nitro-phosphate process.

Granulation efficiency is defined as the mass fraction of the particulate material that leaves the granulator as a finished product with grain sizes in the prescribed range (assuming 100% sieve efficiency). Granulation efficiency is also defined as a mass fraction of the finished product at the dryer outlet (some regranulation in the dryer is allowed in this definition).

The mass ratio of the recycled material to the final product is often referred to as the **recycle ratio**. After neglecting other losses, a 20% granulation efficiency implies a recycle ratio of 4:1. Recycling is needed to generate nuclei for the granulation condition in the granulator and also because once the product passes through the granulator, some particles lie outside the desired grain-size spectrum (the off-size material) and have to be re-run through. For a given mixture and temperature, optimal granulation takes place only within a narrow range of the solid to liquid ratio. The quantity of the recycled fines depends not only on the chemical properties of the material but also on the water content of the slurry and on the granulation device.

The quality of the granules is influenced by the (a) type and fineness of the feedstock, (b) moisture content of the granules, (c) surface tension of the wetting liquid and amenability of the particles to wet, (d) type of motion in the granulator, (e) inclination and speed of the granulator, and (f) type and properties of the binder. The granulator feedstock can be aqueous solutions, slurries or melts.

Investment costs on the slurry granulation process are 33% higher than those on the granulation of solids; the operating and utility costs are also likewise larger.

Fertilizer guarantee: See Guarantee of fertilizers

Fertilizer legislation

Fertilizer legislation refers to the laws and regulations of the government designed to ensure that the consumer gets the promised quality of the fertilizer or mixture.

There are two ways of approval in regulating trade in fertilizers: the type approval and the individual approval. Laws stipulate that each brand and grade of a commercial fertilizer or fertilizer mixture be registered on each bag with the fertilizer grade clearly written on it. Since fertilizers can pollute water and air, the World Health Organization (WHO) stipulates specific limits for various parameters. The nitrate in drinking water, for instance, must not exceed 45 mg/liter; there are also special instructions for packaging and sealing. The regulations on transport and storage are aimed at preventing epidemics while handling organic fertilizers.

Fertilizer mixtures: See Mixed fertilizers

Fertilizer mobility zone

Soluble fertilizer salts concentrate in the soil solution around the zone of fertilizer application. Their rate of movement and spread from the point of application depends on the type of salts, their application rate, soil properties and climatic conditions.

The movement of phosphorus from the point of placement is generally limited because the hydrogen phosphate ion ($H_2PO_4^-$) is only slightly mobile in the soil. Nitrogen salts move in the soil solution, depending on the direction of the water movement. Nitrates move more readily than ammonium (NH_4^+) nitrogen which is adsorbed to the cation exchange sites in the soil. Like ammonium, the potassium ion is also adsorbed on the cation exchange sites, and becomes relatively immobile.

Fertilizer nitrogen, an environmental perspective

Nitrogen (N_2), an element critical to the existence of life, comprises 75 percent of the earth's gases. Nitrogen is the building block of amino and nucleic acids and is a part of chlorophyll. Since nitrogen is instrumental in increasing seed and fruit production, leaf and forage quality and general crop growth, countries have intensified the production of nitrogenous fertilizers.

However, since two nitrogen atoms are bound by a triple bond, nitrogen cannot easily react with other elements. Nitrogen is available only when it is fixed. There seem to be only two natural means of fixing nitrogen. One is lightning flashes which cause nitrogen atoms to combine with oxygen to form plant absorbable nitrates (NO_3^-). Lightening is estimated to account for about 10 million metric tons of total fixed nitrogen per year. The other phenomenon is the action of bacteria, notably *Rhizobium* which converts soil nitrogen into ammonia (NH_3). This in turn is converted by other bacteria into nitrates. Bacterial action accounts for about 140 million metric tons of fixed soil nitrogen.

Artificial injection of nitrogen compounds into the ecological system has sometimes proved to be damaging to the environment. Synthetic production of nitrogenous fertilizers has far reaching effects on natural systems, and disturbs the delicate balance in the environment. There are many factors that go against the over-use of these fertilizers.

The production of synthetic nitrogen fertilizers depends upon the availability of non-renewable fossil fuel. Natural gas, a key component in ammonia production, is found dissolved in crude oil and is limited in its availability across the globe. (Venezuela, Trinidad, the Middle East region, Russia and China are rich in gas). Thus, an increased demand of nitrogenous fertilizers increases the demands on natural gas.

Excessive fertilization injects excessive nitrates into the soil. Being highly soluble, they move through the soil into ground water. When nitrates enter rivers, streams, etc., they promote abnormal algal blooms which draw oxygen from the water and create an oxygen-scarce environment, thus killing aquatic life. This creates a "dead zone". This process of unintentional enrichment of water is called **eutrophication**. The Gulf of Mexico has a dead zone which fluctuates in size from 7680 to 20480 sq. kms. Heavy rains and subsequent run-offs, and leaching of nitrogen aid the process of eutrophication.

Soil micro-organisms need soil organic matter which is a source of carbon in the soil. Chemical fertilizers are said to deplete the carbon content in the soil and jeopardize the microbial population. As a consequence, the carbon to nitrogen ratio is disturbed. In addition, fertilizer salts near bacterial colonies dehydrate the abundant bacterial cells in water. Soil microbes thus get killed and the nitrates in ground waters, aquifers, etc. get into drinking water. This has been shown to lead to **methemoglobinemia** (blue baby syndrome), reproductive disorders, ovarian cancers, etc.

When a nitrogen fertilizer is applied to a soil, nitrogen oxides are formed which are released into the atmosphere, often leading to smog formation. Excessive smog causes respiratory diseases.

When nitrogen oxides and compounds rise in the atmosphere, they react with the ozone in the upper zones. Similarly, some nitrogen fertilizers like urea cause ammonia emission. At extreme levels, ozone may get depleted, which in turn can increase the passage of UV rays on to the earth. However, studies show that nitrogen oxides do not significantly contribute to global warming.

Nitrogen fertilizers gradually make the soil acidic. And when these fertilizers leach into the subsoil, they make rivers acidic. Change in pH levels can threaten plant and bacterial life. Increased acidity mobilizes soil aluminum, thus inhibiting root growth.

Fertilizer placement

Fertilizer placement is a method of applying fertilizers in specified zones of the soil so that it comes within the feeding range of plant roots and the plant receives maximum benefits from its application. Vigorous seedling growth is deemed essential for maximum yield.

A number of methods for fertilizer placement are in use, such as **banding**, dribble banding, **deep banding**, **high pressure injection**, **point injection** and **side dressing**. The basic objectives in fertilizer placement are to (a) achieve the efficient use of nutrient elements from emergence to maturity of the plant, (b) prevent or reduce harmful effects caused to the environment, and (c) avoid fertilizer-induced salt injuries to plants. A proper and timely placement of fertilizers, with the objectives as stated, is important for enhancing a deep rooting system, especially when the soil surface is dry.

Fertilizer placement involves surface or sub-surface applications of the fertilizer before, at, or after planting. The placement depends on the crop, its rooting pattern, rotation practices, deficiency of the soil nutrient, nutrient mobility in the soil, and equipment availability. Before planting, the fertilizer is uniformly applied over the field by tilling or cultivating. By increasing the (fertilizer) use efficiency, crop recovery can be increased with subsurface banding. A subsurface point injection can be effective for immobile nutrients. Surface band or dribble banding is an effective pre-plant fertilizer application. Fertilizers can also be applied along with the seed and used as a starter or pop up operation to enhance early seedling vigor in cold and wet soil. They can be surface applied or dribbled directly over the row, or several centimeters to the side of the row, in cases where planting is done in bands.

The **starter fertilizer** benefits plants by (a) enhancing root and above-ground development, resulting in quicker growth, an early harvest, increased competition with weeds, and reduced heat during pollination, (b) providing a quicker soil cover and reduced run-off and erosion, (c) reducing the grain moisture content at harvest, and cutting production costs, (d) improving nutrient use efficiency, increasing production efficiency, and reducing the potential for water pollution, and (e) boosting the yield and enhancing crop quality and ultimately, profits.

Top dressing applications of nitrogen are common on small grains and pastures; top dressed phosphorus (P) and potassium (K) are not as effective as they are at the pre-plant stage. Both solid and liquid fertilizers can be used for top dressing.

The side-dress application of nitrogen (**anhydrous ammonia** and fluid nitrogen sources) done with a knife or a point injection applicator is common for corn, sorghum and cotton. The side dressing allows flexibility in application time since side dress applications can be made almost anytime; and equipment can be operated without damage to the crop. Subsurface side dress applications can damage the root or cause fertilizer toxicity. The side dress applications of P and K are recommended at the root level, because these are needed early in the season and again at the reproductive growth stages.

The presence of soluble N, P, K or other salts close to the seed may be harmful. There should be some fertilizer-free soil between the seed and the fertilizer band.

Fertilizer quality

Fertilizer quality is the degree to which the chemical and physical properties of a fertilizer match the prescribed specifications. (See also Quality of fertilizer.)

Fertilizer ratio

Fertilizer ratio, also called plant food ratio, is the ratio of the number of fertilizer units in a given mass of fertilizer expressed in the order N, P, K.

The relative proportion of primary nutrients in a fertilizer grade divided by the highest denominator for that grade gives the fertilizer ratio. A 27-3-9 fertilizer has a ratio of 9:1:3. This is rich in nitrogen, low in P and moderate in potassium.

Fertilizer raw materials and feedstock

The primary raw materials for nitrogen fertilizers are natural gas, naphtha, fuel oil and coal. The manufacture of phosphate fertilizers requires sulphur and phosphate rock. Naturally occurring potassium salts form the basis for the production of most potash fertilizers.

Natural gas, naphtha, fuel oil and sulphur are substances (or mixtures) with specifications that can be defined. Their composition varies very little regardless of the place of their origin. While potash ores greatly vary in composition from place to place, the end product of mining, benefaction and processing in each case has more or less a constant composition.

Phosphate rock and coal vary significantly in composition and other characteristics. These variations determine the processes used to upgrade the mined ores. These variations also determine the nature of the manufactured fertilizer from the beneficiated products. A fertilizer plant designed to use a particular phosphate rock or coal may encounter operational difficulties and lower efficiency when the sources of raw materials are different. It is for this reason that generally manufacturers enter into long term contracts with the supplier of these raw materials.

Ammonia is a basic building block for most nitrogen fertilizers with the exception some naturally occurring nitrates. Nitrogen and hydrogen are the basic raw materials used in the manufacture of ammonia. Nitrogen is available in abundance in the atmosphere and is present to an extent of about 78%. However, the sources of hydrogen for nitrogenous fertilizer production are natural gas, naphtha, fuel oil and coal. Water also contributes a portion of the hydrogen needed for ammonia manufacture.

Natural gas, oil and coal are all associated with sedimentary rocks. Natural gas composition varies with the place of origin and it occurs naturally either in association with crude petroleum (associated gas) or as a non-associated free gas. In view of its large reserves, natural gas is the preferred source for hydrogen. Many plants manufacture ammonia using the natural gas route.

The light distillate fraction of petroleum produced during the refining of crude oil, with a boiling point of 40 to 132°C, is known as **naphtha**. This straight-run naphtha is preferred to naphtha produced from high hydrocarbons by cracking or 'hydro cracking' because the latter contain sulphur that is difficult to remove. Naphtha was a favored stock when the price of crude was very low from 1950 to 1975. The process for steam reforming of naphtha was developed by ICI, England.

Coals are formed in swamps under warm climatic conditions and the deposits are associated with prehistoric events and deltaic environments. Vegetative matter under anaerobic conditions slowly transforms to peat by the action of bacteria. By increasing the temperature and pressure, peat acquires the solidity, color and chemical composition of coal. These changes are basic for the progressive increase in the rank of coal.

Coal is characterized or ranked into four groups - peat, brown coals and lignite, bituminous coals, and anthracites or hard coals. Coals contain impurities such as sulphur (between 0.5 and 3%) and clays. A few fertilizer plants are based on lignite and bituminous coal.

Coke oven gas contains about 55% H_2, 25% CH_4, 8% CO and 6% N_2 and is produced during coal carbonization in steel plants. It also contains minor amounts of higher hydrocarbons and carbon dioxide. Its main drawback is the limited amount of the material available and the variation in its composition. The amount of coke oven gas depends on coke production which, in turn, depends on steel production. Only a few plants use coke oven gas for feedstock.

Phosphate rock, which is a natural deposit of calcium phosphate (containing, fluorine, carbonate and other impurities in small concentration chemically known as **fluorapatite**), is the basic raw material used for the manufacture of phosphate fertilizers.

There are two types of phosphate rock deposits, namely, sedimentary and igneous. Sedimentary deposits are exploited to produce more than 80% of the world's phosphate rock production. Igneous phosphate deposits are often associated with carbonates and alkali intrusions. Sedimentary phosphate rocks occur throughout the world.

Most of the sedimentary deposits contain varieties of carbonate fluorapatite that are collectively called **francolite**. Francolite contains a significant amount of carbon dioxide and more than 1% fluorine. Francolite also contains 33.3% to 42.2% phosphorus (as P_2O_5). The apatite from igneous source rocks may be of primary, hydrothermal or of secondary origin. Primary apatite from igneous sources may be fluorapatite, hydroxyl apatite or chloroapatite. Pure apatites from igneous deposits contain slightly over 42% phosphorus (as P_2O_5).

Several methods can be used to measure apatite reactivity. All these are empirical methods and depend on standardized procedures and extraction methods. Common extraction media include neutral ammonium citrate, 2% citric acid and formic acid. The phosphorus content is generally expressed as percentage phosphorus as P_2O_5. In trade it is expressed as **bone phosphate of lime (BPL)** which chemically is the tricalcium phosphate content [$Ca_3(PO_4)_2$].

A wide variety of techniques and equipment is used to mine and process phosphate rock. Phosphate rock is mined by both surface (open cast or strip mining) and underground methods. **Surface mining** can take many forms, from manual methods employing picks and shovels to highly mechanized operations. Surface mining is the most popular method for phosphate deposits. Large bucket wheel excavators are suitable for open pit operations when there is an overburden owing to a large amount of ores to be excavated, and when ores are soft and dry.

There are several underground phosphate rock mining operations in the world. They range from being labor intensive to highly mechanized. A combination of the open pit and underground mine is used in Russia to produce phosphate ores. As surface deposits have mostly been exhausted, underground mines have been developed and there are plans to achieve depths of over 2,500 m.

Sulphur is one of the more common constituents of the earth's crust and the mean sulphur content of rocks is estimated to be 400 ppm by weight. Sulphur naturally occurs as elemental sulphur, metal sulphides in coal and mineral ores, sulphates, hydrogen sulphide in natural gas, and complex organic sulphur compounds in crude oil and coal. All these forms are used as sulphur sources, but the most important sources are elemental sulphur and hydrogen sulphide in natural gas and iron pyrites.

Potassium salts produced and used as fertilizers are generally called '**potash**', a term that originated from the burning of wood in pots or retorts to obtain potassium salts as 'potashes'. Potash is now commonly used to describe potassium-bearing materials and the potassium content is generally expressed on a K_2O equivalent basis.

The most abundant potash mineral is sylvite (KCl). Sylvite and halite (NaCl) form a common potash ore, called **sylvinite**. In other deposits, carnalite ($KCl. MgCl_2. 6H_2O$) is also found with halite. A limited number of soluble double sulphates, 'hartsalz', [sylvite plus halite with kieserite, $MgSO_4$, H_2O or anhydrite $CaSO_4$, langbeinite ($K_2SO_4 \cdot 2MgSO_4$] are also known. There are two basic types of potash mining, encompassing several standard methods as found necessary for specific situations.

Fertilizer recommendation: See Recommended dosage of fertilizers

Fertilizer requirement

A fertilizer requirement is the quantity of nutrients required by a particular plant, in addition to those already contained in the soil, to increase crop growth to the optimal or designated level.

Fertilizer solutions

Liquid fertilizers are also called fertilizer solutions. **Urea-ammonium nitrate solution (URAN)** is an example of a fertilizer solution.

Fertilizer specifications

Fertilizer specifications give details of the composition of a fertilizer in terms of its grade, weight and analysis. They constitute the seller's assurance that the fertilizer conforms to the data given in the specifications and the prevailing government regulations which protect the interest of the buyer.

Fertilizer specifications have to be displayed on the bag or the container and may also be presented on the proforma invoice while selling. The format of displaying the specifications may vary depending on the use or the intent of the fertilizer.

Fertilizer specifications must also include the details of the (a) nutrient content and concentrations, (b) nutrient chemical composition, (c) moisture content, (d) particle size distribution, (e) physical condition, (f) solubility and/or availability, (g) conditioner, (h) special limitations pertaining to phytotoxic production of by-products or additives, (i) packaging details, (j) methodology used in quantifying or qualifying the various parameters, and (k) penalties or discounts for deviations from the stated values and conditions. Obviously, the more detailed the specifications, the more informed is the buyer with respect to what he/she is buying, and in the process, what he/she has to pay.

Sometimes, a product may meet all the stated specifications but may still not be suitable for the intended use. This happens if contaminants are not specified. For example, a phosphate rock, which is available with varying contents of phosphate and impurities, can affect the quality of nitrophosphates, phosphoric acid, superphosphate and ammonium phosphates produced from it. Here, although the phosphate rock may meet all the stated specifications, it can affect the performance of a crop if the specifications do not list the unspecified contaminants or impurities.

Fertilizer spreaders

Fertilizer spreaders are machines used to distribute fertilizers in a field. Solid fertilizers (crystals, granules or powders) are broadcast. Liquid fertilizers are sprayed, and substances like anhydrous ammonia are injected into the soil.

The way a fertilizer is spread onto the soil depends on the stage of development and growth of the crop. A broadcast type machine consists of a hopper which feeds the fertilizer into the spreading device (like a spinning disc or an oscillating spout) for distributing the fertilizer in swaths of variable width (Fig.F.14). These mechanisms are not as accurate as 'full width' distributors (like the once popular 'plate and flicker' type), the more modern agitator, or pneumatic type spreaders. Fertilizers can also be applied by combine drill or by aircraft. The placement drills are particularly useful for application of fertilizers to cereals as top dressing.

Fig.F.14: A broadcast spreader with a spinning disk. (Source:www.daken.com.au/images/fertspred/rond_spt1 60_man.jpg. With permission from Dr. Verther Rondini of Rondini Company, Italy.)

A spinner broadcaster is capable of handling prilled, semi-granular fertilizers and crystalline fertilizers as well as seeds of cereals and grasses. Electronic controls are being increasingly used to monitor and improve the metering and distribution of mineral fertilizers for the automatic discharge of a correct amount of the fertilizer.

Global positioning systems (GPS) are used currently for improved crop management, including fertilizer application. GPS allows the exact position in the field to be determined and relocated without reference to weather, location and time. It is possible to cover specific sites in accordance with the existing soil and crop variations within the field. Fertilizer spreaders can use GPS in conjunction with the soil test data stored in a **geographic information system** (GIS) to apply the needed nutrients to individual areas using different spreading rates.

Fertilizer storage

Fertilizer storage refers to the process of storing fertilizers in large or small quantities till they are needed for agricultural applications. Fertilizers need to be stored securely in appropriate bags and stacked in godowns or warehouses, to ensure their safety and to prevent their deterioration.

Fertilizer to crop price ratio

A fertilizer to crop price ratio gives an indication of the economic returns of that particular crop. Other things being equal, a favorable fertilizer to crop price ratio gives positive economic returns.

Fiber crops

Crops grown primarily for the fiber extractable from their bolls (as in cotton) or stems (as in jute, flax, sisal or hemp) are known as fiber crops. They are mostly composed of **lignin** which is a complex organic polymer deposited in the cell walls of many plants, making them rigid and woody.

Fibric

Fibric is organic material that is only slightly decomposed (less than one third). It is similar to peat. The soil material which hosts fibric is called **fibric soil material**.

In a low oxygen environment, decomposition is very slow and so plant parts are preserved for a long time. It is even possible to recognize the original part of the plant or the source after examining the fibric.

Fibric soil material is found in **histosols**. Histosols contain a major portion of organic matter (about half of the approximately 80 cm of the upper depth). Fibric dominates the organic soil material of histosols (around 30–35 cm deep). The other organic matter in histosols includes muck, peat and mucky peat.

Fibric soil material: See Fibric

Fibrin

Fibrin is an insoluble fibrous protein that causes blood to clot. **Fibrinogen**, a protein synthesized in the liver, dissolves in the blood and circulates in the body. Fibrinogen is converted to fibrin by the enzyme thrombin which builds up a spongy, fibrous network joining the edges of the wound to effect clotting and prevent bleeding. Thus, thrombin is responsible for the formation of fibrin (from the soluble fibrinogen) which forms the fibrous network, thus trapping the blood cells during an injury.

Fibrinogen: See Fibrin

Fibrist

Fibrist is a suborder of histosols that have a high level of organic matter derived from undecomposed natural vegetation with a bulk density of 0.1 g/ml. This suborder consists of fibrous peat of reddish brown color. Fibrists are saturated with water for long periods, making them unsuitable for most crops. This suborder consists of great groups: borofibrist, cryofibrist, luvifibrist, medifibrist, sphagnofibrist and tropofibrist.

Fibrous root: See Root

Fick's first law of diffusion: See Fick's laws

Fick's laws

Diffusion can be defined as a process of mass flow by which atoms (or molecules) change their positions relative to their neighbours in a given phase under the influence of thermal energy and the gradient. The gradient can be any one of the four gradients relating to concentration, magnetic field, stress or electric field.

Consider an unidirectional flow of matter in a binary system of P and Q atoms, moving in opposite directions under the influence of the concentration gradient. Let us assume that Q is the only moving species. **Fick's first law of diffusion** states that

$$\frac{dn}{dt} = -DA \times \frac{dc}{dx}$$

where dn/dt is the number of moles of Q atoms crossing the cross-sectional plane of area A, per unit time, perpendicular to the diffusion direction 'x', and dc/dx is the concentration gradient in the 'x' direction. D is called the **diffusion coefficient** and is a constant characteristic of a homogeneous system.

Fick's law can be used to describe flow under steady state conditions and is identical in form to Fourier's law for heat flow under a constant temperature gradient, as also the Ohm's law for current flow under a constant electric field gradient.

Fick's second law of diffusion is an extension of the first law and is for non-steady state flow.

Plant roots significantly influence the process of

nutrient uptake in the rhizosphere which is the local soil environment. Diffusion and connective flows are particularly important in the case of relatively mobile nutrients, such as nitrate (NO_3^-), borate (BO_3^-) and bivalent calcium (Ca^{2+}) ions. These nutrients have a time scale for diffusion of the order of a day, and they get into the plant readily.

The uptake of nutrients through diffusion is a slow process. But it is a dominant mechanism operating in fertile soils especially when concentrations of relatively immobile elements like phosphorus, zinc and copper in the soil solution are low. The time scale is large for nutrients, such as dihydrogen phosphate ($H_2PO_4^-$) that are affined to solid soil phases.

Fick's second law of diffusion: See Fick's laws

Field capacity of a machine

The field capacity of a machine is used to evaluate the productivity of plows, cultivators, drills, etc. that are used for working the soil. (See also Efficiency.)

Field capacity of soil

Field capacity or **field moisture capacity** is expressed as the percentage soil water that is held when the water potential is less than –33 kPa (1/3 bar). It is a measure of the maximum amount of water the soil can hold or store after it is completely wetted and drained.

Field capacity is also defined as the quantity of water held at a particular suction pressure, 48 hours after wetting. It is expressed in millimeters and is also expressed as a percentage of the oven-dry soil.

Hillel defines the field capacity as the water content of a specified soil volume measurable two days after thorough irrigation and expressed as a percentage fractional volume. As soils drain continuously and unevenly, there is no consistency in the field capacity. Its values are only a pointer to the irrigation water needed and the stored soil water available to plants.

The water available to plants is the difference between the percentage of water at the field capacity and that at the **permanent wilting point**. It is difficult to say when the profile reaches the overall average field capacity because it varies with the soil texture. Field capacity is attained at a lower rate with clayey soils than with sandy soils.

If the soil is wet right up to the water table, or if the drainage outlet ceases, the suction gradient acting upwards balances the gravitational head gradient acting downwards. Water is redistributed at the expense of the initially saturated soil zone. Even when the soil, deep down, is not completely wet, the drainage rate often becomes very low 1 or 2 days after heavy rains or irrigation, which is due to a fall in hydraulic conductivity. The water content then defines the field capacity. This, for many well-structured soils (e.g., in Britain), is attained at suctions close to 5 kPa when all pores of more than 60 μm diameter drain off the water. The field capacity is set at a suction of 10 kPa, which corresponds to the larger than 30 μm pores, in Australia and the USA. The field capacity is measured in pF units, a logarithmic scale in the UK and some other countries. The normal values of pF ranges around 2.5 for the field capacity and 4.2 for the permanent wilting point. The pores drained at the field capacity are called **macropores** and correspond to pores between the soil peds, often created by faunal and root activity.

The concept of field capacity is useful for setting an upper limit to the amount of **available water** in the soil. But this limit is not very precise because the soil may (a) remain above the field capacity owing to frequent rains for several days, and (b) continue to drain slowly for several days after the rains.

Field crop sprayer

A machine used for spraying liquids on a field crop by forcing the liquid (whether fertilizer or pesticide) through a nozzle under pressure is called a field crop sprayer. (Fig.F.15).

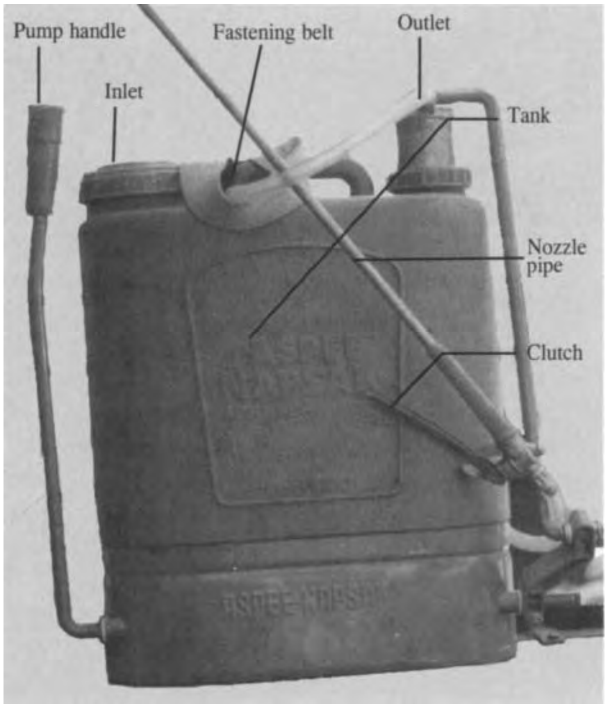


Fig.F.15: Field crops are sprayed with fertilizers or pesticides. Picture shows a Napsak sprayer.

Field day

A field day is a day when farmers and others interested in farming meet at a place to see a demonstration of an improved agricultural practice or crop production technique. Agricultural extension workers and fertilizer promotion workers often attend such meetings.

Field efficiency of machines

The field efficiency of a machine on actual farms is never 100%. It is always less than what the machine is theoretically rated for, because of such losses as friction.

Field experiments with fertilizers

Field experiments with fertilizers are undertaken to reveal information on fertility, nutrient status and deficiencies of the soil. Field experiments are among the diagnostic techniques used on the field.

Field maple

Field maple is another name for **hedge maple**.

Field moisture capacity

Field moisture capacity is another name for **field capacity of soil**.

Filler

A filler is a solid inert material added to a synthetic resin or rubber to change or dilute its physical properties. Calcium carbonate, barites, silicates, glass micro balloons, slate flour and soft clays are common fillers.

Once the desired nutrient ratio of a fertilizer is determined, its property can be modified with the help of fillers like sand or lime. Fillers have no reinforcing or coloring properties. They help to (a) adjust the percentage of the nutrients to a desired ratio, (b) prevent caking of the fertilizers, and (c) increase the fertilizer weight.

Filter process cake

Filter process cake is another term for **press mud**.

Filtration

Filtration is a process of separating solid particles from gas or liquid, using a filter. Filtration thus purifies the fluid or gas and recovers it as a clean material or as free particles or both.

Gas filtration involves the removal of solids (called dust) from a gas-solid mixture. The need of doing so arises on two counts: (a) that there is a contaminant which renders the gas unsafe, and (b) that the separated solids themselves can be valuable products.

For filtration, three kinds of gas filters are used. These are bag filters, granular bed separators and air filters. Liquid filters are of two types, namely, cake filters and clarifying filters.

In **vacuum filtration**, the gas or the liquid is sucked up by a vacuum pump. **Ultra filtration** is filtration under pressure. For example, ultra filtration of blood occurs in the nephrons of the vertebrate kidney. **Gel filtration** is a chromatographic technique for the separation of compounds at the molecular level.

In pedology, filtration signifies the passage of a liquid through soil. If the soil is not fully saturated, the quantity of water that filters through is lesser (because a part of the water is used up in saturating the soil) than when the soil is fully saturated.

The quantity of water (Q) that filters in a unit time is known as the **filtration rate** and is given by the **Kozeny formula**:

$$Q = \frac{C}{\eta} \times \frac{P_o^3}{(1-P)^2} \times \frac{1}{S^2}$$

where C is the coefficient taking into account the form, the cross-sectional area and the tortuosity of the capillaries; η is the viscosity of water, P_o is the porosity accessible to moving water, P is the total porosity and S is the surface area of the particles.

Filtration rate: See Filtration

Filtration velocity

In **Darcy's law** for flow of water through sand columns, the rate of flow (V) in cm/hr is :

$$V = \frac{K+H}{L}$$

where H is the height of water column in cm, L is the height of the sand column in cm, and K is the permeability coefficient. K has the dimensions of velocity and is, therefore, called filtration velocity.

Fine-loamy thermic soil

Fine-loamy thermic soil is the family designation for an 'aridic argiustoll, fine-loamy, thermic' kind of soil, as per the French system of classification and soil taxonomy.

Fine silt

Fine silt is a sub-division of **silt** based on particles, their size being in the range of 2 to 20 μm.

Fischer-Tropsch process for synthetic fuel

Synthesis of liquid or gaseous hydrocarbons or their oxygenated derivatives from carbon monoxide and hydrogen mixture (synthesis gas) is obtained by passing steam over hot coal. The synthesis is carried out with metallic catalysts such as iron, cobalt or nickel at a high temperature and pressure. The process was developed by F. Fischer and H. Tropsch and was used for making synthetic fuels. The energy crisis has stimulated interest in the conversion of coal to hydrocarbons.

Fish fertilizer

A fish fertilizer is also called **fishmeal** or **fish manure**. It is a fishery by-product consisting essentially of processed scrap from the filleting operation or from a whole fish. It contains 4 to 10% nitrogen, 3 to 9% phosphorus (as P_2O_5) and 0.3 to 1.5% potassium (as K_2O). It is applied directly to the field and is used generally at transplanting time. Its effect lasts for 6 to 8 months. Fish emulsion is used as a foliar spray. When non-edible fish carcasses and offal are dried, crushed or powdered, it is called fish manure or fishmeal (Fig.F.16).

Fishmeal manufacture is the largest fish processing operation in the world. About 35 to 40% of the

Fig.F.16: A fish fertilizer.

world's fish catch is converted into fishmeal. The manufacture involves drying and grinding of fish and fish waste.

Fish manure is available as dried fish chunks / pieces and as fish in a powdered form. The major constituents present in it vary with the type of fish. Fishmeal is a quick-acting organic manure and is suitable for all crops and on all types of soils. By law, fishmeal should not contain more than 6% oil and 4% salt.

White fishmeal is derived from non-oily 'white' fish (e.g., cod, haddock, etc.) It usually contains about 66% protein. The other fishmeal is derived from oily fish (such as herring, pilchards, etc.) which after extraction of most of the oil is usually richer in protein than white fishmeal. Fishmeal is mainly fed to pigs and poultry, but is also given to dairy cows, calves and other farm animals.

Fish scrap or **fish tankage**, a wet process, is made from non-edible fish like menhaden, dogfish and offal by steam cooking the entire body and running it through a screw press to remove the oil. The oil contains 20% polyunsaturated fatty acids which lowers the cholesterol content of human diet. The pressed material is dried, ground and sold as a fish scrap or fish tankage for use as a fertilizer in horticulture, especially for growing vegetables.

Fish guano

Fish guano is a phosphatic fertilizer made from unmarketable fish and fish waste after oil extraction. It has 78% nitrogen and 4 to 8% phosphoric acid and is used mainly for horticultural purposes.

Fish manure

Fish manure is another term for **fish fertilizer**.

Fishmeal

Fishmeal is another term for **fish fertilizer** or **fish manure**.

Fish scrap: See Fish fertilizer

Fish tankage

Fish tankage is another term for **fish scrap**.

Fison's process for non-granular mono-ammonium phosphate

A number of processes have been developed for the production of non-granular monoammonium phosphate, an intermediate in the production of compound fertilizers. These include processes developed by Scottish Agricultural Industries, Fison's Ltd., Swift Agricultural Chemicals, Nissan and ERT Espindesa. (See also Monoammonium and diammonium phosphate production processes.)

Fixation of ammonium: See Ammonium fixation

Fixation of phosphate: See Phosphorus inorganic forms

Fixed costs

Fertilizer production is capital intensive. Like any other capital intensive industry, it requires a careful analysis of investment versus returns. As fixed costs constitute a major portion of the total production costs, every effort is made to keep them as low as possible.

The costs arising from administration, maintenance, labor, security, rent of office or factory, salaries, interest payable on capital goods, insurance, etc. are called fixed costs as these have to be paid even when there is no production. In the context of crop production, the fixed costs also include costs of seeds, preparatory tillage operations, post sowing, inter-cultivation, etc. The costs are usually compacted on an annual basis and then allocated to products, and arrived at after considering their various components, listed below:

Depreciation is the acknowledgment of the erosion of the value of an asset through its life. It is used as an accounting tool to distribute the initial investment costs of productive fixed assets (except land) over the lifetime of the assets.

There are many ways to account for depreciation (like the **straight-line method** or **reducing-balance method**), these ways being guided by the legislation of the region, as also the management's perception of profit. In the straight-line method, the provision for depreciation is made each year, by subtracting the scrap value of the asset from the original costs and then dividing this cost by the number of years that the asset is estimated to operate or function. The reducing-balance method is based on the reducing absolute value of the asset.

The cost of operating labor and supervision includes salaries, wages, premiums, overtime, employees' medical insurance, meal subsidies, holidays, vacations, retirement benefits, unemployment taxes, social security taxes, etc. Only those involved in the direct operating labor and supervision of plants, utilities and site services are included in the category of fixed production costs. Generally, a good approximation of the required personnel is achieved if the number of actual operating positions is multiplied by a factor of 4.5 for a 40-hour workweek and by 3.8 for a 48-hour workweek.

Maintenance costs are the costs of material, labor and supervision (often including scheduling in central machine shops) amounting very broadly to 50, 40 and 10% respectively of the total maintenance cost, for a general category of a traditional industry. Generally, annual maintenance costs can be estimated at a minimum of approximately 4% of the fixed investment costs; for corrosive processes or those with extensive instrumentation, this can be 7 to 10%.

Administrative expenses and supervision costs are not generally chargeable to any particular production or maintenance operation. These are for overall management, laboratories, accounting, distribution and marketing, expenses for salaries, wages and benefits, along with annual operating costs.

Insurance and taxes together may typically account for 1 to 3% of the total installation costs although these change from country to country.

For a single product, the project unit costs are simply calculated by dividing the total annual production costs by the number of units produced. Unit costs, therefore, reflect capacity utilization which is a critical factor in calculating the unit cost. For multiple product projects without any historical data to base the fixed cost allocations on, it is generally better to calculate the contribution per unit to cover fixed costs and profits.

Fixed costs of machinery

Machinery costs comprise **fixed costs** that include depreciation, interest on investment, taxes, shelter and insurance (of machines). Fixed costs occur whether or not the machine is used. (See also Machinery costs.)

Fixed potassium

Potassium is present in relatively large quantities in soil, averaging about 1.9%. But 90 to 98% of the total soil potassium is only slightly soluble. Out of the potassium that does not get absorbed by plants, some is entrapped between the layers of 2:1 clays, such as **illite**. This form of potassium that does not get absorbed by the plant is called fixed potassium.

Fixed potassium, unlike **exchangeable potassium**, does not participate in exchange reactions.

Flagellates

Flagellates are organisms having flagella for movement. The colonies of protozoa, like **ciliates** and sarcodina, are also known as flagellates.

Flag leaf

Flag leaf is the last fully expanded leaf of cereals which surrounds the head before its emergence (Fig.F.17). When it covers the head, it is called **boot leaf**.

Flake mica

Commercial mica is rich in potassium and is of two types: sheet and scrap or flake. **Scrap mica** or flake mica is ground for use in coatings of roofing materials and in paint, wallpaper, joint cement, plastics, cosmetics, well drilling products and a variety of agricultural products.

Fig.F.17: Sorghum crop in flag leaf stage.

Flame photometer

Flame photometer is an instrument used to estimate concentrations of elements like sodium, potassium, calcium and magnesium in solution.

Floatation

Floatation is a method of separating minerals from one another derived from waste rocks or solids of different kinds. It is done by agitating the pulverised mixture of solids in water, oil and special chemicals which effect preferential wetting of solid particles of certain types by the oil, while the other types of particles are not wet. The unwetted particles are carried to the surface by air bubbles and are thus separated from the wetted particles. A frothing agent is also used to stabilize the bubbles in the form of a froth which can be easily separated from the body of liquid (froth floatation). The floatation technique is used to purify the phosphate rock mineral for use in phosphoric acid or in superphosphate manufacture.

Floatation of phosphate rock

Phosphate rock contains many impurities. When these are removed, pure phosphate is obtained as calcium phosphate. Floatation of phosphate rock is a technique used for removing impurities and upgrading low-grade ores.

Among the common impurities associated with phosphate ores are clays (such as kaolinite, illite, smectites and attapulgite), quartz and other silicates (usually feldspars), carbonates (mainly calcite and dolomite), secondary phosphates (phosphates bearing iron and aluminum) and iron oxides (such as geothite, hematite and magnetite). It is desirable to remove as much of the impurity as possible from the phosphate ore, increase the apatite content and chemical quality of the rock, and upgrade the feedstock.

Phosphate ore beneficiation is done by many methods. **Froth floatation** is a widely used technique in the phosphate industry.

Froth floatation is generally employed with siliceous ores when other less expensive or less complicated techniques fail to produce phosphate concentrates suitable for chemical processing. Prior to its conditioning for floatation, the floatation feed of phosphate rocks is delimed. In the floatation of phosphate ores, apatite particles are generally directly transferred to the froth fraction (direct floatation) by using anionic collectors such as fatty acids. The anionic collectors selectively attach themselves to the phosphate particles, render them hydrophobic and lift them to the surface by the froth and air bubbles formed (Fig.F.18). The mineral bearing froth may simply overflow the cells or paddles or may be skimmed off. Quartz and other silicates are removed from the bottom of the floatation cells. A second stage of floatation may be required to remove silica from the phosphate-rich float by cationic collectors (usually amines), when silica is floated and the phosphate particles settle to the underflow.

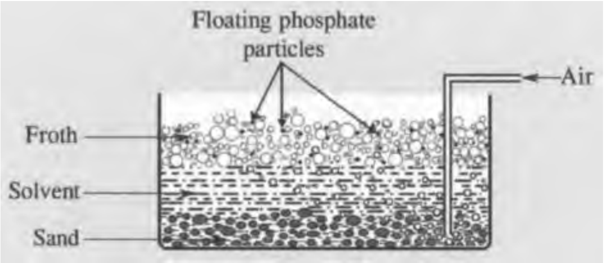


Fig.F.18: Froth floatation of phosphate ore.

A selective floatation of carbonates from phosphate rock is rather difficult owing to the similarity in the physicochemical properties of the carbonate and phosphate minerals. Several treatments have been proposed, including floatation, calcination, acid washing, magnetic separation and heavy media separation for the removal of free carbonates from the phosphates.

Flocculant: See Flocculation

Flocculation

Flocculation, also sometimes called **coagulation**, is a process in which colloid particles aggregate into small lumps or masses. Often, the term is used for a reversible aggregation of particles in which the forces holding the particles together are weak and the colloid can be redispersed by agitation. This is not true for other forms of aggregation (coalescence and coagulation). The substance that induces flocculation is called **flocculant**. Flocculants are used in water purification, liquid waste treatment and other special applications. Inorganic flocculants are lime, alum and ferric chloride. Polyelectrolytes are examples of organic flocculants.

The stability of particles of a lyophobic colloidal dispersion depends on the layer of electric charge on the surface of the particles, around which electrolyte ions of the opposite charge are attracted, forming a mobile ionic 'atmosphere'. The result is an electrical double layer on the particles that consists of an inner shell of fixed charges with an outer mobile atmosphere. The potential energy between the two particles depends on a repulsive interaction between the double layers on the adjacent particles and an attractive interaction due to the **van der Waals** forces between the particles.

During large separations, the repulsive forces dominate and account for the overall stability of the colloid. As the particles get closer, the potential energy increases to a maximum level and then falls sharply at very close separations, where the van der Waals forces dominate. This phenomenon of particles coming together is known as **coagulation**. The minimum of potential energy corresponds to 'coagulation' and is irreversible. If the ionic strength of the solution is high, the ionic atmosphere around the particles is dense and the potential energy curve shows a shallow minimum at the larger separation of particles, which corresponds to flocculation of the particles. Ions with a high charge are particularly effective for causing flocculation and coagulation.

Flooding method

The flooding method is a type of irrigation method in which water released from the field ditches is allowed to flood over the land. (See also Irrigation methods.)

Flora

The entire spectrum of plant life, habitat or the geological period of a particular region is called flora. **Fauna** is the corresponding term for animal life. The lower plants or microscopic plants in a particular microhabitat visible only through a microscope are known as **microflora**. Fungi, algae, actinomycetes, etc. are different types of microflora (Fig.F.19). Bacteria are the most numerous among microflora.

Fig.F.19: Fungi contribute to soil microflora.

Floral leaves

Leaves show considerable variation in size, shape, texture, vein arrangement and type of attachment to the stem, and are recognized according to their types. A floral leaf or **bract**, which is a leaf type, has organs like sepals, petals, stamens and carpels specialized for reproduction.

Floriculture

Floriculture refers to the cultivation of ornamental and flowering plants. Scientific research has provided floriculturists with techniques to control blooming of flowers. For example, poinsettias bloom with red leaves at Christmas time. Research has also produced such new varieties as thornless roses and double snapdragon. (See also Horticulture.)

Florist's mounting media

Foamed phenolic resins and polyurethane resins are used as plant growth media and as a florist's mounting medium for florists.

Flow characteristic of fertilizers

The free flowing nature of many solids is particularly useful for fertilizers. Fertilizers are exposed to humid environments during handling and in transit. Moisture affects the flowing nature of solid fertilizers. Two fertilizers can have similar critical relative humidity (CRH) values and yet may differ significantly in their ability to flow under humid conditions.

The ability of a fertilizer to remain free flowing under humid conditions is determined by measuring the amount of time the material remains flowing in a rotating drum under a constant temperature and an elevated humidity condition. In addition to the measurement of the free-flow time, the sample can be subsequently analyzed to determine the moisture content at which the product becomes non-flowing.

There are several methods to evaluate the degree of moisture tolerance of fertilizers. These include small-pile storage tests and drill ability tests. Generally, in a bag of free flowing fertilizers, there is always some non-flowing material in the form of sticky lumps caused by atmospheric moisture. The time taken by a fertilizer to be poured out varies depending on the moisture content. For example, 50 kg of ammonium nitrate of grade 34-0-0, containing 25%, 50% and 75% non-flowing quantity was found to take 7, 12 and 16 minutes respectively to pour out completely. Some typical flow data for a few common fertilizers is given in Table-F.1.

Flower

Flower is the part of a plant that is modified for reproduction. Each flower is borne on a stalk or pedicel, which is expanded to form a receptacle that bears floral organs (Fig.F.20). The sepals are the first of these organs and are normally green and leaf-like. Above the sepals, there is a ring of petals which vary in color and shape. The ring of sepals is termed the calyx and the ring of petals, the corolla. Calyx and corolla are collectively called perianth. Above the perianth are the reproductive organs comprising stamen and **carpel**. Pollen produced by the stamens is transferred to the stigma, either by insects or by wind. Various forms of flowers have evolved to aid insect or wind pollination.

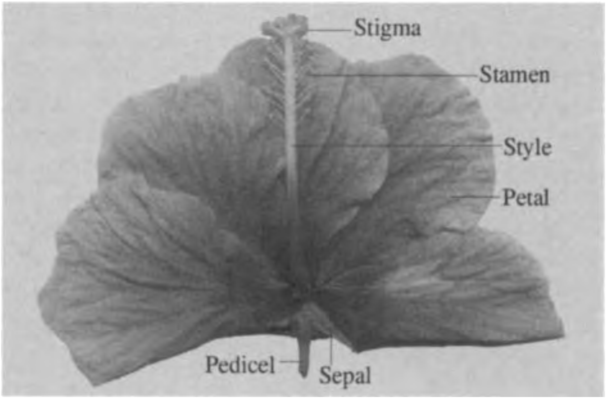


Fig.F.20: A flower of hibiscus.

Flowers of sulphur

Flowers of sulphur is another term for **agricultural sulphur**.

Table-F.1: Flowability data of some granular fertilizers.

Fertilizer	Grade	Flowability in minutes (at 30°C and 90% RH)		
		25% Non-flowable	50% Non-flowable	75% Non-flowable
Ammonium nitrate	34-0-0	7	12	16
Ammonium nitrate based composition	12-6-22-3MgO	37	43	48
Ammonium sulphate	21-0-0	175	220	280
Ammonium sulphate, ammonium phosphate, potassium chloride, sand	6-24-24	155	175	205
Ammonium sulphate, ammonium phosphate, potassium chloride, sand	10-10-10	75	90	105
Diammonium phosphate	18-46-0	70	130	180
Monoammonium phosphate	11-52-0	80	165	190
Triple superphosphate	0-46-0	180	240	300
Urea	46-0-0	5	10	15
Urea, ammonium polyphosphate, potassium chloride	19-19-19	10	20	30
Urea, phosphate rock, potassium chloride, kieserite	12-6-22-3MgO	31	38	40

Source: Fertilizer Manual, 1998, UNIDO, IFDC and Kluwer Academic Publishers, The Netherlands. With permission.

Flow-through process

Flow-through process is a process of measuring adsorption, wherein a solution is in uniform motion relative to a column or a pad of soil particles. (See also Measuring adsorption.)

Flue dust

Flue dust is mainly a waste product from iron and steel manufacturing processes, and it contains 5 to 15% potassium. If flue dust is free of contaminant metals (cadmium, lead, etc.), it is used as a fertilizer.

Fluid fertilizers

Fluid fertilizers are also called **liquid fertilizers**. Two known types of fluid fertilizers are: (a) clear liquids in which all or nearly all of the ingredients used are in an aqueous solution, and (b) suspensions that contain solid particles. These solids may be insoluble materials, soluble salts in their saturated solution or a combination of the two. Fluid fertilizers are used both for **foliar application** as well as soil application. Micronutrient sprays of a soluble salt or chelate in water are used to correct deficiencies, particularly of tree crops. Because some metal salts form acidic solutions, the slightly soluble basic salts [like $CuSO_4 \cdot 3Cu(OH)_2 \cdot H_2O$] may be preferable for foliar applications.

It is a common practice to combine pesticides with the fluid fertilizers of macro and micronutrients during application. Liquid fertilizers may be produced by dissolving fertilizer salts in water. However, for large-scale use, it is more common for the manufacturer to prepare the liquid mixed fertilizer at the plant for use by farmers.

In formulating liquid mixed fertilizers, it is not sufficient that all ingredients are water-soluble since many reactions occur forming water-insoluble compounds of micronutrients. In general, most micronutrients are soluble in aqua ammonia or in a solution of urea and ammonium sulphate. The pH is kept above 7. Micronutrient formulations except those of iron are available in aqua ammonia and ammonium sulphate. The metallic elements are added as sulphates but they are present in the solution as complex metal amine sulphates. Boron and molybdenum are added as boric acid and molybdic acid. In general, boron and molybdenum are soluble in nearly all neutral ammonium orthophosphate solutions. Copper, iron and zinc are soluble in ammonium polyphosphate solutions to the extent of 1 to 3% and manganese is soluble to the extent of 0.2%.

When micronutrients are incorporated in suspension fertilizers, solubility is not a technical problem although it may be an agronomic problem. Very fine particles of micronutrients are added to suspension fertilizers so that they do not clog spray nozzles.

Fluidized drum granulation process for ammonium nitrate production: See Ammonium nitrate production processes

Fluid lime

Fluid lime or **fluid limestone** is a suspension of fine limestone (100 to 200 mesh) in water in a 50:50 proportion, containing 1 to 2% gelling clay (attapulgite clay, sepiolite clay, sodium bentonite clay, xantham gum, etc.).

Generally, the smaller the particle size of the liming agent, the quicker its reaction in soil. This in turn helps to adjust the soil pH to a suitable level for optimum crop growth. If the particles are smaller than 0.2 mm they are difficult to handle and are, therefore, applied in a suspension form.

Fluid lime is stored in tanks.

Fluid limestone: See Fluid lime

Fluorapatite:

Fluorapatite is the best known type of **apatite**, a group of calcium phosphates with a common formula $Ca_{10}(X_2)(PO_4)_6$. Fluorapatite is a type of amorphous phosphate rock containing fluorine and carbonates as impurities. It also naturally occurs as a crystalline mineral. Fluorapatite is regarded as an important fertilizer input.

Fluorine

Fluorine is the lightest of the halogens, occurring naturally in **fluorapatite**, fluorite and cryolite. A pale yellow toxic gas, fluorine is made by electrolysis of potassium fluoride in liquid hydrogen fluoride. It is the most reactive, electronegative and oxidizing of all elements, and reacts with almost all elements, giving fluorides. It is used in rocket propulsion and in the production of uranium and fluorocarbons.

Fluvial erosion

The transport of topsoil or erosion caused by rivers downstream is called fluvial erosion. (See also Water management.)

Foamed soil conditioners

There are several types of synthetic soil conditioners. Foamed polystyrene and foamed urea-formaldehyde resins are used as foamed soil conditioners. (See also Soil conditioners.)

Fodder crop

Crops raised as feed and fodder for animals are called fodder crops. Clover, grasses and alfalfa are examples of fodder crops.

Fold

Fold in the context of agriculture is a wired enclosure, usually movable, to enclose sheep or pigs in the field. It is moved around in the field of a growing arable crop to guide consumption by the animals. This practice is known as folding.

A fold also means a wave-like form in sedimentary rock layers. This form results from deformation in the earth's crust. A basin shaped fold in which the beds of rocks dip toward each other is known as a **syncline** and those rocks where they are folded into an arch shape are known as **anticlines**. More complex folds result when the rock strata are subjected to intense horizontal pressures.

Foliage leaves

Foliage leaves are the main organs for photosynthesis and transpiration in a plant system.

Foliar application

Foliar application involves spraying nutrients on leaves for their rapid absorption. Other terms used for foliar application are **foliar spray**, **foliar feeding**, **foliar nutrition** and **foliar fertilization**.

Foliar application becomes useful when nutrient uptake by roots gets reduced. Foliar application is different from fertigation where nutrients are mixed with irrigation water. A foliar spray enables the nutrients to move into the plant cells through the stomata, leaf cuticles and parts of the epidermis. Although generally used for correcting micronutrient deficiencies, the spraying of a few kilograms per hectare, of nitrogen, potassium and phosphorus can show immediate effect on plant growth. Iron chelates are also sprayed on leaves to overcome iron deficiencies.

For micronutrients like iron, zinc, manganese and copper, much more material is required for soil application than for foliar sprays. Foliar spraying helps the rapid utilization of nutrients and permits correction of the deficiency in a shorter time than with soil application. It is the most effective means of applying fertilizers when nutrient fixation in the soil is problematic. Foliar nutrient sprays are excellent supplements to soil applications (Fig.F.21).

Foliar application has a number of advantages over soil application. In foliar application, nutrients act rapidly, their utilization being high. They are delivered where needed, and the risk of loss by leaching and contamination of ground water is reduced. Supplying micronutrients through foliar application does not entail extra cost if fertilizers are combined with agricultural pesticides.

The main disadvantages of foliar fertilization are that (a) the action time is often quite short, (b) the quantity of primary nutrients delivered is relatively small as concentrations higher than 1 to 2% can cause leaf burn, and (c) it is best suited only for micronutrients required in small quantities.

Foliar application of phosphorus is less common than that of nitrogen because of the damage most phosphorus compounds can do to leaves. The maximum permitted concentration of phosphorus is 0.5% for corn and 0.4% for soybeans. Various environmental factors (like temperature, humidity, wind and light) affect the rate of absorption and translocation of nutrients applied to the foliage.

To be effective, foliar sprays have to be repeated 2 to 3 times because each round can carry only a small amount of nutrients. For optimal nutrient uptake through leaves, the nutrient must remain as long as possible in the dissolved state on the leaf surface. Thus, spraying in overcast weather or toward the evening gives better results than spraying on sunny days, as water evaporates rapidly and causes leaf burn.

Fig.F.21: Foliar application facilitates rapid utilization of nutrient elements.

Foliar fertilizers contain primary nutrients and/or micronutrients which are absorbed by leaves on application. The most common foliar fertilizer is urea which is highly soluble in water and readily absorbed by plants.

Solutions with organic ingredients (like amino acids), readily soluble salts (like potassium nitrate or micronutrients, mostly based on sulphate) and salt mixtures (containing macronutrients and special micronutrient mixtures) are also used for foliar fertilization.

Foliar fertilizers are applied to remedy apparent nutrient deficiencies. When the deficiency is recognized, the missing nutrient is supplied by spraying. If the deficiency is not well defined, a complete foliar fertilizer or mixed micronutrient fertilizer is employed in an attempt to remedy the hidden nutrient deficiencies which may impair the crop yield and quality.

Nutrient sprays may be applied through handguns (of either a single nozzle or multiple nozzles), or oscillating or stationary cyclone-type orchard sprays. Nutrients are also sprayed by overhead sprinklers as well as by such equipment used for spraying pesticides. The droplet size affects the crop response and has to be controlled.

Foliar fertilizers are usually applied along with pesticides to lower application costs, to reduce the stress of the pesticide being sprayed alone, to improve the quality of the pesticide spray liquids and to stabilize them, to reduce the evaporation at low humidity and to lower the surface tension of water.

Foliar feeding

Foliar feeding is another term for **foliar application**.

Foliar fertilization

Foliar fertilization is another term for **foliar application**.

Foliar fertilizers: See Foliar application

Foliar nutrition

Foliar nutrition is another term for **foliar application**.

Foliar spray

Foliar spray is another term for **foliar application**.

Foliar symptoms

Foliar symptoms are nutrient deficiency symptoms in leaves. These appear as chlorosis, necrosis, cupping, pigmentation, or as folding and wrinkling of leaves.

Foliar symptoms are also the symptoms on leaves, of a disease caused by biotic or abiotic factors. Foliar symptoms can be similar for different diseases. (See also Deficiency symptoms.)

Foliar transpiration

Foliar transpiration is transpiration through leaves. It is of two kinds, namely stomatal and cuticular, depending on the part of the leaf where transpiration takes place.

Foliar uptake

The foliar uptake is the absorption of nutrients through stomata of leaves. (See also Nutrient uptake.)

Folist

Folist, a suborder of histosols is a kind of organic soil, made up of leaf litter of less than 1 m thickness on rock or gravel. Folist is a freely drained soil containing a sizeable quantity of organic carbon. These soils are not saturated with water for long periods and make agriculture possible. This suborder has the following great groups: Crysfolists, Torrifolists, Ustifolists and Udifolists.

Fool's gold

Pyrites resemble gold in external appearance and hence it is also known as fool's gold.

Forest

A forest is an area of vegetation covered chiefly by trees and undergrowth. It constitutes a major biomass. However, its degradation or conversion into grazed pastures or cultivated fields causes major environmental crisis and political conflicts, because forests have a large number and variety of animals and plant species as well as valuable timber. Forests influence regional climates and accumulate carbon from atmospheric carbon dioxide.

Deforestation reduces the water retention capacity of soil, increases downstream flooding and leads to soil erosion. Consuming forest products such as fuel, wood, timber, industrial raw materials, etc. leads to large-scale nutrient removal which has to be replaced by plantations with short and long harvest intervals.

To facilitate forest management, forests are classified on the basis of the trees present therein. One classification is based on the size of the individual tree, referred to as seedlings, saplings, poles, standards or veterans. A forest containing trees ranging from small seedlings to poles to large veterans is said to be all aged. Forests with trees essentially of the same size and age are called **even-aged**. Foresters talk of a **pure forest**, if it is composed mainly of one species. A tolerant tree is the tree that can grow in the shade of other trees and vegetation. An intolerant tree is the one that cannot survive in shade.

Deciduous trees (such as oak, ash, elon, beech or maple), shedding their leaves annually, often dominate temperate forests with abundant rainfall and moderate temperatures. Such forests with one kind of deciduous trees or another are found in the temperate regions of Europe, Asia, North America and Chile. The evergreens and conifers dominate the cold **coniferous forests**. These are composed mainly of gymnosperms, which include evergreen trees like pines, firs, redwoods and hemlocks. These forests are found in parts of America and many parts of Europe and Asia.

Fig.F.22: A tropical forest.

Tropical rain forests (also called **equatorial forests** when established in equatorial regions) are forests with regular heavy rainfall (Fig.F.22). These are characterized by broad-leaf evergreen tree species that grow in warm and moist tropical regions. They are found in Southern Mexico, Central America, Amazon basin of South America and parts of Africa and Asia. The **monsoon forest** in Southeast Asia with heavy rainfall is interspersed with periods of drought. **Thorn forests** are **deciduous forests**, found in Australia, South-West of North America, parts of Central and South America and South-West Africa. They receive sparse rainfall, are inhabited by small thorny trees and grade into savannah, woodland and semi-desert.

Forest A_1 horizon

Forest A_1 horizon is the A_1 horizon found under forests where bush fires do not occur frequently. In this horizon, organic matter is derived from biological decomposition.

Forest humus types

In the classification of forest humus, the fundamental taxonomic unit is identified chiefly from the sequence of organic or organo-mineral horizons and sub-horizons on the surface of the soil profile. It is very clear now that differences in the composition of forest humus occur because of the nature of the vegetation in the forest. This variation affects the physical, chemical and biological properties of the forest soil. It is possible to alter the forest humus by changing the stand composition, and by controlled burning, thinning, etc.

There have been attempts to classify forest humus. Generally, the classification applies to well drained soils and not to peat or mineral soils. The thickness and composition of the H layer and/or the A_1 horizon is crucial in the process of forest humus classification.

The three principal types of forest humus are mor, mull and moder. **Mor** is acidic in nature and occurs in coniferous forest soils where biological activity is low. Acidophilic fungi and invertebrates convert the plant residue to mor humus. The C/N ratio of mor humus is around 30.

Mull is characteristic of rendzinas, phaeozems, chestnut soils and soils under cultivation. It is biologically very active. The pH is neutral (to alkaline) and the C/N ratio is around 10. They form stable mineral organic complexes.

Moder, which is in between mor and mull, is medium humified humus. It is common in sod-podzolic soils, loesses and mountain grassland soils. Acidophilic fungi and arthropodans help to transform plant residues into moder humus. The C/N ratio is around 20. Moder humus has labile mineral-organic complexes which bind weakly with the mineral portion of soil.

In addition, there are two transitional types of humus, **moder-mull** and **moder-mor** with overlapping features of moder and mull and moder and mor respectively. Similarly, there are more sub-types of moder, mull and mor, depending on specific characteristics.

Forest soils

Forest soils, whether they are shallow, steep, acidic, wet, droughty or rocky, usually require lesser amounts of nutrients than other soils. Many forests can, however, be profitably fertilized to produce trees large enough to be harvested in 20 to 30 years instead of 60 to 200 years. An accidental or a controlled fire converts nutrients in tree residues to soluble mineral forms. Ash also acts as a lime addition, raising the soil pH.

Formamide

Formamide is an organic compound containing the amide group $-CONH_2$. It is made from formic acid or its ester with ammonia. It is also made from ammonia and carbon monoxide.

$$HCOOH + NH_3 \longrightarrow HCONH_2 + H_2O$$

$$CO + NH_3 \xrightarrow{\text{catalyst}} HCONH_2$$

Formamide is used in making liquid fertilizers for foliar application of nitrogen. For example, a mixture of formamide, urea and ammonium nitrate is used as a solution fertilizer and has a salt-out temperature of 0°C. It contains more than 35% nitrogen, unlike the aqueous formulations of urea, and ammonium nitrate, which have 32% nitrogen.

Formamide is a good solvent for many organic compounds.

Formula

In the context of fertilizers, a formula represents amount and grade of the materials used in making a mixed fertilizer. It is used in some countries to express the percentage of each of its N-P-K constituents in a compound fertilizer.

Formula is another way of representing a chemical compound using symbols for the atoms present. Subscripts are used for the number of atoms. The molecular formula simply gives the type and numbers of the atoms present; for example, the molecular formula of acetic acid is $C_2H_4O_2$. The empirical formula gives the atoms in their simplest ratio, which is CH_2O for acetic acid. The **structural formula** indicates the way atoms are arranged. Commonly, this is done by dividing the formula into groups. Acetic acid can be written as CH_3COOH.

Structural formulae can also show the arrangement of atoms or groups of a compound in space and so distinguishes between isomers. The **space formula** shows the arrangement of the atoms and bonds of a compound in three dimensional spaces and so distinguishes between stereoisomers.

Fragipan

Fragipan refers to the subsurface horizon of medium texture with a bulk density higher than that of the horizons above and below it. It is non-cemented but restricts the entry of water and roots into the soil matrix.

When dry, fragipan is hard and compact. It is brittle when moist, and its structural units rupture suddenly if pressed between two fingers. It has low organic matter and hence low permeability (causing imperfect drainage). It has bleached cracks of a coarse texture of the polygonal pattern. On the surface and within the polyhedral discontinuing mottles, clay coatings are observed.

Fragipan, which is generally found below the B horizon, may be 15 to 200 cm thick, tending to increase in less favorable drainage conditions. While its boundary with the horizon above is abrupt, it is gradual or has a diffused boundary with the horizon below.

In Western Europe, the genesis of fragipan appears to be linked to the quaternary glaciations, especially to the Wurm glaciation. The fragipan horizon becomes compact between a continuously frozen subsoil and periodically frozen surface (during winter).

Fragipans are commonly associated with ultisols, alfisols, spodosols and inceptisols.

Francolite

The most predominant mineral of phosphate is francolite which is calcium carbonate-fluorapatite. Its formula is $Ca_5(PO_4,CO_3)_3(F,OH)$.

Freckling

Freckling is a necrotic leaf spot condition. It is a symptom of low silicon in sugar cane, receiving direct sunlight. Direct sunlight exposes the sugar cane plant to ultraviolet radiation, which seems to be the cause of freckling. Silicon, when available in adequate quantities, acts as a filter, to keep out the harmful ultraviolet radiations from the plant. For a silicon deficient area, the addition of 2 ton/ha of silica fertilizer is recommended to overcome the deficiency.

Free acidity

Free acidity is the sum of all acidic components in an unneutralized state.

Free flowing

To be free flowing is a desirable quality of a powdered fertilizer which enables its easy spreading on soil. In this condition, the fertilizer particles do not stick to each other or form a lump.

Free fulvic acid

Free fulvic acid is a kind of **fulvic acid** which is mobile and soluble in phosphoric acid.

Free swell test

Free swell test is a type of puddle test designed by **Gibbs-Holtz's**, which studies the change in the volume of dry soil expressed as a percentage of the original volume. (See also Puddle tests.)

Freeze-dried inoculant

An **inoculant**, which is dried rapidly at a low temperature, is called a freeze-dried inoculant. It is a type of bio-fertilizer formulation.

Freeze drying

Freeze drying or **lyophilization** is the process by which water from foods, drugs and other substances is removed for preserving them for later use. Unlike other food drying processes, the freeze drying method freezes substances, changing any frozen moisture into water vapour, in its refrigerated vacuum chambers. Freeze dried substances, which retain most of their original characteristics, do not shrink and are easily soluble. (See also Lyophilization.)

Frenching

Zinc deficiency, which is recognized by different names in different crops, is called frenching in citrus crops.

Freundlich isotherm

Freundlich isotherm is an adsorption isotherm which gives the quantity of material including ions adsorbed on the solid surface. Freundlich isotherm is used to describe the removal of ions (like phosphate) by soil constituents from dilute solutions and given by

$$M = Acb$$

where M is the amount of phosphate adsorbed, A and b are soil-dependent constants, and c is the concentration of the phosphate ion in solution.

Friable soil

Friable soil is a soil that crushes under gentle pressure. Depending on the moisture content in the soil, the degree of friability changes. Extending this logic, there are very friable, firm, very firm and extremely firm soils. (See also Consistence of soil.)

Fried and Dean method for estimation of nitrogen in soil: See A value

Frits

Frits are melted soluble glass particles containing measured quantities of micronutrients like copper, iron, boron, zinc, manganese and molybdenum. Impregnated and granulated powdered glass is mixed with appropriate fertilizers so that a **complete fertilizer** is formed to render its application more complete. Such a complete fertilizer is useful when nutrients are required to be released slowly. In sandy and humid areas, where micronutrients tend to be lost by leaching, frits have become particularly useful.

Frits are made by fusing salts of micronutrient elements with glass (soda glass or borosilicate glass) or glass components like feldspar, soda ash, silica, flurospar, cryolite, sodium nitrate and borax, and then powdering them before mixing with desired fertilizers. Melting the ingredients and rapidly cooling them by pouring into water or onto water-cooled steel rolls form frits. They are easy to handle, relatively inert and mixable with fertilizers without affecting the product stability; their solubility is governed by the particle size. There are other advantages of fritting, such as its ability for effecting (a) more even distribution of nutrient, (b) reduction in loss of volatile materials, and (c) conversion of poisonous materials (lead compounds) into their less dangerous forms.

Frits are effective as soluble micronutrients for many crops like cotton, corn and peaches. Frits are identified by the micronutrient present in them, for example, **copper frits** when copper is present. Similarly, there are **boron frits, zinc frits, molybdenum frits, manganese frits, iron frits**, etc.

Frontal effect in precipitation

When warm moist air is lifted above cool dense air, the moist air cools and precipitation occurs. This is known as the frontal effect in precipitation. This is a dominant factor in the type and distribution of precipitation.

Froth floatation

Froth floatation is a widely used technique in the phosphate industry and is done for phosphate ore beneficiation. (See also Floatation of phosphate rock.)

Fructose

Fructose is the stereoisomer of glucose and occurs in green plants, fruits and honey. Fructose is sweeter than sucrose. It is used as a fluid and nutrient replenisher.

Fruit

A fruit is the ripe ovary of a flowering plant containing the seed or seeds. Its main functions are to protect the developing seeds and to help scatter them when they are ripe. The majority of fruits are formed only from the carpel or carpels of the flower and are known as **true fruits** (Fig.F.23). Some fruits include other parts of the flower, especially the receptacle, which are called **false fruits** or accessory fruits, for example, fig and apple. The fruit begins to develop after fertilization.

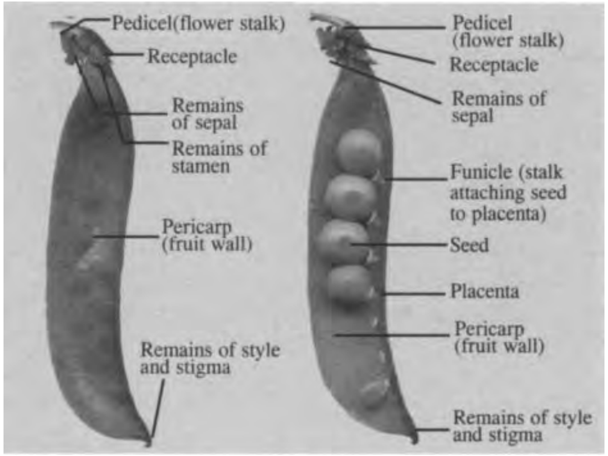


Fig.F.23: Fruit of pea (Pisum sativum).

Fruit vegetables: See Horticulture

F-test

The F-test is used for comparing the precision of two sets of data. (See Significant difference in analysis.)

Fuel gas

Fuel gas is a product of coal, an important source of chemical raw materials. Distillation of coal (pyrolysis) yields coal tar and hydrocarbon gases which are upgraded by hydrogenation or methanation to synthetic crude oil and fuel gas, respectively.

Fuel oil

Fuel oil is the heavy fraction obtained from the cracking of crude oil. It has a calorific value of 10,500 kcal/kg, and is used as a raw material for the production of nitrogen fertilizers.

Fugacious leaves

Fugacious leaves are leaves that fall as soon as they are formed.

Fugacity

Fugacity is the tendency of molecules to escape from a liquid surface. It is largely responsible for evaporation. (See also Liquid.)

Fulvic acid

Fulvic acid, a natural ionic molecule, is created by the activity of beneficial microbes that live near plant roots. Such microbes thrive in the soil humus which contributes up to 60 to 70% of carbon in the soil. Humus is divided into three components based on its solubility. These are fulvic acid (**FA**), **humic acid (HA)** and **humin**, the acids being soluble in sodium hydroxide and other alkaline solutions. But while humic acid precipitates on acidification, fulvic acid remains soluble in the alkaline extract.

Fulvic acid appears to be composed of microbial metabolites and both old and young humus material not highly associated with the mineral fraction. The carbon to nitrogen to phosphorus ratios in the fractions of humic acid and fulvic acid allow assessment of the origin and turnover of nutrients in the soil organic matter from different depths and zones. HA to FA ratios are used to determine the degree of humification in the soil. The higher the HA to FA ratio, the greater the humification.

Fulvic acid is said to play a critical role in converting metallic and clay based mineral molecules into simpler forms for plant uptake. Thus, a fulvic acid rich environment is believed to provide plant health.

Since the fulvic acid molecule has both a negative and a positive charge, it can be an electron donor or acceptor. Recent studies have pointed out FA's critical role in energizing living cells and in reviving healthy metabolism. Fulvic acid is increasingly finding its way into the pharmaceutical industry.

The extraction of soil organic matter with alkali and its separation into a humic and fulvic acid fraction is a common technique to separate and examine the soil organic matter in the manner shown in Fig.F.24. The molecular weight ranges from several hundreds for fulvic acids to over 300,000 for humic acids and humin. Fulvic acids are poor in carbon and rich in non-protein nitrogen. They are formed in all types of environments but only acid and poorly aerated conditions create large amounts.

Fulvic acids are divided into **free fulvic acids**, **soda fulvic acids** and **pyrophosphate fulvic acids**, depending on the extractant. Free fulvic acid is mobile and soluble in phosphoric acid. Soda fulvic acid is soluble in alkali and abundant in young humus and organic matter-enriched soils. Pyrophosphate fulvic acids are soluble in pyrophosphates.

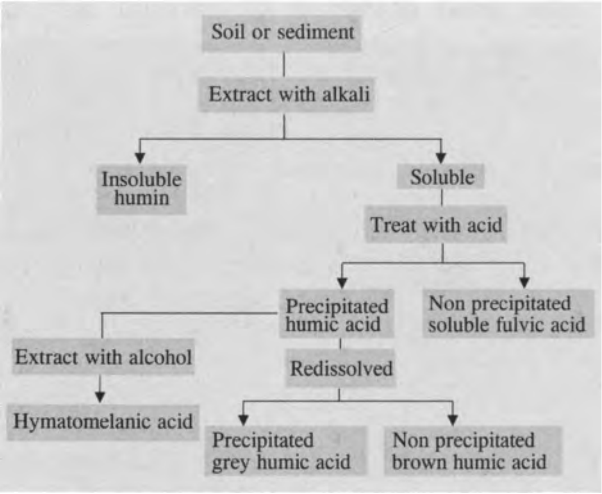


Fig.F.24: The extraction pathway of organic matter for separation of humic and fulvic acids.

Fumigants

Fumigants are volatile chemicals applied to confined spaces or into a soil. They produce a gas that destroys weed seeds and micro-organims and acts as a **soil sterilant**. The most common soil sterilants are methylbromide, methane, allylalcohol, carbon disulphide, chloropicrin and tetra chloromethane. They are packed in special pressure-resistant containers. The application of a fumigant for the disinfestation of an area is called **fumigation**.

The most effective temperature for the use of fumigants is about 25°C. They are used chiefly in enclosed areas (barns, greenhouses, ships' holds, etc.) and are also applied locally to soils, grains, fruits and garments. Some commonly used fumigants are formaldehyde, hydrogen cyanide, carbon tetrachloride, p-dichlorobenzene, ethylene oxide, sulphur dioxide and other sulphur compounds. Care must be taken while handling and applying fumigants because of their toxicity.

Fumigation: See Fumigants

Functional nutrient concept of Nicholas

Plants contain small amounts of 90 or more elements. Out of these, only 20 elements are essential for the growth and development of higher plants. These essential elements are called **plant nutrients**.

According to Nicholas, all mineral elements - whether essential or beneficial, are termed **functional nutrients**. Plant nutrients are utilized for plant growth and reproduction. In addition, there are beneficial elements required by animals which feed on plants. These are required for normal growth. For example, selenium is not needed by plants, but it must be present in forage, since it is essential for animals.

The actual requirement of functional nutrients determines whether they are **macronutrients**, **secondary nutrients** or **micronutrients**. If macro and secondary nutrients are needed in, say, kilograms, micronutrients are required in grams or milligrams. And yet, both the nutrients are essential for the most optimum crop production. They must also be positionally available, that is, the concentrations must be adequate within the soil volume in which crop roots are active.

Functional nutrients: See Functional nutrient concept of Nicholas

Fungi

Fungi, an important group of microflora, are **eukaryotes**. These are achlorophyllous (which means lacking chlorophyll) thallophytes and have or possess somatic (physical) structures which are generally filamentous and branched. They have cell walls with prominent nuclei. The reproduction of fungi is by both sexual and asexual means. Fungi find their place in the kingdoms Protista and Fungi.

Kingdom Protista is further classified into two divisions – myxomycota and oomycota. Fungi belonging to these divisions have heterotrophic or autotrophic modes of nutrition. The fungi classified under both these divisions are slime moulds having plasmodial feeding stage. The mycelial fungi under oomycota bear aseptate hyphae, forming asexual spores called zoospores (sexual spores called oospores, are resting spores).

Kingdom Fungi contains the true fungi, that is mycelial or yeast fungi, which have absorptive, heterotrophic nutrition. These are classified into chytridiomycota (primitive fungi with flagellated asexual spores); zygomycota (aseptate hyphae, sexual spores called zygospores, are resting spores; asexual spores formed in sporangia); ascomycota (mycelial fungi or yeasts, sexual spores called ascospores formed in asci; asexual spores called conidia are abundant in some groups); and basidiomycota (sexual spores called basidispores formed on basidium, asexual spores abundant in some members, large fruiting bodies are common).

With advances in ultrastructural, biochemical and molecular biology, some mycologists established phylogenies and now, fungi are classified into three different kingdoms. These are Chromista, Fungi and Protozoa. Of the three, only kingdom Fungi consists exclusively of true fungi. The kingdoms Chromista and **Protozoa** mainly consist of non-fungal phyla.

Fungi are abundant in soils and perform many functions. Yeasts, moulds, mildews and mushrooms are some well known fungi. The presence of chitin in the cell wall is one of the major distinguishing features of the organisms in the kingdom Fungi. Fungi may be parasites, (many of these cause crop diseases) or saprophytes, but they are important in the release of nutrients to the soil from dead plants and animals. Fungi range in size from microscopic (lower fungi) to visible specimens (higher fungi, such as mushrooms as in Fig.F.25). Microscopic fungi exist in soil in abundance, about a million per gram of soil. They contribute to the mass of soil organic matter more than any other organism in acid soils.

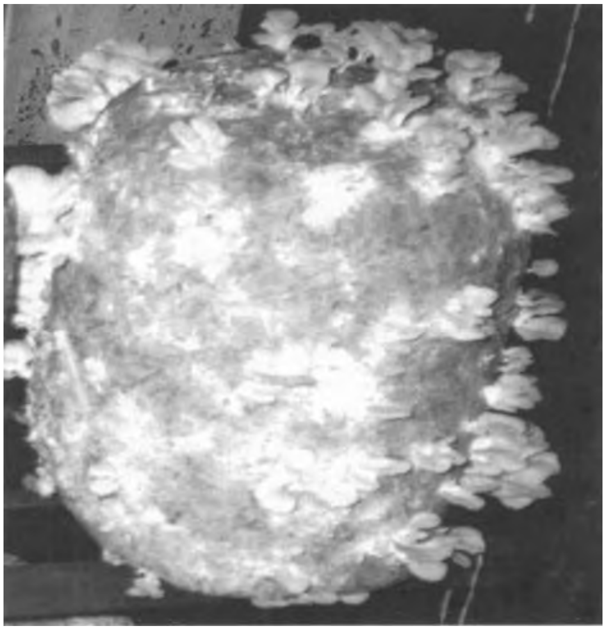


Fig.F.25: Fruit bodies of an edible fungus called mushroom.

Fungi are prevalent in soils rich in plant residues. Fungal population declines rapidly as the readily decomposable material disappears. Fungi generally produce spores, which help them survive in adverse conditions. They are heterotrophic and aerobic and produce a filamentous growth under neutral or slightly alkaline conditions. The filamentous body, known as **mycelium**, extends to many centimeters in the soil and even much longer in undisturbed forest soils (for example, **mycorrhizal fungi**).

Fungal mycelium spreads over surfaces and helps bind mineral particles, turning them into aggregates. They are sensitive to waterlogging or wet soil conditions. They have a very high efficiency of energy utilization in that 50% of the carbon is converted into the cell material while the rest is released as carbon dioxide. In comparison, bacteria convert only 20% of carbon into cell material. Fungi are, hence, of great importance in humus formation and nutrient recycling. Ecologically, fungi play an essential role as decomposers.

Other than angiosperms, fungi are the most economically important group in ways which are both, beneficial and deleterious. In addition to edible mushrooms, fungi are used in fermentation processes for the production of bread, alcoholic beverages, many cheeses (e.g., yeasts like *Saccharomyces* spp.) and many antibiotics (e.g., *Penicillium chrysogenum* in the production of penicillin). On the other hand, pathogenic fungi are responsible for devastating crop losses that have, in the past, impacted human history, and for debilitating diseases of humans and domestic animals. Rust fungi and smut fungi are examples of damaging pathogens harmful to cereal crops.

Fungicidal compound

A fungicidal compound is another word for **fungicide**. A fungicidal compound is a chemical compound that kills or completely eradicates a fungus.

Fungicide formulation: See Fungicides

Fungicides

Fungicides are substances which kill or inhibit the growth of fungi. The chemical compound that carries out this activity is called a fungicide or a **fungicidal compound**. The effect of such a compound is called fungicidal effect.

Most fungicides include among other things, a lime and sulphur mixture, cupric oxychloride and **Bordeaux mixture**, the latter being a mixture of copper sulphate and hydrated lime.

Fungicide formulation is the form in which a fungicide is sold for use. It is a mixture of active ingredients with additional materials such as carriers and diluents added (to make it safe to store and to be diluted as required). Dusts, baits, fumigants, aerosols and granules are usually applied at the strength purchased.

A formulator is the one who combines the active fungicidal ingredients with solvents, diluents and other suitable substances to produce a fungicides package which is labeled and ready for use.

Agricultural fungicides are chemicals used to minimize crop losses caused by phytopathogenic fungi. The useful compounds must be toxic to fungi but non-toxic to the crop. The fungicide activity, depending on the concentration of the fungicide, may be **fungistatic** (capable of temporarily inhibiting fungal growth) or fungicidal (able to kill fungi).

Fungal plant diseases develop generally in conditions of high humidity and temperatures like those at the onset of the summer rains. The use of fungicides and the post-harvest treatment is a relatively low-cost method to prevent crop losses, even in situations where the risk of crop loss is low. The action of fungicides may be curative, eradicative or protective.

All plants are liable to fungal attacks, the symptoms of which can be wilt, rot, blight or mildew. The damage caused by fungi to agricultural crops may be quantitative or qualitative. Non-infectious or infectious agents can induce plant diseases. The former are promoted by unfavorable environmental factors, like temperature extremes, poor water relations and mineral deficiency or excess, while the latter are caused by living organisms like fungi, bacteria, viruses and nematodes.

There exist both **systemic fungicides** and **non-systemic fungicides**, although there can also be some in between. Non-systemic fungicides (also called **contact** or **residual protective fungicides**) do not penetrate plant tissues but perform a protective function. They form a protective barrier on the plant surface and prevent the fungi from entering the host by inhibiting spore germination or mycelial growth. Most non-systemic fungicides react with the thiol groups in the enzymes of the fungi and so inhibit metabolic processes. They are, therefore, considered as multisite or multisided inhibitors. Non-systemic fungicides include inorganic sulphur or copper and organic mercury compounds, although mercury-based compounds are being replaced.

Systemic fungicides enter plant tissues and are transported to the plant sap. They may be transported upward (**acropetal translocation**) or downward (from the leaves to roots, otherwise called **basipetal translocation**). They usually inhibit fungal growth after the pathogen penetrates the host tissues and thus, systemic fungicides have curative properties. The spectrum of activity of such fungicides may be narrow and confined to specific types of fungi as in the case of ethirimol and the compounds controlling powdery mildews. They may also be relatively broad as in the case of the triazoles. Systemic fungicides generally interfere with biosynthetic processes (such as respiration, protein synthesis, and membrane functions) and are site-specific inhibitors. They inhibit fungal growth and spore production more effectively than they do spore germination.

Modern systemic fungicides are based on benzimidazoles, carboxanilides, pyrimidines, morpholines, antifungal antibiotics, phenylamides, ethyl phosphite triazoles and strobilurins.

Compared to non-systemic fungicides, systemic fungicides are required in a significantly smaller amount per unit area at less frequent intervals. Because systemic fungicides inhibit fungal growth inside the plant tissues, they can be curative as well as eradicative. However, the spectrum of diseases controlled by systemic fungicides is narrow and some fungi can develop resistance if such fungicides are used regularly.

Fungicides are commonly administered via seed and soil treatment, foliar and fruit sprays, trunk injections and post-harvest treatment. To be effective, fungicides must come into contact with the pathogen and hence they must be distributed uniformly on the surface. The type of equipment chosen for applying fungicides influences the efficiency of the fungicide. High-pressure liquid chromatography (HPLC) and gas chromatography (GC) techniques mostly give a quantitative analysis of fungicides while a formulation can influence retention and persistence of the chemical on the target surface.

Fungigation

Fungigation is the application of fungicides through irrigation waters in an open or closed system.

Fungistatic

A substance or compound which temporarily inhibits fungal growth is known as a fungistatic.

Fungitoxic

A substance or compound which is toxic to a fungus is called a fungitoxic.

Fungus

Fungus is the singular form of **fungi**.

Furcellaran: See *Furcellaria*

Furcellaria

Furcellaria are red algae which are used in extracting agar-agar. They are cartilaginous, brownish in color and tolerant of poor, saline environments. They commonly grow in groups or clusters and are often found on sandy or muddy shores of the north Atlantic region. *Furcellaria fastigiata*, harvested in large quantities in Denmark, yields an agar called "**Danish agar**".

Furcellaran is a polysaccharide extracted from these algae. It is exploited commercially for its hydrophilic colloidal property. It contains one sulphate group per three or four sugar units, which can be modified by treatment with hot alkali to increase its water and milk gel strengths.

Furnace acid

Furnace acid or **white acid** is phosphoric acid made by burning phosphorus. Other than in the fertilizer industry, it is used in the chemical industry. (See also Phosphoric acid.)

Furnace process for phosphoric acid

Furnace process is one of the two basic processes for the production of phosphoric acid. The furnace process includes the blast-furnace process (not in use commercially since 1938) and the electric-furnace process which is extensively in use to make elemental phosphorus. Most of the elemental phosphorus is converted into phosphoric acid for non-fertilizer uses. (See also Phosphoric acid.)

Furrow: See Furrow irrigation

Furrow irrigation

Furrow is a narrow groove or trench in the soil made by a plow, as the mould-board turns over the soil in a more or less continuous strip (**furrow slice**). Small, close furrows are termed **corrugation**. A completely plowed field prior to cultivation, is said to be **in the furrow**.

Furrow irrigation is the earliest adapted method of irrigation wherein water flows by gravity from a main ditch to each furrow (Fig.F.26).The seeds are sown atop the ridges before irrigation water is let in. Crops like corn and cotton planted in double rows or beds are irrigated by directing the water into the furrow in between the beds. Berries, grapes and orchards require two furrows for irrigation between adjacent rows of plants because of the wide spacing between them.

Fig.F.26: Furrow irrigation is the oldest form of irrigation. The irrigation water flows through the furrows.

Soil erosion is greater when furrow irrigation is used on soils having a steep slope. To reduce water loss in furrow irrigation, the amount of water running down the furrows should be reduced when water reaches the lower end of the furrow.

Furrow slice: See Furrow irrigation

Fused calcium magnesium phosphate

Fused calcium magnesium phosphate is manufactured by fusing phosphate rock and olivine or serpentine (magnesium silicate) in an electric or a fuel fired furnace at 1550°C. Calcium magnesium phosphate contains 10% of total phosphorus (22.5% P_2O_5), of which 8% (19% P_2O_5) is citrate soluble. The quenched material is allowed to drain and then dried and ground. The specified fineness condition is that at least 70% of the material should pass through a 100 mesh screen.

According to the U.S. Department of Agriculture, greenhouse tests show that the product is, on average, more effective than superphosphate when used on acid soils. Field tests in Japan have given good results on many different crops and soils. The product has a liming value equivalent to 0.5 to 0.7 tons of calcium carbonate ($CaCO_3$) per ton of the material. The magnesium oxide content is available to growing plants. For some plants, soil-soluble silica may be an advantage.

Fusible alloys

Fusible alloys are alloys, usually containing bismuth, lead, tin, cadmium or indium, and melting in the range of about 51 to 260°C. (See also Eutectic solutions.)

FYM

FYM is short for **farmyard manure**.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

G

Gamma alumina

Alumina is a white or colorless oxide of aluminum. It occurs in two forms, **α-alumina** and **γ-alumina**. The γ-alumina turns into the stable α form on heating.

Ganats

Ganats, also called ***khanats*** or ***kharezes,*** are horizontal wells which are common in Iran and Afghanistan. These are among the means of extracting subsurface water in these areas. (See also Ground water.)

Gangue

Gangues are such minerals and rocks mined with a metallic ore. They have no value in themselves, and are used only as a by-product. They are separated from the ore in the milling and extraction processes, often as slag. Common gangue materials are quartz, calcite, limonite, feldspar, pyrite, etc.

Garbage tankage

Garbage tankage, also known as **city tankage** or **biogenic compost**, is a compost made from biologically degradable waste including kitchen waste, collected separately from households. The biologically usable portion of domestic waste is 30 to 40%; the household garbage has approximately 1% each N, P_2O_5 and K_2O.

As biogenic composts are made from biologically degradable waste collected separately, their pollutant levels are lower than those of composts made from municipal waste. Domestic waste contains metals in roughly the given quantities, as follows: lead (290 ppm), cadmium (4 ppm), chromium (260 ppm), nickel (40 ppm), mercury (2.5 ppm) and zinc (1020 ppm). Domestic waste is steam-treated, dried, pulverized, granulated or pelletized, and then used as a manure or fertilizer.

Gas

Gas is one of the three states (solid, liquid and gas) into which matter can be classified. Gases are characterized by a low density, low viscosity, high compressibility, optical transparency, complete lack of rigidity, an ability to fill whatever volume is available to them and form completely homogeneous mixtures with other gases. Air, hydrogen, nitrogen and steam are well-known examples of gases. All materials vaporize at sufficiently high temperatures, though many undergo chemical changes. Steam and carbon dioxide are products of combustion, and several gases that are naturally available or derived from petroleum products or coal are used as fuels.

Gases readily dissolve in liquids. The solubility of gases increases with pressure and falls with temperature. Dissolved carbon dioxide is responsible for bubbles in soda. In contrast to solid and liquids, the molecules in gases are far apart from one another and move freely and randomly. At a given pressure, equal volumes of gases contain the same number of molecules ($2.7 \times 10^{25} / m^3$) at room temperature. The impact of the molecules on the walls of the container are responsible for the pressure exerted by gases. Usually a small change of pressure or temperature produces a large change in the volume of gas. The equation of state describes the relation between the pressure, volume and temperature of the gas. At high temperatures and low pressures, all gases obey ideal gas law $PV = RT$.

Gas or gaseous fuel is a liquid fuel. It is an important energy source for homes, institutions and industries, as it is used to heat and cool buildings, cook, heat water and produce steam. There are two kinds of gases: natural and manufactured. Natural gas is recovered by drilling deep down the earth into gas deposits. Gas is also manufactured by processing coal or petroleum, and is used in the manufacture of nitrogenous fertilizers. Gas is increasingly used as a transportation fuel in cars, trucks and ships as it hardly creates any air pollution.

Gas filtration

Gas filtration is removing solids (called dust) from a gas-solid mixture. It is used to remove the carbon particles from gases. (See also Filtration.)

Gasoline

Gasoline, also known as petrol, is a mixture of volatile hydrocarbons having 4 to 12 carbon atoms per molecule. It has an octane number of at least 60. It is used as fuel for internal combustion engines and as a solvent. The major components of gasoline are branched-chain paraffins, cycloparaffins and aromatics.

There are several methods used for the production of gasoline. Among these, distillation or fractionation yields a straight run product of relatively low octane number, which is used primarily for blending, thermal and catalytic cracking, reforming, polymerization, isomerization and dehydrocyclodimerization. The various means of converting hydrocarbon gases into motor fuels by modification of chemical structure usually makes use of catalysts. The present source of gasoline is petroleum; gasoline may also be produced from shale oil and tar sands as well as by gasification of coal.

While gasoline can be synthesized from carbon monoxide and hydrogen, almost all gasoline is made by refining, cracking and alkylation. The fractions are blended to produce the required fuels. Motor gasoline boils between 30°C and 200°C. If the fuel is too volatile, the vapor bubbles are formed which hinder the flow of fuel (vapor lock).

Different kinds of gasoline are:

(a) **Cracked gasoline**: Gasolines are produced by catalytic decomposition of high-boiling components of petroleum. Such gasolines have higher octane ratings than that produced by fractional distillation. The difference is due to a higher content of unsaturated, aromatic and branched-chain hydrocarbons. The actual properties vary widely depending on the source, temperature, pressure and the catalyst used in cracking.

(b) **High-octane gasoline**: It is a gasoline with an octane value of 90 to 100.

(c) **Lead-free gasoline**: It is a gasoline containing no more than 0.05 g of lead per 4.5 l designed for use in engines equipped with a catalytic converter.

(d) **Natural gasoline**: It is the gasoline based on butane, pentane and hexane hydrocarbons. It is used in blending to produce finished gasoline with adjusted volatility but having a low octane number.

(e) **Polymer gasoline**: A gasoline produced by polymerization of low molecular weight hydrocarbons such as ethylene, propene and butene is called polymer gasoline. It is used in small amounts for blending with other gasolines to improve their octane number.

(f) **Pyrolysis gasoline**: Gasoline produced by thermal cracking as a by-product of ethylene manufacture is pyrolysis gasoline. It is used as a source of benzene.

(g) **Reformed gasoline**: It is a high octane gasoline obtained from low octane gasoline by heating the vapors to high temperatures or passing the vapors over a catalyst.

(h) **Straight-run gasoline**: Gasoline produced by distillation, without the use of cracking or other chemical conversion processes, is called straight-run gasoline.

(i) **White gasoline**: It is an unleaded gasoline especially designed for use in motor boats. It is uncracked and strongly inhibited against oxidation to avoid gum formation, and is usually not colored to distinguish it from other grades. It also serves as a fuel for camp lanterns and portable stoves.

Aviation fuel contains a less of low and high boiling components. The octane number or maximum power is carefully controlled by the structure of gasoline components. The gasoline may further be improved by an antiknocking additive. Other additives include lead scavengers (ethylene bromide), antioxidants, metal deactivators, anti-icing agents and detergents. The host of properties exhibited by gasolines results from the use of additives. These gasolines are used as a source of hydrogen in ammonia manufacture and as a source of energy for tractors and jeeps.

Geiger-Muller counter for radioactive tracing

Geiger-Muller counter or Geiger counter detects the presence of a radioactive labeled compound, which in its chemical and physical behavior is identical to a stable compound. It can count individual particles at the rate of about 10,000 per second. Thus, Geiger counter is used to detect the presence of radioactive material, by measuring radiation of alpha, beta, gamma particles and x-rays. This process of radioactive tracing is widely used in chemistry, biology, medicine and engineering.

Gel

Gel is a colloid in which the dispersed and the continuous phases of material form a three-dimensional network and a jelly like mass. Gels behave like elastic solids and retain their characteristic shape while solutions take the shape of the container. Generally, gels have a low solid content and are rich in liquids. Silica gel, gelatin, jellies and transparent elastic gels are examples of gels.

Silica gel is a rigid gel made by coagulating a solution of sodium silicate and heating it to evaporate the water. It is used to support catalysts, and as a drying agent because it readily absorbs moisture from air. The silica gel itself is colorless, but when used in desiccators etc., a blue cobalt salt is added to it. This salt turns pink when it absorbs water indicating that the silica gel needs to be regenerated by heating.

Gelatin is a colorless or pale yellow water-soluble protein obtained by boiling the collagen with water and, then, evaporating the water. It swells on addition of water, and dissolves in hot water to form a solution that sets to a gel on cooling. Gelatin is used in photographic emulsions and adhesives, in bacteriology for preparing culture media, in pharmacy for preparing capsules and suppositories, and in jellies and other foodstuffs.

A **gelling agent** is a substance that is added to a suspension to increase its viscosity, prevent the settling of solids from the suspension and improve the characteristics of the suspension. Cellulose acetate, ethyl cellulose, hydroxyl ethyl cellulose and silica are examples of gelling agents.

The force required to break a gel represents the **gel strength**.

Mechanical agitation liquefies the gel. The property of the gel to regain its original structure is known as **thixotropy**. This happens when the forces bonding the dispersed particles into a cross-linked structure (gel) are weak. A majority of the paste-like and jelly-like systems are thixotropic. Cell protoplasm, gelatin solution and bentonite suspension are examples of thixotropic gels. The opposite of thixotropy is **rheopexy** which is the conversion of dense liquid suspensions into pastes by mechanical actions like stirring, shaking, etc.

Gelatin

Gelatin is a colorless or pale yellow water-soluble protein obtained by boiling collagen with water and evaporating the water. It is an ingredient in jellies and baked goods. It is also used to make medicinal capsules, and coat photographic films.

Gel filtration

Gel filtration is a chromatographic technique where compounds are separated at the molecular level depending on the size or weight of the molecule.

Gelisols: See Soil taxonomy

Gelling agent

A gelling agent is a substance added to a suspension to increase its viscosity, prevent the solids from settling down and improve the characteristics of the suspension. Cellulose acetate, ethyl cellulose, hydroxyl ethyl cellulose and silica are some examples of gelling agents.

Gel strength: See Gel

Gene bank

Gene bank is another term for **seed bank**. (See Germplasm.)

General purpose tractors

When a tractor, a powerful motor vehicle with large rear wheels, is used for a range of tasks like hauling equipment, transporting produce, straw, etc. to and from the farm, it is called a general purpose tractor. General purpose tractors also have a very broad range of horsepower, from about 25 to over 300 hp. The smaller sized tractors are very popular for horticultural purposes and mowing. The mid-sized tractors are used extensively for cultivating, spraying, tilling and mowing (Fig.G.1). The large-sized ones are normally used for primary tillage and for providing power take-off (PTO) horsepower for larger mobile and stationary machines, such as balers and forage harvesters and blowers.

Fig. G.1: A mid-sized tractor is used for farming activities.

Genetic engineering

Genetic engineering is the manipulation of genetic material or DNA, to effect a particular result. The transfer of genetic functions between plants by breeding methods is possible only between closely related species. The barrier to breeding distantly related species imposes limits on the extent to which desirable genes can be introduced into many economically important plants. It is, therefore, of importance to develop artificial methods which can bypass this barrier in breeding technique. Gene splicing, the most prominent technique of genetic engineering, creates recombinant DNA. It promises to revolutionize a number of economic sectors from agriculture to pharmaceuticals. For example, by implanting an insulin producing gene into the DNA ring of the common bacterium *Escherichia coli*, one can produce plenty of insulin in the body. Similarly, with such gene transfer one can develop new characteristics in plants selectively and immediately, as opposed to the time-consuming, imprecise method of cross-breeding. Paul Berg was awarded the Noble Prize for developing the technique of gene splicing, along with Stanby N Cohen and Herbert W Boyer.

Genetic erosion

The loss of genetic information brought about by the extinction of **land races** is called genetic erosion.

The genetic composition of local varieties of plants forms the base for genetic diversity and provides the starting point for further cultivars to be developed. However, owing to reasons of urbanisation, mindless deforestation, and an undue focus on high-yielding varieties of certain food crops like rice, many local varieties are pushed into extinction, causing loss of vital and unique genetic information.

Genotype

Genotype is the unique genetic makeup of an individual organism. The genotype is represented in the form of DNA. The entire hereditary information of an individual is the genome of that individual and it is contained in the DNA.

The genotype along with the environmental variation that affects an individual, together forms the **phenotype**.

Geographic information system

Geographic information system (**GIS**) is the computerized system that facilitates landscape-scale and site specific assessments of soil fertility.

Geological erosion

Geological erosion is another name for **natural erosion**. Here, geological processes and climatic actions (rain, wind, temperature variations and glaciers) cause erosion over long geological periods (Fig.G.2). Geological erosion is responsible for the abrasion of hills and mountains, and the current form of the earth's surface.

Fig. G.2: Land erosion by water.

German compost

German compost was the brand name of the first commercial product of bone superphosphate, also known as **dissolved bone** or **vitriolated bone** (in Europe). It is manufactured by treating ground bones with sulphuric acid.

Germicides

Germicides are substances that kill or prevent the growth of micro-organisms, particularly bacteria and fungi. They are used to prevent sepsis from contaminating body surfaces and surgical instruments. Some of them are also used as disinfectants. The commonly used germicides include iodine, chlorine, hypochlorous acid, ethanol, potassium permanganate, etc. Heat, ultraviolet light and ionizing radiation have also been used as germicides.

Germination

Germination is the resumption of growth of a plant embryo contained in the seed after a period of reduced metabolic activity or dormancy. The important requirements of germination are adequate water supply, sufficient oxygen and favorable temperature. During germination, stored food reserves are rapidly used up to provide the energy and raw materials required for the new growth. The embryonic root and shoot, which break through the seed coat are termed the radical and plumule respectively. There are two forms of germination - hypogeal and epigeal. In hypogeal, the seed leaves or cotyledons are below the ground, as in broad beans. In epigeal they are above the ground and are the first synthetic organ. Castor oil seeds are an example of the epigeal variety.

Germplasm

The genetic instructions and specific encoded information of a plant, which are unique to the individual plant and which help classify it under a type of plant, is called germplasm. Artificial selection and natural evolution have been taking place for thousands of years. Farmers have always selected plants with apparently advantageous characteristics suited to their specific climatic conditions. This process resulted in the propagation of local varieties or **land races**. These land races, by virtue of being around for so many years, have developed robust characteristics, are able to grow in poor soils, and incidentally, often have high nutritional quality.

Germplasm is the basic tool of a plant breeder. Biotechnological research and hybridization have been carried out on land races to derive modern varieties. But since the cultivation of land races has been replaced by that of modern plant varieties there has been a loss of genetic information. This loss of genetic diversity is known as **genetic erosion**. In India alone, only a quarter of the 30,000 land varieties of rice, has survived.

Seed banks, also called **gene banks,** are a solution for genetic erosion. They are storehouses of both native (or wild) and domesticated seeds. These seeds are dehydrated and preserved in specialized temperature-controlled equipment (liquid nitrogen). Such seeds may then be supplied to agricultural institutes or farmers for cultivation. The objective of a seed bank is thus to preserve traditional seeds from various regions or cultures, so as to preserve genetic diversity, and retain inherent plant strengths resulting from natural evolution. Some of the major seed banks are National Seed Storage Laboratory, USA (there are over 15 such facilities in the USA alone), Seed Savers Exchange, Native seeds, etc.

Historical literature in India, for instance, talks at length of some unique properties of rice germplasm being beneficial to consumption. *Peetvasnavrihi* (yellow rice) is said to improve digestion, whereas a variety *sambaka* was said to be rich in β-carotene.

Gibberellic acid

Gibberellic acid is an organic acid used as a plant growth hormone. It is formed by the fungus *Gibberella fujikuroi* in aerated submerged culture.

Gibberellins

Gibberellin is a growth promoting substance found widely in plants. It was first isolated from the fungus *Gibberella*. Gibberellin increases the rate of photosynthesis and helps in the elongation of cells. It promotes the flowering and germination of plants. With a general formula of $C_{19}H_{22}O_6$, gibberellins are also produced by *Azotobacter, Azospirillum,* etc.

Gibbs and Holtz's free swell test

Gibbs and Holtz's free swell test is a kind of puddle test for soil that was first designed by Gibbs and Holtz. (See also Puddle tests for soils.)

Gilgai

Gilgai is a hollow space which is filled with rainwater. Vertisols, which are clay soils, expand and contract with change in moisture when subjected to wet and dry weather cycles. This is usually expressed as slicken sides occurring as diagonal, polished and grooved slip surfaces, wedge-shaped structural units and micro-topography in the form of gilgai.

GIS

GIS is short for **geographic information system**.

Glabrous leaf surface

Glabrous leaf surface is a leaf which has a smooth and hair free surface.

Glacial moraines

The mass of the parent material has a distinct shape with characteristic particle sizes. Its minerals or organic masses are known as **landforms**. A glacial moraine is one such landform.

Glass electrode: See pH meter

Glassy chalcogenides

Glassy chalcogenides is a class of amorphous semiconductors used in switching and memory devices that contain one or more of the chalcogens - sulphur, selenium or tellurium.

Glauconite

Glauconite is a clay-type mineral and a source of slow-release potash. It is sold as '**greensand**' and is very popular in alternative agriculture. The total potash content of greensand is about 7% and is only slowly available because all the potash in greensand is deeply locked in the mineral. Greensand is reported to have beneficial effects on the soil structure. Being a high-cost fertilizer, its use is limited only to high-value horticultural crops.

Glaucous leaf surface

A glaucous leaf surface is a surface that is covered with whitish waxy material or with a powdery bloom as in grapes (Fig.G.3).

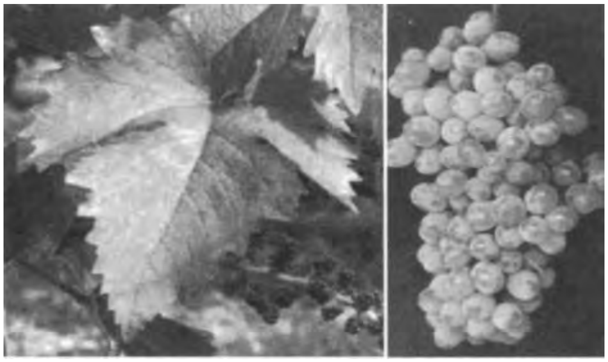


Fig.G.3: Glaucous surface of grape leaf and berries (right).

Gleification: See Gley

Gley

Gley is a sticky waterlogged soil, lacking in oxygen and typically grey to blue in color. When soil is waterlogged and inadequately aerated for long periods, the soil iron is reduced to its ferrous state. This causes spots of rust color (**mottles**) to develop on the soil. The **gley soil** layer is the **gley horizon**, which is denoted by the letter G. A darker color of the soil horizon usually indicates high organic matter content in the soil. Gleization or **gleying process** is the phenomenon responsible for the gley horizon. For rice culture, gleying means maintaining the soil layer under reduced conditions or maintaining water on the soil surface during the rice-growing season.

Gleification is the phenomenon by which the soil turns bluish, greyish or greenish when it contains ferrous salts and when it is poorly aerated for a long time. When the ferrous salts are re-oxidized with improved aeration and better porous structure of the soil, **degleification** occurs. This is the opposite of gleification. Various cultural practices are responsible for gleification and degleification.

Gley horizon: See Gley

Gleying process: See Gley

Gley soil: See Gley

Gleysols

Gleysols (denoted by GL) are soils of unconsolidated material showing gleyic properties. Gleysols cover a total land area of over 700 million hectares concentrated mainly in the sub-arctic regions of Russia, Siberia, Alaska, etc.

Gleysols are also present in humid, temperate and low lying tropical regions. These soils may be **hydromorphic** in nature, and are present within 50 cm of the surface. They may have an A-horizon, a histic H-horizon, a cambic B-horizon and (petro) gypsic horizon.

Gleysols do not contain coarse-textured material and alluvial deposits. They have several subclasses like calcic gleysols, mollic gleysols and andic gleysols.

Gliricidia

Gliricidia sepium is a small to medium sized, fast growing tree, which grows to heights of between 2 to 5 meters, with stems of around 30 cm in diameters. The tree has alternately arranged compound leaves, with 7 to 25 leaflets per leaf.

Gliricidia flowers at the beginning of the dry season with colors ranging from light pink to reddish white. It is a leguminous tree which fixes nitrogen from the atmosphere. It produces 15 to 50 nodules per plant.

Gliricidia, a native of Central America, is a sturdy tree which adjusts well to a range of climatic and soil conditions. It grows well on volcanic, clayey, sandy, saline and even alkaline and acidic soils. Rainfall ranging from as low as 600 mm to a high of 3500 mm is tolerated by the tree. It also tolerates temperature of upto 42°C and dry spells of upto 8 months.

Barring the following conditions, gliricidia is gaining popularity for a variety of reasons: (i) Temperature below 20°C is unfavorable to the tree. (ii) In altitudes of over 1200 meters, Gliricidia is uncommon. (iii) Gliricidia cannot tolerate pH of less than 4.5 or high aluminum saturation of greater than 60%.

Gliricidia renders the following benefits to our ecosystem: (i) Gliricidia is an ideal candidate for quick forestation of land. Since its twigs can produce roots, propagation through cuttings is easy. (ii) Gliricidia is commonly called **green manure** because of its use in enriching the soil and providing abundant nitrogen to plants. The leaves are rich in protein and nitrogen, and supply the necessary nitrogen when incorporated in rice fields. When these trees form bunds on rice fields, their own vegetative growth becomes vigorous, in turn providing enough nitrogen supplies through further incorporation. Gliricidia has a role to play in the productivity of many important crops like jute, tea, coffee, maize and rice. For instance, in the cultivation of jute, Gliricidia can substitute 40 kg of nitrogen fertilizer by just 5 kg of its leaves per hectare. Gliricidia compost acts as a urea substitute in jute cultivation. (iii) The wood is very durable and thus ideal for furniture, poles, implements, etc. The wood is a good source of fuel, emitting very little smoke. (iv) The leaves of the tree provide nutritious supplements of crude protein (18 to 30%) to livestock, especially cattle and sheep. Pod peels can also form dry season fodder. (v) Conservation of moisture, reduction of soil temperature, and erosion control on sloping lands (hedgerows) are among the beneficial uses of Gliricidia to the environment.

Giliricidia is also used as a shade (for tea, coffee, etc.), a support (for cassava, yam, etc.) and as a windbreak.

Gliricidia flowers make good honey. It is also observed that planting Gliricidia around or in between crops reduces insect and fungal attack; it also controls weed growth. Thus, it is used in the production of insecticides, weedicides and rodenticides.

Global positioning system

Global positioning system (**GPS**) is one of the techniques employed for site-specific management of large fields. It is useful in crop management, including fertilizer application.

Global positioning system allows the exact position in the field to be determined and re-located without reference to time, location and weather. Fertilizer spreaders can use the GPS in conjunction with soil test data stored in a **geographical information system (GIS)** to apply the nutrients needed for individual areas.

Global warming

Global warming refers to the observed increases in the average temperature of the Earths' atmosphere and oceans in recent decades. The average global temperature is reported to have risen by 0.6° ± 0.2°C in the last century. The increased volumes of carbon dioxide and other greenhouse gases released by the burning of fossil fuels and land clearing are considered as the main sources for this warming.

An increase in global temperatures can in turn cause other changes including a rise in the sea level and temperature as well as changes in the amount and pattern of precipitation. These changes may increase the frequency and intensity of extreme weather events, such as floods, drought, heat waves, hurricanes and tornados. Other consequences include a higher or lower agricultural yield, glacier retreat, reduced summer stream flows, extinction of species and an increase in the range of diseases.

Climatologists accept that the Earth has warmed substantially, atleast in the West, but the causes of this change are not always very clear. There is also a strong view that even if greenhouse gases are stabilized at present day levels, a further warming of perhaps 0.5 to 1.0°C could still occur.

Greenhouse gases are transparent to short wave radiation from the sun. However, they absorb some of the longer infra-red radiation from the earth, making it more difficult for the earth to cool. The CO_2 levels are expected to continue rising due to ongoing fossil fuel usage, though the actual rise will depend on uncertain economic, sociological, technological and natural developments. Globally, the majority of anthropogenic gas emissions arise from fuel combustion. The remainder is accounted largely for 'fugitive fuel', emissions from industrial processes (excluding fuel combustion) and agriculture. These contributed 5.8%, 5.2% and 3.3%, respectively.

The expected release of possibly as much as 70,000 million tons of methane from permafrost peat bogs in Siberia, which have started melting due to the rising temperatures, may lead to significant additional sources of greenhouse gas emission.

Various alternative hypotheses have been proposed to explain the observed increase in global temperature, including but not limited to the following. (i) The warming is within the range of natural variation. (ii) The warming is a consequence of coming out of a prior cool period – the little ice age. (iii) The warming is a result of variances in solar irradiance. At present, these have little support within the science community as an explanation for recent warming.

The predicted effects of global warming are many and varied, both for the environment and for human life. The effects include rise in sea levels, impacts on agriculture, reduction in the ozone layer, increased intensity and frequency of extreme weather events and the spread of disease. In some cases, the effects may already be felt although it is difficult to attribute specific natural phenomena to long-term global warming. Some scientists believe that global warming is already causing death and disease across the world through floods, hurricanes, environmental destruction, heat waves and other extreme weather events. They also feel that global warming has led to a negative glacier mass balance, causing a glacier retreat around the world. Some glaciers that are in disequilibrium with the present climate have already disappeared, and increasing temperatures are expected to cause continued retreat in the majority of alpine glaciers around the world. Of particular concern is stated to be the Hindu Kush and Himalayan glacial melts which are a large and reliable source of water for China, India and much of Asia, and form a principal dry season water source. Research has found a strong correlation between increasing temperature and glacier retreat.

Even a relatively small rise in sea level would make some densely settled coastal plains uninhabitable and create a significant refugee problem. A sea level rise of less than 1 meter through 2100 is predicted but this is predicted to increase in the next millennium. The estimated 1 meter rise may displace around 200 million people. Financial institutions have warned that the increasing frequency of severe climatic events, coupled with social trends could cost almost 150 billion US dollars each year in the next decade. These are all, of course, studied speculations.

The creation of biomass by plants is influenced by the availability of water, nutrients and carbon dioxide. A rise in atmospheric carbon dioxide can increase more biomass. A rising temperature can also increase the efficiency of the metabolism of most plants, potentially allowing them to create more biomass. A rising temperature can also increase the growing season in colder regions. It is argued that these effects can create a greener, richer planet, with more biomass available.

Some models predict a possible increase in plant productivity. However, there are several negative impacts like decrease in productivity above optimal temperature. A greater variation in temperature is likely to decrease wheat yields and grain forage quality, if CO_2 and higher temperatures are further increased. Satellite data for the period 1982 to 1991 for the northern hemisphere showed an increased productivity and widespread droughts between 1991 and 2002.

Melting of Arctic ice may open the Northwest passage in summer in another ten years which would cut 5000 nautical miles from shipping routes between Europe and Asia. Negative impacts of ice melting include increase in the global warming rate as ice reflects more sunlight than open water, which is occurring from the ice melting. There are also ecological effects of melting polar ice and separation of ice blocks. For example, dead polar bears are being found in polar waters due to drowning of these animals as these bears use sea ice to reach prey and swim to another block when one breaks up.

Globular proteins

Globular proteins have compact, rounded, usually water-soluble molecules. Enzymes that catalyze biochemical reactions are important examples of this type of proteins. (See also Protein.)

Globulins

Proteins are classified as globulins, **albumins** and **prolamines** based on their solubility. Globulins are water insoluble proteins, but soluble in salt solutions. In humans, blood globulins resist disease.

Glucose

Glucose is a monosaccharide sugar found in honey and fruits. It is the primary product of plant photosynthesis, which is optically active and dextrorotatory.

Glucose and its derivatives are critically important in the energy metabolism of living organisms. It is transported around the animal body through blood, and by lymph and cerebrospinal fluid, to cells where the energy is released during glycolysis.

The structural formula of glucose is shown in Fig.G.4.

Fructose, the stereoisomer of glucose, occurs in green plants, fruits and honey. It is sweeter than sucrose.

Yeasts readily ferment glucose to produce ethyl alcohol and carbon dioxide. It is also metabolized by bacteria into acetic and butyric acids, lactic acid, butyl alcohol, acetone, hydrogen, carbon dioxide and many other compounds.

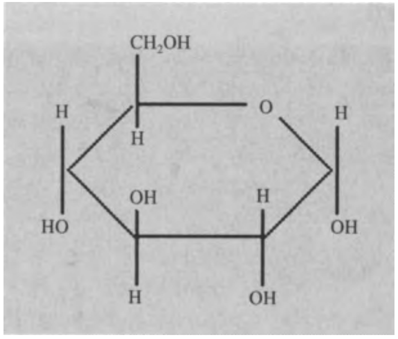


Fig.G.4: Structural formula of -D-glucose.

Plants and animals convert complex carbohydrates (like starch and glycogen) into glucose to meet their energy needs. Glucose is produced commercially by hydrolysing corn starch with dilute mineral acid. Commercial glucose is mostly used in the manufacture of confections and in the canning industry.

Glucosylation

The process of attachment of a glucose residue to the nucleic acid molecules of certain bacteriophage mutants is called glucosylation. This renders the nucleic acid resistant to the influences of host cell nucleases, thus enabling the phage to infect hitherto resistant stains of the bacterium. Glycosylation is possible only when the bacteriophage previously infects a bacterium possessing the necessary enzyme system.

Glutinous rice

The glutinous variety of rice is native to Southeast Asian countries and is very popular in Japan. It has short grains and has high starch content. When cooked, it turns starchy and translucent. However, unlike what seems to be implied, rice contains no gluten, a protein that is very sticky in nature. Glutinous rice is commonly called **sweet rice**, or **sticky rice**.

Glycerides

A glyceride is a lipid which consists of a glycerol molecule with up to three fatty acids attached to it. Glycerides function as fat storage molecules. Depending on the number of fatty acids it has, a glyceride is either called a monoglyceride, diglyceride or a triglyceride. Fatty acid esters with glycerol are found in plant oils and animal fats. They are thus available widely in nature. Fats are triglycerides. Margarine contains monoglyceride and diglyceride.

Glyceryl esters

An ester of glycerine and carboxylic acid is a glyceryl ester. An ester is an organic compound corresponding to an inorganic salt, produced by reacting an organic acid and alcohol.

Glycine

Glycine is the simplest naturally occurring amino acid and is a constituent of most proteins. Its formula is $H_2N{\cdot}CH_2{\cdot}COOH$.

Glycoluril

Glycoluril is a condensation product of urea and glyoxal containing 39 to 40% nitrogen. Its solubility in water at 30°C is 0.2% and hence it is used as a slow-release nitrogen fertilizer.

Glycolysis

In the first stage of respiration, known as **internal respiration** (or **tissue respiration**), glucose is broken down to pyruvate by anaerobic respiration. This process is called glycolysis.

Good heart

Good heart is a fertile soil which is capable of producing good crop.

Good quality water

Good quality water has an **electrical conductivity** (EC) and **sodium adsorption ratio (SAR)** of less than 2 and 10, respectively. The classification of irrigation water is based on EC and SAR.

Good soil

Soil productivity is determined by the **Storie index rating**. The estimation of numerical fertility (NF) is used to grade soils as poor, average and good. A good soil has an NF value of 70. (See also Fertility, numerical estimation of.)

Gossans : See Pyrites

GPS

GPS is short for **global positioning system**.

GR

GR is short for **gypsum requirement**.

Grade

The word grade is used in many ways. In the context of fertilizers, grade is an indication of the content of plant-nutrients in fertilizers, expressed as whole numbers in terms of available nitrogen (N), phosphorus (as P_2O_5), and water-soluble potash (K_2O). Usually, three numbers separated by a hyphen denote the grade of a fertilizer. These numbers always refer to the content of the guaranteed minimum primary nutrients in the order of N, P and K which are always expressed as percentages by weight. If other nutrients are present, their contents are also indicated in the grade of the fertilizer product, each extra number being followed by the chemical symbol of the nutrient it represents. A fertilizer grade of 18-18-0 is guaranteed by the manufacturer to have 18% nitrogen, 18% phosphorus and 0% potassium. A fertilizer product with a grade of 12-6-22-2 MgO is guaranteed by the manufacturer to contain 12% nitrogen, 6% phosphorus, 22% potassium and 2% magnesium oxide. The use of grades assures the consumer that he/she is purchasing plant nutrients through the named fertilizer product.

In the context of soil, grade is used as a criterion to define the soil structure. It denotes the degree of soil development, which is the value and importance of the aggregation in relation to the entire mass ratio of the aggregated to the non-aggregated. The four grades of soil structure are (a) structure-less, (b) slightly developed, (c) moderately developed, and (d) well-developed.

A sloping surface on which water flows is also called the grade. Furrow irrigation, flood irrigation and streams are the grades through which water runs.

Grafting

Grafting is a method of propagation by inserting or joining a bud or a scion of a plant on the root stock of another plant. Grafting is practiced to form a living union which develops into a whole plant of the same variety as the scion.

Grahm's salt: See Sodium metaphosphate

Grain: See Seed

Gram-negative bacteria

The Gram-negative bacteria, named after a Danish physician Hans Christian Gram, are bacteria, which lose the initial color of the Gram stain and then take on the color of the final stain (light pink). *Rhizobium* is an example of Gram-negative bacteria. **Gram-positive bacteria** are bacteria that retain the Gram stain. *Bacillus* is a Gram-positive organism. (See also Staining.)

Gram-positive bacteria: See Gram-negative bacteria; Staining; Gram reaction

Gram reaction

In the method of **Gram staining** for staining bacteria in tissue sections, the section is stained using a violet dye mordant with iodine solution and decolorized in alcohol; not all bacteria are stained as some are decolorized. A counter stain, usually pink, is now used to show the decolorized cells, and the method is usually applied to a smear of a culture. Bacteria that retain violet stains are said to be **Gram-positive**, those decolorized and taking up the counter stain are **Gram-negative**. The two groups have characteristic biochemical differences, and are called Gram reaction.

Gram staining

Gram staining is a differential staining procedure in which bacteria are classified as **Gram-negative** or **Gram-positive**, depending on whether they retain or lose the primary stain when subject to treatment with a decolorizing agent. The procedure is named after a Danish physician, Hans Christian Gram. The staining procedure reflects the underlying structural differences in the bacterial cell of Gram-negative and Gram-positive bacteria.

Staining has considerable medical value because the cell walls not only determine the staining difference, but also the behavior and antibiotic sensitivity of the bacteria. In Gram staining, heat fixed bacteria are first stained with crystal violet and then with iodine solution, which is followed by an alcohol or acetone rinse. The Gram-positive bacteria become bright purple, and the Gram-negative bacteria become decolorized on staining. (See also Staining.)

Granite dust: See Granite fertilizer

Granite fertilizer

Granite is mostly feldspar, the mineral which has a low solubility. It is a source of potash. **Granite dust** is often commercially sold as a slow-release potash fertilizer for organic production. The granite dust contains potash in the range of 1 to 5% based on the overall mineral composition of the rock.

Granular fertilizer

Granulation is a significant advance in fertilizer technology, and provides considerable advantage to both the manufacturer and the user.

Fertilizers in the form of granules are granular fertilizers. Granulation of fertilizers (or **pelletization of fertilizers**) is the process of converting powdered fertilizers or final slurry into granules, ranging from 1 to 5 mm in size, during fertilizer production. The average granular fertilizer product is in the form of particles of around 1.00 to 3.35 mm in diameter. The Association of American Plant Food Control (AAPFC) defines 'granular fertilizer' as a fertilizer of which 95% or more is retained on a series of sieves within the range of 4.75 mm to 850 μm openings. According to the European and Japanese definition of granular fertilizer, the granules are generally in the range of 2.0 to 4.0 mm in diameter.

Granular fertilizers cake less because of their less surface area, and they are, therefore, more advantageous to use. They produce less dust, hence, have lower product losses (Fig.G.5). (See also Particle size distribution of fertilizer; Fertilizer granulation.)

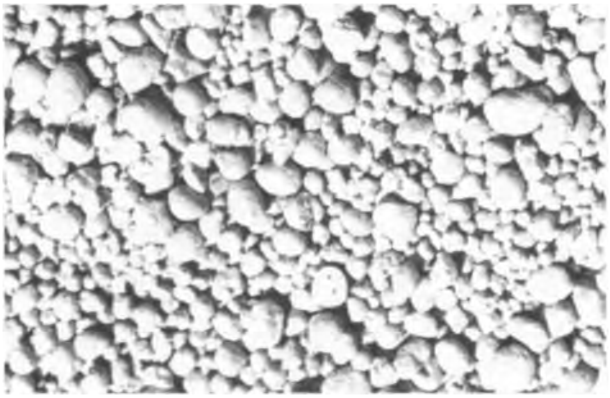


Fig.G.5: A granular fertilizer contains granules of around 1 to 4 mm diameter.

Granular mixed fertilizers

When two or more granular fertilizers of a similar granule size (1 to 4 mm) are mixed to form a compound fertilizer, it is known as a granular mixed fertilizer. A granulated fertilizer mixture contains any two or more plant nutrients mixed in a granular form or is granulated after mixing individual components.

The granulation of fertilizers offers a well-defined grain size distribution, nutrient content and good application properties. Besides, the higher bulk density of the granules needs a lower storage space and can also be stored and transported more economically.

Granular mixed fertilizers do not cake as much as powdered mixed fertilizers and cause less dust which minimizes product losses. Granules produced from various feedstocks (solids, slurries, melts) by granulation technique do not segregate as it happens with bulk blends.

Granular fertilizers delay the nutrient delivery to the plant until the granules disintegrate completely and thus ensure nutrient supply to the plant over a longer period.

Granular soil inoculant

There are different types of inoculants: granular, **agar based**, **peat based**, **carrier based**, **freeze dried**, etc. There are several methods of applying inoculants or biofertilizers. Some inoculants are applied to the seeds and some to the seedlings, but by different methods.

Granular soil inoculant is for treating the soil. The inoculant is mixed with several substances before broadcasting. For instance, *Azospirillum* is mixed with FYM and soil, phosphate solubilizing inoculant is mixed with compost or soil, before applying to the soil.

In the granular soil inoculant process, grains of sand, marble or calcite are wetted by peat based cultures using adhesives. Granular inoculants, the shelf life of which is generally short, are broadcast over the fields by farm machinery or airplanes. (See also Inoculant.)

Granular strength of fertilizers

Fertilizer granules should have sufficient mechanical strength to withstand normal handling and storage without fracturing. Their mechanical strength depends on their porosity, shape, crystal surface, moisture content, chemical compositions and method of production.

The granules should ideally have a high crushing strength, abrasion resistance and impact resistance.

The three aspects of the mechanical strength of granules are as follows:

(i) **Crushing strength of granules**, which is the minimum force required for crushing the granules, is measured by applying pressure to individual granules of a specified range, and noting the pressure required for fracturing each granule. Often, a simple finger test gives an idea about the strength of the granule. If a granule can be crushed between the thumb and the forefinger, it is 'soft'; if it can be crushed with the forefinger on a hard surface, it is 'medium hard', and if it remains intact, it is considered 'hard'. Particles of 2.36 to 2.80 mm diameter with a crushing strength of less than 1.5 kg/cm^2 tend to fracture easily and form dust during handling. Particles with a crushing strength of about 1.5 to 2.5 kg/cm^2 would need special handling precautions, whereas those with a crushing strength greater than 2.5 kg/cm^2 can do away with special precautions. As crushing strength increases significantly with the particle size, granules of equal size should be considered for comparing the crushing strength.

(ii) **Abrasion resistance of granule** is the resistance to the formation of dust and fines and to granule fracturing. Granule fracturing happens because of the occurrence of granule-to-granule and granule-to-equipment contact during handling. Abrasion resistance is determined by measuring the percent dust and fines created by subjecting a sample to abrasive action. For example, in the rotary drum or screen-type actions, steel balls are used as the abrading tools. The values of abrasion resistance are useful in estimating the product degradation during processing, handling, storage and application.

In the **Rotary drum-type method for determination of abrasion resistance**, a pre-screened sample is weighed and placed in a drum with an abrading medium. The drum is rotated at a specified speed for a predetermined period. After separating the abrading medium, the sample is mechanically sieved to separate the dust, fines and fractured granules.

In the **screen type method for determining abrasion resistance**, a pre-screened sample is weighed and placed on a sieve with an abrading medium. The sieve containing the sample and the abrading medium is placed in a mechanical shaker and shaken for a predetermined period at a specified amplitude and frequency. The dust, fines and the fractured granules are collected in a pan below the sieve and measured.

Urea prills with a low single particle crushing strength show a relatively high degradation in abrasion-resistance test, whereas a diammonium phosphate granule, with a high crushing strength, shows a relatively low degradation in the same test. However, potassium chloride granules that have high single-particle crushing strength show relatively high degradation in the abrasion resistance test probably because of irregular, block-like particle shape.

(iii) **Impact-resistance of the granule** is its resistance to breakage on impact against a hard surface. This knowledge comes in handy when fertilizer spreaders are to be used, or the material is to be discharged from an overhead point, into a ship or a fertilizer bag.

Impact can be created by dropping a sample from a given height or impinging a sample on to a steel plate. Its strength is determined by measuring the granule breakage after subjecting the sample to a standardized impact. The resistance is normally calculated by determining the percent difference in round granules (sphericity) before and after the impact test (or by pre-screening the sample to a specified size before the impact test) and then re-screening the sample after the test to determine the amount of breakage.

Granulation efficiency

Granulation efficiency is the mass fraction of the particulate material that leaves the granulator as a finished product with a prescribed range of the grain sizes (assuming 100% sieve efficiency). Granulation efficiency is also defined as a mass fraction of the finished product at the dryer outlet (some re-granulation in the dryer is allowed in this definition). (See also Fertilizer granulation.)

Granulation equipment: See Fertilizer granulation

Granulation of fertilizers

Granulation of fertilizers (or **pelletization of fertilizers**) is the process of converting powdered fertilizers or final slurry into granules, ranging from 1 to 5 mm in size, during fertilizer production. (See also Fertilizer granulation.)

Granule

Many fertilizers are produced as (spherical) granules. A granule is bigger than a prill.

Granule apparent density

Granule apparent density is determined by submerging a known weight of granules and measuring the volume of mercury that is displaced. (See also Bulk density of fertilizer.)

Granulometry

Granulometry, which uses the inputs of sieve analysis, is the science of particle size analysis of a powdered material. This science comes in handy in the production of fertilizers.

Grassed waterway

Grassed waterways are the waterways covered with special grasses that resist erosion. Such waterways, natural or man-made, are used to reduce soil erosion.

Grasses

Grasses are large group angiosperms that are of great importance to man. Strictly speaking, grasses only include those species belonging to the family Gramineae but the name applies to any plant with a similar growth habit, for example, sugar cane and bamboo. Grasses also include cereal crops, such as wheat, rice, corn, sorghum and millet.

Grasses are self or wind pollinated and have hollow or pithy jointed stems bearing lanceolate leaves. The fruit is a **grain**.

Grasses provide about 53% of the total feed units (forages and grains) consumed by all domestic livestock, in the form of pastures, native range grazing and harvested forage (hay, green feed and grown silage). Grasses have other roles like in the conservation of soils, in the development and conservation of water resources, in upstream flood control, in wildlife and game management and in a wide range outdoor recreation.

Grass species may be **annual** or **perennial**. Some perennial species are perpetuated by creeping stems as well as by seeds. Stems that creep underground are termed **rhizomes** or **root stocks**, whereas surface-creeping stems are called runners or stolons. In sub-humid to semi-arid regions, species are predominantly perennial and are perpetuated mostly by seed. In other areas, both annuals and perennials occur. All grasses have fibrous root system that permeates the soil extensively, making grass effective in preventing soil erosion and restoring soil humus content.

Grasslands

Grasslands are large open areas, covered mainly with grasses, as also with clovers, moss, lichens, heather, etc. These are largely used for grazing (Fig.G.6). Rainfall on grasslands is generally insufficient to support higher plant forms.

There are three main types of grasslands which are (a) **savannah**, or tropical grasslands found in parts of Africa and South America, (b) **prairie** found in middle and North America, Argentina, South Africa and North Australia, and (c) steppes found mainly in central Asia.

Grasslands are of considerable economic importance. They provide food for domestic animals and are often excellent crop land for cultivation. There is always a need to have them, either naturally or man-made. Saurashtra in the state of Gujarat, India, has natural savannah type grasslands.

Grassland production has been enhanced over the years by the development and application of new techniques - notably, the increased use of nitrogenous fertilizers, new grazing methods, improved herbage conservation and irrigation.

The nitrate losses by leaching from grasslands are small because of the dense and extensive grass root system, as well as very long growth seasons and nitrate uptake. Grasslands also accumulate soil organic matter which is rich in nitrogen. They also slow down soil erosion because of the deep and extensive root system of the grasses.

Grass tetany

Grass tetany, also known as **hypomagnesemia**, is a dangerous disease afflicting cattle, evidenced by their abnormally low blood magnesium levels. This is caused by their consumption of forage crops with a magnesium concentration of less than 2 g/kg. The factors responsible for grass tetany include a high concentration of potassium (>30 g/kg), K/Ca^{++}, Mg^{++}, equivalent ratio >2.2 and a nitrogen concentration >40 g/kg in the plant. Grass tetany often occurs in the spring. The soil magnesium level may be increased by adding dolomite, or the use of magnesium fertilizers is advisable.

Grave

Potatoes or other root crops were earlier stored by neatly piling them and covering them with earth and straw, called a **clamp**. Clamps are now mostly replaced by indoor storage systems, known as graves, **hogs**, **burys**, **pies** and **pits**.

Gravimetric analysis

Gravimetric analysis is the method of determining the amount of a substance present in a solution to form a precipitate. The filtrate is then dried and weighed. For example, when silver nitrate in an acid medium is added to a soil solution, the chloride ion precipitates as silver chloride which is separated by filtration or centrifugation and weighed. From the mass of silver chloride formed, the moles of the chloride ion in the original sample can be calculated.

Gravity erosion

Gravity erosion, also called **mass wasting**, occurs when large masses of soil are moved and wasted by gravity.

Fig.G.6: Grassland with vegetation like grasses, clover, heather, etc. is used for grazing.

The movement can be instantaneous as in a landslide, or slow and persistent over many decades as in soil creep. Erosion by gravity moves less quantity of soil than that done by wind and water.

Gravity water

Based on its movement, soil water is classified as gravity water, capillary water, hygroscopic water and plant available water. Gravity water or **vadose** is the water present in soil above the water table, which drains away by gravity.

Gravity wells

The wells, the depth of which reach the water table where water is not under pressure, are called gravity wells. (See also Ground water).

Grazing

Grazing is the action of animals feeding on vegetation.

Great families

A great family is a subdivision of soil based on its particle size or geomorphologic characteristics. (See also Soil family.)

Great group

Great group is a suborder of soil taxonomy. It may have the same arrangement as that of soil horizons and have a comparable temperature and moisture range. However, the accumulation of clay, iron and humus changes the feature of that part of the suborder; forming pans or hard zones that interfere with the water movement or root penetration. The presence of calcium, magnesium, sodium, potassium, gypsum, etc. and properties like soil temperature distinguish a great group from another.

Green acid

Green or **wet process phosphoric acid** is the phosphoric acid made by treating rock phosphate with sulphuric acid.

Green bacterium: See *Thiobacillus*

Greenhouse

A greenhouse is a house or tent-like structure with glass walls in which plants are protected and cultivated under controlled conditions (Fig.G.7).

Although heating is not essential in greenhouses, proper ventilation is essential to maintain the temperature within. Shading may also be necessary to keep the temperature down. Greenhouses enable plants to be grown in places with unsuitable climate, making it possible to force plants to bloom or bear fruit out of season.

Greenhouse effect

Greenhouse effect is the effect caused by trapping of the sun's warmth in our planet's lower atmosphere due to the greater transparency of the atmosphere to visible radiation from the sun than to infrared radiation emitted from the planet's surface. This infrared radiation, because of its longer wavelength, is absorbed by carbon dioxide. The overall effect is the increase of the average temperature of the earth and that of its atmosphere. This results in **global warming**, an effect resembling the one in a greenhouse (Fig.G.8) where light and ultraviolet radiations of longer wavelength pass through the glass into the greenhouse while infrared radiation is absorbed by the glass with only a part re-radiated outside the greenhouse.

Greenhouse effect is a major environmental hazard as a small increase in temperature could change weather

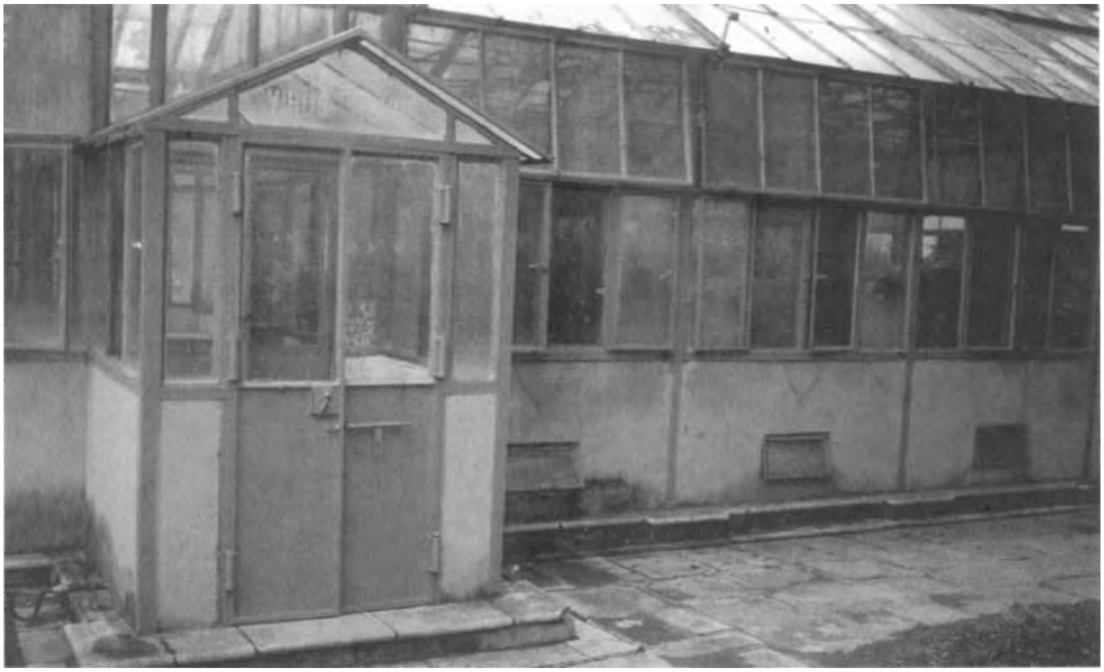


Fig.G.7: A greenhouse with glass walls is also called a glasshouse.

Fig. G.8: A row of greenhouses.

patterns and agricultural output. An increase in temperature might also induce glaciers and polar ice caps to melt, raising sea water level. Some scientists have predicted that green house gas levels will double over the next 50 years as fossil fuel consumption continues to increase. This, in turn, will further increase global warming which will produce dramatic climatic changes, greater heat stress and more frequent droughts in the southern farming regions, causing agricultural regions to shift northwards.

Carbon dioxide from coal-fired power stations and automobile exhausts is the main greenhouse gas. Other contributory pollutants are nitrogen oxides, ozone, methane, and chloro-fluoro-carbons. In 1992, representatives of 160 nations met in Rio de Janeiro, Brazil, and agreed to reduce carbon dioxide emissions to curb the greenhouse effect.

Greenhouse experiments

Greenhouse experiments or **pot culture experiments with fertilizers** are part of diagnostic techniques used to ascertain the soil nutrient status. For a relatively quick and inexpensive diagnosis, such techniques are performed under controlled conditions (as shown in Fig.G.9). In these experiments, soil samples taken from a plow layer depth at different places of the same field are mixed thoroughly and then used. (See also Diagnostic techniques.)

Greenhouse gases

Greenhouse gases include carbon dioxide, methane, chloro-fluro-carbons, etc. They absorb infrared radiations re-radiated by the earth, creating a **greenhouse** like condition and increasing the soil temperature.

Fig. G.9: Pot culture experiments in greenhouses are quick and inexpensive diagnostic techniques for nutrient status in soil.

Green leaf manuring: See Green manure

Green manure

Green manure is a crop or green plant biomass buried or plowed into the soil to supply plant nutrients, particularly nitrogen, besides providing humus to the soil.

In the well-known **green leaf manuring** practice, green leaves and twigs are first used as winter cover and then plowed in as green manure and to prevent the accumulated nitrates from leaching out.

Green manure crops include grain legumes (cowpea, horse gram, green gram, etc.), woody perennial legumes (*Sesbania, Crotalaria, Desmodium,* etc.) and others of the lupin group like wild indigo, buckwheat, etc. Italian ryegrass, mustard, etc. are also used as green manure (Fig.G.10).

Fig. G.10: Jute (Corchorus olitorius) is used as a green manure.

Green manure helps to increase the organic matter content, partial pressure of carbon dioxide and solubility of the native calcium carbonate ($CaCO_3$). It also lowers the soil pH and increases plant nutrients to the soil.

Sesbania, a green manuring legume, is tolerant to waterlogging and high exchangeable sodium percentage. It is an ideal crop for green manuring in salt affected soils. It grows during summer – a lean period for rice and wheat crops – and fits into the cropping pattern of alkali soils.

Normally, a 45-day-old *Sesbania* crop attains a height of 1.5 to 1.8 m, and is ideal for use as green manure. It decomposes easily and quickly. About 50% of the organic nitrogen in this green manure is converted into a readily available ammoniacal form within 4 to 6 days and the rest within 10 to 20 days, ensuring a steady supply of nitrogen to the rice crop. A 45 days old *Sesbania* crop, without a decomposition period increases rice yield and saves 10 to 15 days of cultivation and decomposition of the green manuring crop. A longer growth period renders the plants hardy, woody and difficult to decompose. It is observed that the increase in rice yield by green manuring can be equivalent to adding 80 kg of nitrogen/hectare through a chemical fertilizer like urea.

Gliricidia and alfalfa are among the few common shrubs and trees useful for green leaf manuring. *Tithonia diversifolia*, which grows as hedge, is also used as a green leaf manure and in the production of a liquid fertilizer.

For better results, green manure crops should be plowed back after 45 to 60 days of growth prior to flowering, and decomposed in anaerobic conditions. This practice augments the production of organic acids and trapping of the decomposing products for dissolution of the soil calcium carbonate ($CaCO_3$). Thus, even just after the green manuring crop is fed into the soil, rice seedlings can be transplanted without any harmful effect.

It is thus clear that green manuring involves the practice of growing legumes to a certain vegetative stage and then incorporating them into the soil, to improve crop yield. This practice is used in reclaiming land (sesbania), increasing the carbon dioxide (CO_2) evolution, improving physical condition of the soil, mobilizing iron and manganese, and ensuring a steady supply of nitrogen to the plants, the latter being another way of utilizing biological nitrogen fixation *in situ*.

Green revolution

Since time immemorial, people have nurtured some special traits in plants. They have for instance, sown such plants as they thought were easy to grow and good for their taste and pocket. This has been the basis of modern day plant breeding. But changes brought about through the process of human selection can vary drastically, when compared with evolution through natural selection. A classic example of a dramatic variation from its ancestor, seen in a modern plant is the modern day corn. This corn is totally dependent on cultivation compared with its rugged wild grass ancestor, the teosinite.

In the modern day perspective, to contain the problems of starvation in the developing world it was necessary to establish an efficient agricultural system. Plant breeding contributed to improved yields and quality of agriculture. In this area, the United States has contributed substantially in terms of actual research as well as financial assistance. Research was mainly done on wheat, rice and corn.

Centers were established in developing nations, to develop and select new varieties, while preserving diverse species. The process of creating stronger disease-resistant crops involved the use of genetic material from indigenous plants, and procreating the same on a large scale. Countries, where experimental stations were established, included Guatemala, Peru, Ecuador, Mexico, etc.

The results of crop breeding, plant pathology and genetic engineering were so astounding that toward the end of the 1960s food production increased dramatically, setting off the "Green Revolution" [William Grand, Head of the U.S. Foreign Aid program (USAID) in 1968, is credited with coining this term].

Wheat, rice and corn have been the triggers of the green revolution. The development of high-yielding varieties and an efficient nutrient management yielded high returns. Dr. Norman E. Borlaug is known to have done pioneering work in this field. He developed high-yielding dwarf strains of wheat from crosses with a dwarf variety from Japan at the Centro International de Mejoramiento de Maiz y Trigo, or CIMMYT for short, (International Center for Maize and Wheat Improvement). The result of this work was a strong, rust-resistant plant with stiff stems which did not lodge. The cultivation of this plant met with stunning success in India, Pakistan and Mexico. It was for this technological break-through that Dr. Borlaug was awarded the Nobel peace prize in 1970.

Meanwhile, considering the vast consumption of rice globally, efforts were initiated to conduct systematic research on producing high yielding rice. With the help of international bodies, research centers were established in many parts of the world to help farmers produce more yields in the same lands at lower input costs like labor, water and fertilizers.

The Ford Foundation, Rockefeller Foundation, International Rice Research Institute (IRRI), International Center for Tropical Agriculture (ICAT, Colombia) and numerous agricultural research institutes and private sector initiatives have been carrying out local research for creating a hybrid, high yielding rice crop (like rice genome studies, adopting new rice types for rice ecosystems, nutrient management, etc.). The development of the first semi-dwarf breeding lines for rice in the mid-60s and their subsequent adoption by farmers is a contender for ushering in the green revolution.

Innovative research, plant breeding, genetic engineering, etc. heralded the green revolution.

But there is a strong view that this path-breaking solution may not be a universal solution after all. The following arguments view the green revolution in a guarded and precautionary mode.

(i) The high yielding crops are highly dependent on external inputs such as fertilizers and pesticide application. This is a game of hosts versus parasites. Prima-facie, although scientists can exploit and strengthen the genes responsible for resistance to attack, a parasite may produce an enzyme that may not be blocked by the plant molecule. Hence, a constant vigil on the part of farmers is critical.

(ii) The high-impact crops depend on adequate water and mechanized farming. This necessitates larger plots of land, which may be a recluse of rich farmers. With Asian cropping being carried out mostly through 'small' land holding (around 250 million of such small farmers exist in Asia) the economies of scale may be considered impossible to achieve.

(iii) Environmental damage has been witnessed in large proportions in areas of these high yielding crops. Some of the culprits include (a) an overuse of inorganic fertilizers. Two barrels of oil are required to produce a barrel of nitrogen fertilizer. The need for fossil fuels in some specialized produce is also a cause for worry, (b) misuse of natural water reserves. Since irrigation depends on natural water systems like rivers, underground aquifers, etc., a continuous demand for water puts pressure on the natural reserves which usually do not get replenished, and (c) an ever-exploding population. Any amount of production, it is believed, would be insufficient for a population that is estimated to double the present number by 2025. To provide adequacy, production of food crops will have to grow more than double.

Scientists believe that there are no clear-cut answers to this parity between demand and supply of food. To achieve a balance between the preservation of environment and food adequacy, long term environment friendly solutions may have to be adopted. These include **reduced tillage**, **no tillage**, reduced run-off and leaching, increased efficiency of water, use of organic fertilizers (manure, compost), increased use of improved strains of *Rhizobium* and other nitrogen fixing bacteria and a conservative use of pesticides and fungicides.

Greensand: See Glauconite

Green sickness

Green sickness is another word for **chlorosis**.

Green tissue test

Green tissue test is used to evaluate the in-field nutrient status of the plant. In this test, at least 10 to 15 samples from average plants are collected for the test to be conducted immediately.

Green vitriol

Green vitriol, or **copperas**, is a blue-green, water-soluble crystal of ferrous sulphate heptahydrate ($FeSO_4 \cdot 7H_2O$). It is the best known ferrous salt.

Grey leaf

Grey leaf, also called **grey speck**, is a disease in cereals. It mainly affects oats, and sometimes wheat and barley. It is caused by a deficiency of manganese and is characterized by grey streaks on leaves, causing many young plants to die and thus leading to poor grain yield.

If the symptoms of grey leaf develop early when the plants are small, a side dressing with manganese sulphate or its foliar application can generally correct the deficiency.

Grey speck of oats

Grey speck is another name for **grey leaf**. Grey speck of oats is a manganese deficiency disease in oats. (See also Manganese.)

Grid line intersect method for estimation of root colonization

Grid line intersect method is a method used to quantify root colonization. It estimates the percentage of roots colonized by the mycorrhizal fungi. (See also Mycorrhizae.)

Grigg's reagent

Grigg's reagent is an aqueous solution of ammonium oxalate of pH 3.3, used to extract molybdenum from soils.

Gross return

A gross return in the case of soil produce is its total monetary value.

Gross sample

A gross sample is obtained by taking a number of increments in a random manner from points in the bulk material, which gives each part an equal chance of being selected. This is essential, as particles of different compositions are not uniformly distributed within bulk material like soils, fertilizers, sediments, etc.

Gross weight

Gross weight is the total weight of a material including the container. For example, the gross weight of a 50 kg fertilizer bag is taken to be 50.5 kg because it includes 0.5 kg of the bag weight.

Ground limestone

Limestone or dolomite, used in agriculture for liming the soil, is ground to a fineness to ensure that 50% of the particles pass through a 1.70 mm Indian Standards (IS) sieve, and 50% is retained on a 150 micron IS sieve.

Groundnut cake

Groundnut cake, also called **groundnut oil cake**, is the material left behind after extracting oil from groundnut. As groundnut is edible, the pressed groundnut cake (Fig.G.11) can be used as livestock feed. A crushed groundnut cake, called **groundnut meal**, has a high nutritive value and contains about 7.3% nitrogen (N), 1.5% phosphorus (as P_2O_5), 1.3% potassium (as K_2O), and 35 to 45% crude protein. When groundnut cake is added to soil, it provides organic matter. In many parts of the world, groundnut cake is applied to the fields of sugar cane and banana because of its nutritive value and ability to supply organic matter.

The groundnut cake from the country *ghani* (oil mill) contains a little more oil than the one made from hydraulic or expeller-pressed mills, and is slower in releasing nitrogen.

Fig.G.11: Groundnut cake.

Groundnut meal

A crushed **groundnut cake** is called groundnut meal.

Groundnut oil cake

Groundnut oil cake is another name for **groundnut cake**.

Ground phosphate rock

Rock phosphate is mined and ground (to a 100 mesh fineness) to make **commercial rock phosphate** or ground phosphate rock. Ground phosphate rock, when mixed with sulphuric or phosphoric acid, is converted into **superphosphate** (16% P_2O_5). If mixed with phosphoric acid, rock phosphate is transformed into **triple superphosphate** (20 to 22% phosphorus).

$$Ca_3(PO_4)_2 + 2H_2SO_4 + H_2O \longrightarrow Ca(H_2PO_4)_2 \cdot H_2O + 2CaSO_4$$
$$Ca_3(PO_4)_2 + 4H_3PO_4 + 3H_2O \longrightarrow 3Ca(H_2PO_4)_2 \cdot H_2O$$

While most countries do not classify ground phosphate rock as a fertilizer, rock phosphate fertilizer has the advantages of (a) low cost, (b) low capital investment, (c) low levels of special skills required for manufacture, (d) a low energy requirement, (e) negligible processing losses, (f) suitability to direct application, (g) relative invariance to economies of scales, and (h) a significant liming value when ground.

The disadvantages of rock phosphate fertilizers are that they (a) vary widely in their reactivity and their agronomic value, (b) are inconvenient for handling and applying as fine powders, (c) contain relatively low percentage of phosphorus (as P_2O_5) compared to triple superphosphate, and (d) have no water-soluble phosphate. Depending on the chemical nature and the fineness of the phosphate rock, citrate soluble phosphorus can vary in its total phosphorus content from 5 to 17%.

Phosphate rock is effective in warm climates, moist soils, and on crops with long growing periods. Ground phosphate rock is generally effective on acid soils (pH 6.0 or less), but is less effective, particularly in the first year of application, on short-season crops grown in cooler climates. The rock phosphate dosage is generally several times higher than that recommended for soluble phosphorus fertilizers. Plants differ in their capacity to utilize rock phosphate owing to the **cation exchange capacity** (CEC) of the roots - the higher the CEC, the greater the root capacity to extract phosphorus from rock phosphate.

Ground phosphate rock has been promoted and used for reclaiming abandoned farmlands with low phosphorus content, or new lands with low native phosphorus fertility. Strategies for increasing the efficiency of ground rock phosphate include (a) mixing rock phosphate with soluble phosphate fertilizers, (b) mixing rock phosphate with elemental sulphur or sulphur-producing compounds, (c) use of phosphate solubilizing micro-organisms, (d) combining nitrogen fertilizers with rock phosphate by bonding, granulating or compacting, (e) composting with animal manure or organic residues, and (f) including fine rooted legumes in rotation to generate a low pH rhizosphere with a low calcium concentration.

Ground water

Ground water is an important source of water. It is a component of the **hydrologic cycle** (Fig.G.12) which is the continuous circulation of water near the earth's surface. The subsurface water, ground water or **phreatic** (meaning "well" in Greek) **water** comes predominantly from rainwater saturating the earth by infiltration and percolation. It usually collects in porous rock formations, called **aquifers** and is reaped through wells, springs or dug-out ponds. Horizontal wells, called ***ganats*** or ***khanats*** or ***kharezes*** are used in countries such as Iraq, Iran and Afghanistan.

Deforestation, overgrazing and other forms of land degradation reduce rainwater infiltration and cause accelerated run-off, which further leads to a fall in the ground water levels or water tables. A **water table** is the level below which land is saturated with water. **Hydrology** is concerned with properties and movement of the earth's water. Near lakes, swamps and continually flowing streams, the ground water table is at the soil surface, whereas it may be several hundred meters deep

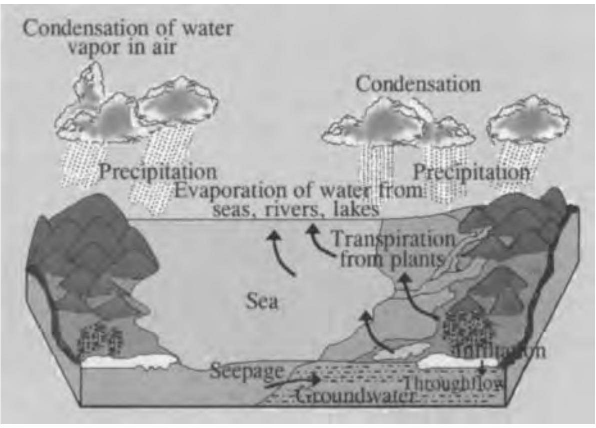


Fig.G.12: A hydrologic cycle.

in dry regions. A good water-bearing source from which groundwater is derived should have a high hydraulic conductivity and a high drainable porosity, called **specific yield**. Specific yield is the volume of water drained by gravity divided by the total volume of a saturated aquifer sample. The specific yield of most unconfined aquifers ranges from 10 to 30%.

It is a matter of concern today in many areas of the developing world that ground water is harvested faster than it is replenished. This process is known as **water mining**. Great 'fossil' ground water deposits are now being extensively mined. The problem is most acute in the Near East and in the coastal belts of India and South-East Asian regions, where sea water intrusions make ground water unsuitable for human consumption and crop production.

Owing to excessive water pumping, the ground water level is falling below the reach of shallow tube-wells, making irrigation expensive. Where the area or zone above the water table is saturated with water, it is called **capillary fringe**.

In some areas, ground water has a nitrate concentration above 50 mg per liter. Ground water also frequently contains calcium and magnesium ions responsible for water **hardness**. The hardness reflects the nature of the subsoil and rocks where water accumulates.

Wells are classified as **gravity well**, **artesian well** or a combination of the two depending on the type of the aquifer that supplies water. Gravity wells reach the water table where water is not under pressure. Where the ground water table is close to the surface, dug-out ponds or open pits dug below the water level are suitable for water storage.

An artesian well is dug vertically into the water table, causing natural pressure to eject water continually without pumping. It is not necessarily a flowing well. The level to which water rises in a pipe placed in the **water-bearing formation** is known as the **piezometric head** or (in three dimensions) a piezometric surface. Whenever the piezometric surface measured in a vertical hole drilled into the aquifer rises above the ground water table, the artesian conditions prevail.

Groupings of transplants, '1+3', '2+1'

Transplants are grouped as '1+3', '2+1', etc; the first number indicating the number of weeks the plant has been in the seedbed and the second, the number of weeks in the transplant bed.

Growth

Growth is the increase in the size of an organism, reflecting an increase in its cell numbers, its protoplasmic material, or both.

The cell number and protoplasmic content do not always increase together. Cell division can occur without any increase in protoplasm, creating a larger number of smaller cells. Alternatively, protoplasm can be synthesized with no cell division so that the cells become larger. Any increase in protoplasm requires the synthesis of cell components and cell membrane. These, in turn, require the synthesis of macromolecules such as proteins, nucleic acids and polysaccharides from amino acids, sugars and fatty acids.

One of the major differences between animals and plants is that the final size and shape of animals can be predicted within limits, whereas it is much more difficult to say just how tall a plant will grow or how many branches it will have.

Growth curve

Growth curve is the curve that shows the change in the number of cells over time in a culture growing medium. Growth curves are characteristic S shaped curves and are divided into three parts: (a) the lag phase during which the cells prepare for growth, (b) the exponential phase when the actual growth occurs, and (c) the stationary phase when the growth ceases.

The time for organisms to double their mass ranges from 20 minutes for some bacteria to 180 days for a human being from birth.

Growth factor of a fertilizer

The growth factor is a specific substance that must be present in the growth medium to cause cell multiplication.

The growth factor of a fertilizer is the amount of fertilizer required for producing at least 50% of the maximum possible yield. The unit of the growth factor of a fertilizer is a **Baule**. (See also Baule unit.)

Growth media for plants

Apart from soils and natural growth media for plants, there are several other artificial, synthetic or semi-synthetic media for better plant growth. These media provide support to roots by way of water and essential nutrient elements for normal growth of plants.

Soil, peat, compost, sphagnum moss, cocopith (Fig. G.13), vermiculite, polyurathane foams and artificial media as used in plant tissue culture are some of the commonly known growth media.

There are some other new growth media being used in some parts of the world. Among them '**rock wool**' is one which is produced by spinning volcanic rock in blast furnaces. The use of rock wool as an insulation is well-known, but when the oil is removed, the product is used as a growth medium in agriculture. Since the product does not break down or decay, it virtually lasts forever with hardly any problem of insects. The product is available commercially in the form of pellets, cubes or mats. Rock wool when used alone tends to pack tight and may thus limit aeration and root growth. To overcome the problem, it can be mixed with bark, perlite or tree fern fibers.

Fig.G.13: Cocopith is a common growth medium for pot cultures in greenhouses.

Secondly, **lava rock**, if used as a potting medium, retains a good amount of water and air, and helps the roots grow well.

Similarly, shredded tires of 6 to 12 mm size pieces are also tried as a potting medium. Although its use is in the experimental stage, the medium is reported to retain moisture, produce good root growth on balanced fertilization and have no insect problems.

Growth regulators

Growth regulators of plants or **plant growth regulators** are non-nutrient organic chemicals, which do not occur naturally in plants. When applied, in small amounts to leaves, stems or roots of a plant, they influence its growth and development. For example, chlocholine chloride is used to reduce plant height.

Growth retardant

A substance that decreases the rate of growth of a fungus, higher plant, etc. at very low concentrations is called a growth retardant. Certain growth inhibitors/retardants can also function as growth stimulants under certain circumstances.

Growth stages of cereal crops

Growth stages of cereal crops are: (a) tillering when additional shoots develop to form the lower buds, (b) jointing or elongation when stem internodes begin elongating rapidly, (c) booting when the upper leaf sheath swells due to the growth of a developing spike or panicle, and (d) heading when the seed head emerges from the upper leaf sheath.

Guanidine

Guanidine, a colorless crystal with a melting point of 50°C, is soluble in water and alcohol. It is an analogue of urea and is also known as amino urea. Guanidine synthesis occurs by treating urea with ammonia under pressure or by heating calcium cyanamide with ammonium iodide.

Guanidine forms a number of salts like the carbonate, phosphate, nitrate, sulphate and hydrochloride which can be used as fertilizers.

Guanidine phosphates

Guanidine phosphates are salts of guanidine and are used as fertilizers.

Guano fertilizers

Guano is seabird excreta. Several islands off the coasts of Peru and Chile have thick deposits of guano. It is a natural fertilizer with a high content of ammonia, phosphorus and sulphur compounds.

Guano, the collection and marketing of which is a big industry in Peru and Chile, is converted by acid treatment to guano fertilizers. They consist mainly of inorganic substances and contain 8 to 16% nitrogen, 2 to 7% phosphorus and 1 to 3% potassium. Some varieties contain nitrogen up to 50% in the form of ammonium phosphates and calcium ammonium phosphates, and have a short-term effect on the nitrogen supply. Although guano is said to be a bird related manure, guano group of manures includes whale guano, goat guano, fish guano as well as bat guano.

Fish guano is a phosphatic fertilizer made from unmarketable fish and fish wastes after extracting the oil. This guano has 78% nitrogen and 4 to 8% phosphoric acid and is used mainly for horticultural crops.

Guaranteed analysis: See Guarantee of fertilizers

Guaranteed minimum price

A guaranteed minimum price is one of the economic management policies adopted by the government to ensure that small farmers do not suffer if the prices of output in the open market fall. A guaranteed minimum price ensures a minimum income to the farmers and acts like an insurance against losses caused by climatic disasters, and protects the interests of the farmers. (See also Support price.)

Guarantee of fertilizers

Guarantee of fertilizers relates to the quantitative and qualitative characteristics that a product must comply with to fulfill contractual or legal requirements. They stipulate that a product must comply, for all legal or contractual requirements with International Standards Organization (ISO). Plant nutrients, compounds and allied substances guaranteed are liable for inspection and analysis in accordance with the methods and regulations prescribed by the country's regulatory authority.

A fertilizer bag has to carry a label giving the following information about the product (a) **declarable content** of an element or oxide, (b) **guaranteed analysis** (Japan), where the minimum amount of each of the main components expressed as percentages is guaranteed by the manufacturer, (c) guaranteed analysis (Philippines), giving the contents in terms of the minimum percentage of plant food according to manufacturer's label, and (d) guaranteed analysis, (The Association of American Plant Food Control Officials) which gives the minimum percentage of plant nutrients claimed in the order as total nitrogen (N), available phosphate (as P_2O_5) and soluble potash (K_2O). The guarantees for other nutrients are expressed in the elemental form (Fig.G.14).

Fig.G.14: Declarable contents of elements on a label guarantee nutrient contents in the fertilizer.

The buyer may also require guarantee for plant nutrients other than nitrogen, phosphorus and potassium, expressed as the chemical formula of the element. The sources (oxides, salts, chelates, etc.) of such nutrients have to be stated on the application for registration and may be included on the label. Other beneficial substances or compounds determinable by laboratory methods also may be guaranteed with permission from the regulatory authority and experimental station.

Guggenheim method for sodium nitrate

Guggenheim method is one of the methods for manufacturing **sodium nitrate**. In this method, **caliche** (fertilizer extracted from a mined product, mostly mined in Chile, hence the name **Chilean nitrate** or **Chilean saltpeter**) is dissolved in warm water and cooled to 0°C to produce sodium nitrate crystals. These crystals are circulated through heat exchangers which keep the crystals suspended to form the pellets. These pellets are also coated to ensure free flowing characteristics.

Caliche contains sodium nitrate (8 to 20%), potassium, magnesium salts like borate, sulphates and chlorides. Approximately, ten tons of caliche give one ton of sodium nitrate of 99% purity, which is stored in airtight containers.

Gully erosion

Erosion sometimes cuts the soil so deeply that it is not easy to level the land, and normal farm implements cannot remove the rills. Slopes result into water run-offs that increase in volume or speed to cut the land to cause erosion. The water, accumulated in narrow channels or gullies, erodes the soil, removing it from the gully to deeper areas and ranging from 30 cm to 30 m in depths. Such erosion is known as gully erosion (Fig.G.15).

Fig.G.15: Gully erosion causes narrow channels or gullies on soil surface as seen in the picture.

These gullies are often characterized by an upstream segment where erosion is active, and a downstream portion where sedimentation occurs. Very often, gullies result from unfilled rills. Gully erosion follows **sheet erosion** and **rill erosion.** A threshold exists for channel head location, which depends on the area (A) of the drainage basin and the valley gradient (s) at the gully head as:

$$A \geq as^{-b}$$

where 'a' is a constant that depends on precipitation, land use, etc., and 'b' varies between 0.3 and 0.4.

Gunter's chain

Gunter's chain is used to measure land. It is approximately 20 meters in length and is divided into 100 equal lengths or links.

Gypsic horizon

Gypsic horizon is the horizon of secondary enrichment, mostly of calcium sulphate or **gypsum**. It is a layer of 15 cm thickness. It has at least 5% more gypsum than the underlying C horizon. The product of its thickness in cm multiplied by the percent gypsum content is at least 150. Gypsum can accumulate uniformly or in the form of masses of crystals.

Gypsic horizons mostly occur in **aridisols**, but a few **inceptisols** and **gelisols** are also known to have gypsic horizons.

Gypsisols

Gypsisols are soils that cover large areas of the desert lands of Egypt, Libya, Oman, Tunisia and Bahrain, covering around 100 million hectares. Gypsisols are characterized by the accumulation of calcium sulphate (gypsum) in the upper 1.25 meters, together with insignificant amounts of clay and organic matter. In many cases, calcium sulphate hardens to form a rock-like material. Surface crusting is also common if the soil has a high silt content. All these conditions make cultivation, plowing, irrigation, etc. very difficult.

Gypsum

Mineral gypsum ($CaSO_4 \cdot 2H_2O$) is the most commonly used amendment for **sodic** and **alkali soil** reclamation. Gypsum reclaims alkali soils and is thus beneficial to agriculture. Much of the high-grade gypsum comes from the wet process phosphoric acid industry. Given the high demand for phosphorus in the world, many industrial plants have been set up in many countries. This has given rise to huge amounts of phosphogypsum waste, giving rise to disposal problems. **Mineral gypsum** also poses the same problem.

In India, for instance, mineral gypsum reserves run to over 1000 million tons. When mined, the large lumps are crushed, ground and passed through sieves to the required particle size. The powdered gypsum is then bagged and transported to the destination points.

Gypsum is a hydrated form of calcium sulphate ($CaSO_4 \cdot 2H_2O$). It is a white or yellowish solid which can be ground to particle sizes from 10 to 100 mesh.

Pure gypsum has 18.6% sulphur and 23.2% calcium. A 70 to 80% pure commercial agricultural grade gypsum contains 13 to 15% sulphur, 16 to 19% calcium and varying amounts of impurities such as the oxides of iron, aluminum, calcium and magnesium.

Gypsum is only slightly soluble in water. It is, however, more soluble than calcium carbonate. It is decomposed and precipitated by sodium carbonate as follows:

$$CaSO_4(aq) + Na_2CO_3(aq) \longrightarrow CaCO_3(S) + Na_2SO_4(aq)$$

Gypsum is soft and can be easily scratched with a fingernail. While it is generally non-crystalline, it also has a crystalline form, **selenite**, which occurs as transparent crystals associated with clay.

A saturated solution of gypsum in water has an electrical conductivity of about 2.2 mmhos/cm (2 dS/m). To dissolve 1 ton of gypsum, about one-tenth hectare meter of irrigation water is required under normal soil conditions. Solubility increases in the presence of sodium and chloride ions in water, but decreases due to common ion effect in the presence of calcium and sulphate ions.

Gypsum in soil is solubilized in the soil solution. Its solubility depends upon the fineness and particle size of the material availability of water, the extent of mixing, the soil solution composition and the exchange complex. Solubilized gypsum is found in an ionic form as divalent calcium (Ca^{++}) and sulphate ion (SO_4^{2-}) as shown below:

$$CaSO_4 \cdot 2H_2O(S) \rightleftharpoons Ca^{2+}(aq) + SO_4^{2-}(aq) + 2H_2O$$

The reaction of gypsum in soil is a simple exchange between the calcium ion in the soil solution and the exchangeable cations on the exchange complex (clay particles).

$$2Na^+(aq) + SO_4^{2-}(aq) \longrightarrow Na_2SO_4(aq)$$

The exchanged cations coming in the soil solution react with the sulphate ions to form soluble salts.

$$2Na^+(aq) + SO_4^{2-}(aq) \longrightarrow Na_2SO_4(aq)$$

In the presence of carbonates in solution, gypsum may undergo double decomposition reaction and precipitate as calcium carbonate, as illustrated in the first equation given earlier.

Gypsum is thus one of the most efficient sources of sulphur. However, the choice of the source is determined by the characteristics of the soil (whether calcareous or non-calcareous), of the crop (whether oilseed or cereal) and of the application methods (whether pre-sowing or top-dressing). Generally, oilseeds need higher calcium and prefer gypsum for pre-sowing in non-calcareous soils while ammonium sulphate may be preferred as top-dressing for a sulphur deficient cereal, particularly on calcareous soil.

The Bureau of Indian Standards (BIS) specifies the following four criteria for purity and particle size of mineral gypsum for agricultural use: (i) Scope: This standard prescribes the requirements, packing and marking, methods of sampling and testing of gypsum as an amendment for alkali soils. It covers only mineral gypsum. (ii) Requirements: Fineness: The material shall all pass through a 2 mm sieve but at least 50% of it should pass through a 0.25 mm (60 mesh) sieve, when tested by the method prescribed in I. S. 1288-1973. (iii) Calcium sulphate content: The material shall contain not less than 70% calcium sulphate dihydrate by mass as tested, according to the method prescribed. (iv) Sodium content: The sodium content of the mineral shall not be more than 0.75% by mass (as Na).

Gypsum-coated urea

Gypsum-coated urea, containing around 35% nitrogen, is urea prill coated with gypsum. This treatment makes it a slow release fertilizer and reduces its moisture absorption tendency.

Gypsum process

Gypsum process is a method of manufacturing ammonium sulphate fertilizer, where ammonia is treated with pulverized calcium sulphate, carbon dioxide and water to produce ammonium sulphate fertilizer.

$$CaSO_4 \cdot 2H_2O + 2NH_3 + CO_2 \longrightarrow CaCO_3 + (NH_4)_2SO_4 + 2H_2O$$

Gypsum requirement

Gypsum requirement (GR) is the amount of gypsum necessary to be added to reclaim a soil. It is calculated using the formula:

$$\text{Gypsum requirement (GR)} = \frac{\text{Metric tons of gypsum needed}}{\text{Hectare of soil to some fixed depth (30cm)}}$$

(See also Calcium sulphate).

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

H

HA

HA is short for **humic acid**. It is a partially decomposed, aromatic, dark colored organic matter that originates from terrestrial vegetation.

Haber-Bosch process for ammonia synthesis

Most of the world's ammonia (NH_3) is produced synthetically by a direct union of the elements through the Haber-Bosch process. The process involves an exothermic reversible reaction that proceeds with a decrease in volume:

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

The process was invented by Fritz Haber, a German scientist, who received a Nobel prize in Chemistry for his invention. Karl Bosch further developed the process to produce ammonia on an industrial scale. The process has thus come to be known as the Haber-Bosch process.

In the Haber-Bosch process, the optimum conditions for ammonia production are (a) temperature between 446 and 496°C, (b) pressure of 200 to 900 atmospheres, (c) a catalyst containing finely divided iron with molybdenum or calcium as a promoter, finely divided osmium or uranium or finely divided nickel over pumice stone or ferric oxide with traces of silica and potassium oxide, and (d) pure gases (impure gases poison the catalyst).

Haem

Haem is another term for **Heme**.

Half-life

The half-life period of a reaction is defined as the time required for reducing a reactant to half of its original value. It is also defined as the time required for the completion of half the reaction. For example, the half-life of radioactive compounds varies from 1590 years for radium, to a few seconds for some other radioactive substances. The half-life is given by the equation:

$$\text{Half-life } (t_{1/2}) = 0.6931/\lambda = \text{constant}$$

where λ is the disintegration constant of the element. Thus, the half-life of a given radioactive substance is independent of the initial amount of the substance, and is dependent on the disintegration constant (λ) of the element. Phosphorus ^{32}P, which has a half-life of 14.3 days is used in the mechanistic studies of the phosphate fertilizer pathway in plants.

The term, half-life, is also used in plant virus inoculum for the time taken to lose half its infectivity on aging, or in heat inactivation studies. Half-life is also used to express the progressive decline in transmission of some viruses by their vectors, as the period between acquision and inoculation increases.

It is important to know **half-life of pesticides or insecticides** because of its widespread and persistent effects on the environment, human beings and animals. Persistent pesticide residues are readily estimated from the linear, semi-logarithmic curves of residue persistence (degradation of residue concentration versus time) and the calculation of the residue half-life, which is independent of the application rate. From the values so obtained, it is easy to determine the time interval required, from the stage of pesticide application to the stage of the pesticides reaching toxicologically safe levels. This time is expressed on the pesticide label as the safe interval before crop harvest.

The magnitude and duration of the pesticide residue on agricultural commodities depend on the applied dosage, the chemical nature of the insecticide and the physical nature of the treated plant surface. Organochlorine insecticides have the greatest impact on environmental quality because of their relatively long persistence, their very high lipid-water partition coefficients, and their relative resistance to biological degradation.

The estimated average half-life of some pesticides (in years) are: DDT 2.8, Dieldrin 2.5, Endrin 2.2, Lindane 1.2, Chlordane 1.0 and Heptachlor 0.8. Organophosphate insecticides react in the presence of light, air and moisture, and are readily degraded. Their half-life ranges, for instance, from 1 to 2 weeks for malathion to 3 to 6 months for parathion, diazinon and chloropyrifos. Carbamate insecticides like carbonyl have half-lives of 1 to 2 weeks, carbofuran and aldicarb, between 1 and 4 months.

Half-life of pesticides or insecticides: See Half-life

Halite

Halite is a naturally occurring sodium chloride (NaCl) deposit. The most abundant potash mineral deposit is **sylvite** (KCl). Sylvite with halite forms the common potash ore, called **sylvinite**.

Hallucinogen

Alkaloids present in some plants have hallucinogenic effects when consumed. Hallucinogen alters moods of the consumer and changes his perception of time and space. (See also Psychoactive plants.)

Halomorphic soil

A soil with large amounts of soluble salts (such as carbonates, sulphates and chlorides of calcium, magnesium and sodium) is called halomorphic soil. They are generally formed in wetland conditions and are formed due to soil salinity. **Peat soils** and **gley soils** are examples of such soils.

Halophilism

Halophilism is the association of organisms with high osmotic concentration which is a result of soil salinity. The environment in which halophiles live has ten times the salt content of ocean water. The Great Salt Lake and the Dead Sea are two halophilic environments.

Halophiles are armed with mechanisms that help to control the osmotic pressure to a certain level. They are coated with a protein which allows only the desired level of salt to enter the cell. Halophiles are divided into the following three categories based on sodium ion concentration and these are (a) the intolerant halophiles which cannot tolerate more than 1 % sodium chloride, (b) the facultative halophiles which cannot grow on a medium having 1% to 20% sodium chloride, and (c) the obligate halophiles which require at least 15% sodium chloride and can grow in as much as 31% sodium chloride.

Halophytes

Plants that readily accumulate common salt ions are called halophytes. Salt-tolerant grasses, herbs, desert and shoreline shrubs are common among halophytes.

True halophytes are those that grow in soil water with more than 0.5% NaCl. **Xerophytes** are a type of halophytes that are adapted to desert soils which have high levels of salt toxicity and stress.

A plant either resists or avoids the presence of salts. Tolerance to salt is possible through physiologically adapting itself to maintain the protoplasmic viability in the cells. Plants resist salt by adapting themselves so that the root membranes exclude their concentration in the cells.

Halophytes are classified as excretives or succulents. The former throw out excess salts through glandular cells, developed for this purpose. Species of the genus *Atriplex* (or salt bush) are examples of excluders. They release excess salt through their leaves.

Succulents keep the salt concentration low by increasing water retention within large vacuoles. Halophytes that grow in aquatic conditions are called hydro halophytes. Most mangroves and species of salt marsh are hydrophytes. Many more classifications exist among halophytes depending on the adaptations developed by plant species to survive in similar harsh conditions.

Hans Christian procedure for Gram staining: See Gram staining

Hardening of fertilizer

Hardening or **caking** of a fertilizer happens because of the crystallization of water-soluble salts, and the formation of bridges between fertilizer grain surfaces during storage. Fertilizers should be free-flowing during transportation and field applications. A conditioner is added to the fertilizer to prevent hardening during storage and handling, and to maintain its free-flowing character.

Hardness

The resistance of a pesticide or detergent to decomposition or biodegradation is known as hardness or **persistence**.

Hardness also means the proportion of calcium carbonate or calcium sulphate contained in a given sample of water. Based on the presence of calcium and magnesium salts, water can either have **temporary hardness** or **permanent hardness**.

Hardness is also the resistance of a material to deformation of an indenter of specific size and shape under a known load. The definition applies to all types of hardness scales, except the Mohs-scale which is based on the concept of scratch hardness and used chiefly for minerals.

The most generally used hardness scales are Brinell (for cast iron), Rockwell (for sheet metals and heat treated steel, diamond, pyramid, knoop) and scleroscope (for metals). Durometer hardness is used for softer materials like rubber and plastic.

Extremely shortwave radiation is also known as hardness. For example, hard-x-rays.

Hardpan

Hardpan, another name for **pan** and **sole**, is the hard stratum of a strongly compacted soil. Hardpans often impede drainage and root growth, and are broken down using a subsoiler.

Hard rock phosphate

There are four kinds of phosphate rock: (a) hard rock phosphate, (b) **soft rock phosphate**, (c) **land pebble phosphate**, and (d) **river pebble phosphate** with varying phosphorus oxide (P_2O_5) content (from 2 to 21 %).

Hard water: See Water, hard

Hard wheat

Wheat grown in limited rainfall areas is called hard wheat. It is considered to have high protein content.

Harrows

Harrows are implements used for light, shallow or secondary cultivation. Harrows are ideal for breaking clods, levelling surfaces, covering seeds after sowing in the field and for destroying or collecting weeds. They have heavy prongs which penetrate deep into the soil and help cultivate the land.

The harrows (Fig.H.1-H.2) can be zigzag or spring-tined and can be connected to a chain, disc, drag, Dutch frame or power source. Disc harrow, spike-tooth harrow, spring-tooth harrow and knife harrow are among the most common types of harrows. Power driven rotary tillers perform the function of both plowing and harrowing.

In harrowing, surface soil is further granulated and smoothened for planting. Harrowing irons out the furrows and the ridges formed by the previous plowing and disking operations. The depth of the penetration of the disk harrow depends largely on its weight.

Fig.H.1: A tractor-mounted disc harrow.

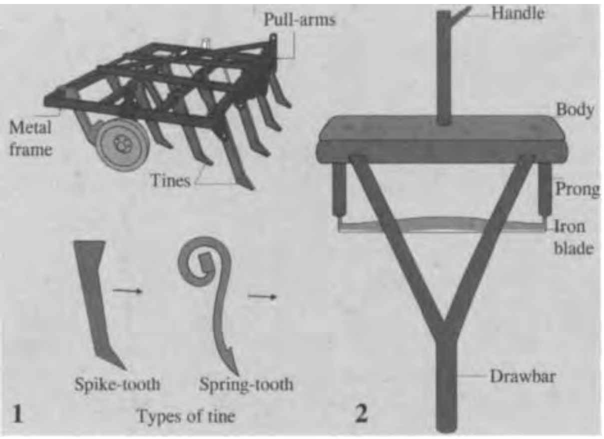


Fig.H.2: 1.Spike-tooth and spring-tooth harrows. 2. A wooden harrow with an iron blade.

Harvest index

Crop production can be measured by the total biomass yield, or the yield of economically useful parts of the plant. The total yield of the plant material is known as the **biological yield** and the ratio of the grain or economic yield to the biological yield is called the harvest index. Since the harvest index, expressed as a percentage, is a ratio of the grain weight to the total plant weight in a cereal crop, it can be used for comparing the efficiency of grain production in crops.

The grain yield is directly proportional to the harvest index and is not related to the biological yield. The harvest index for rice is more than 50% and for wheat, less than 60%.

Among various crops, sweet potato has the highest harvest index. Raising the index further calls for improvements in the rate of growth and translocation of the photosynthate. The relationship between the biological yield, the **economic yield** and the harvest yield can be expressed as:

$$\text{Economic yield} = \text{Biological yield} \times \text{Harvest index}$$

Harvesting

Harvesting involves gathering of the ripened crop (Fig.H.3). The maturity of the crop is not always easy to determine, but is usually related to the crop age. As a general rule, a crop is considered mature when its harvestable parts attain the maximum dry matter. Changes in color or accelerated senescence and loss of vegetative parts can also indicate maturity.

Fig.H.3: Harvesting of soybean using a mechanical harvester.

In grains, maturity is associated with the reduction in the moisture content. Usually the moisture content in the seed decreases from 90% at pollination, to about 40% at physiological maturity. Ripening, often expressed by a color change, is an external indication of maturity, particularly in fruit.

Harvesting just at maturity ensures the maximum yield. However, the time of harvesting depends on the characteristics and quality requirements of the crop. Harvesting may be delayed deliberately in order to reduce moisture content in the field and enable better handling and storage. However, in some fruit and leaf crops, a high moisture content is preferable. In dry weather, if crops are left in the field to dry, the moisture content comes down to around 30%, resulting in losses due to the shattering or shedding of the grains. In highly humid or wet weather, grains can imbibe water and sprout on the plant, whereas in very dry conditions they may get bleached, which reduces quality. Furthermore, attacks from insects, fungi and birds become a serious threat, if harvesting is delayed. The root and tuber crops, like potato, keep better in the soil, but their quality depreciates if harvesting is delayed.

After harvesting, it is advisable to dispose of crop residues properly. Burning them or incorporating them into the soil prevents a carry-over of any propagules, pests and diseases present in the harvested crop. Although in some places crop residues are used as animal feed, fuel or for erecting fences, crop residues are best used as manures and incorporated in the soil to enhance the organic content and the fertility of the soil.

Harvest worker

A harvest worker is a casual worker employed during the harvest season.

Haugh

In Scotland, a riverside meadow or flat land in a river valley is called haugh.

HDPE

HDPE is short for high density polyethylene or polythene. It is used as a lining material for making waterproof storage bags for fertilizers. It is made by coordination polymerization technique of ethylene, has a high degree of crystallinity and a higher density due to the unbranched nature of the polymers.

Heart

Heart, apart from its physiological reference, also means a fertile soil. A soil capable of producing good crops is called **good heart**; an infertile soil in poor conditions is termed **poor heart**.

Heart rot

The decay of the **heartwood** of a tree (which is the wood at the center of a tree trunk or branch) is caused by a fungal disease called heart rot. Heartwood cells contain oils, gums and resins, which darken the wood.

Boron deficiency in beet, cauliflower, etc. results in the death and browning of the root center and the young leaves which is also called heart rot - a term similar to brown heart (Fig.H.4).

Fig.H.4: Heart rot in cauliflower, a boron deficiency disease.

Heartwood : See Heart rot

Heat of adsorption

The formation of a layer of gas, liquid or solid molecules on the surface of a solid or liquid is known as **adsorption**. The process is always accompanied by the evolution of heat, which is called the heat of adsorption.

Heat of dissociation

The reversible decomposition of a molecule into two or more simpler fragments, atoms, radicals or ions is known as dissociation. The heat generated during the split or dissociation is the heat of dissociation. The heat required to split or dissociate the molecular bond is called the **dissociation energy**. It is determined experimentally by calorimetry, by electron impact methods, spectroscopy or by kinetic methods.

Heavy land

Land that has a high clay content and is harder to cultivate than a light soil is called heavy land or **man's land**.

Heavy metals

Elements with high atomic weights and densities are called heavy metals. This term is normally used for elements like lead (Pb), cadmium (Cd) and mercury (Hg), which may have harmful effects on plants and animals. However, most of the plant micronutrients also belong to this category.

Heavy soil

A soil with 40% or more clay, less than 45% sand and less than 40% silt is called a **clay soil**. Such soils are also called heavy soils as they require more effort and heavy machinery for plowing and cultivating than the sandy or light soils.

Hedge maple

Acer campestre is called hedge or field maple in Europe. This is an example of a **calciole plant**. This deciduous plant which grows best in well drained soils tolerates drought and is best known as a hedge plant.

Heme

Iron is a structural component of porphyrin molecules like cytochromes, which have two parts: an iron complex called heme (or **haem**) and a protein. Heme is an iron (II) complex that contains iron in Fe^{2+} or gets coordinated to four nitrogen atoms of a planar porphyrin. The heme in hemoglobin is also a porphyrin derivative. Physiological processes in plants have shown that chlorophyll is formed from protoporphyrin by the removal of iron from hemin. On the contrary, in animals iron is introduced into protoporphyrin to form heme (Fig.H.5).

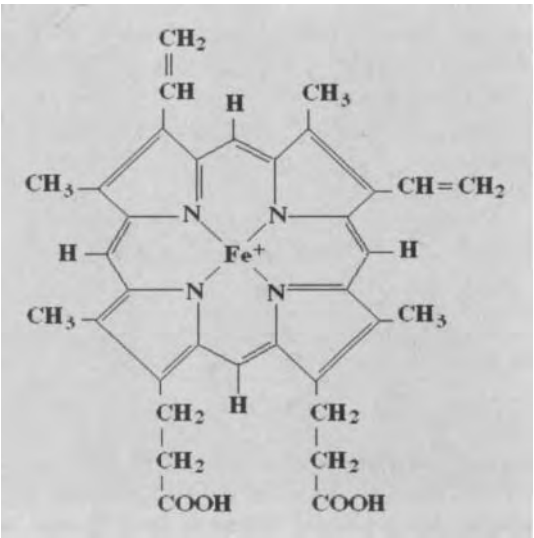


Fig.H.5: Structure of the heme group.

Iron plays a central role in almost all living cells. In mammals, the principle source of energy comes from oxidation of carbohydrates, proteins and fats. Although oxygen is the oxidizing agent for these processes, it does not react directly with these molecules. Instead, the electrons from the breakdown of these nutrients are passed along a complex chain of molecules, called respiratory chain, eventually reaching the oxygen molecule.

The principle electron-transfer molecules in the respiratory chain are these iron-containing molecules like heme.

Hemicellulose

Hemicellulose is one of the broad complex divisions of polysaccharides (the other being pectin) having a polymerization of 150 cellulose molecules or less. It is a collective term for beta and gamma cellulose.

Hemicelluloses are alkali-soluble polysaccharides, while pectin is acidic. These polysaccharides as well as cellulose (which is also a polysaccharide) are constituents of a plant cell wall and function to ensure a high mechanical strength and rigidity to the wall.

Hemicelluloses sometimes become store houses of nutrition, as in the case of some seeds, for example, date seeds and nasturtium seeds.

In the food processing industry, it is a common practice to add special enzymes while processing so that the cell walls therein may be made more soluble and integrated for consumption. An example of this is seen during the production of fruit juice.

Hemicellulose is obtained by steam treating a mixture of soft and hard woods, and can be used as an animal feed supplement.

Hemic material: See Hemist

Hemist

Hemist is a suborder of the world soil order **histosols**. The organic material in hemist soils, called **hemic material**, is decomposed in such a way that the origin of half of the material cannot be easily determined. Fibers of the decomposed material can be broken just by rubbing between the fingers.

The bulk density of hemist soils ranges from 0.1 to 0.2. They have an **aquic** or **peraquic** soil moisture regime. This suborder of histosols also includes sulphidic horizon. The **great groups** under hemists are halpohemists, cryohemists, luvihemists, sulphihemists and sulphohemists.

Herbaceous perennials

Herbaceous perennials are plants that have aerial shoots that die down each autumn, only to be replaced in spring by new shoots from an underground structure. Lupin and rhubarb are examples of herbaceous perennials. Herbaceous perennials are also called **non-woody perennials**.

Herbaspirillum spp.

The *Herbaspirillum* is a kind of beneficial bacterium which commonly infects the root systems of the sugar cane plant. It is also seen, in some cases to inhabit maize. Two strains of this bacterium are well known, namely, *H. seropedicae* and *H. rubrisubalbicans*.

It is the capacity of the bacterium to fix nitrogen and to secrete growth promoting hormones that make it a valuable biofertilizer inoculant.

Herbaspirillum spp. colonizes the vascular tissues of sugar cane with the help of the AM fungi (via its mycelium) making its way to the roots. Being slow growing, this bacterium does well in the presence of small amounts of fertilizers. They also grow well in sucrose. But the absence of sucrose in the interior cells of the xylem vessels leads to low oxygen tension, which in turn, facilitates fixation of elemental nitrogen by the enzyme nitrogenase.

Root colonization is evident in an increased foliage biomass and enhanced growth of the aerial portions of sugar cane. Depending on the variety of sugar cane being cultivated, half of the total nitrogen need of the plant is met by the bacterial action. Laboratory experiments in many areas of India and Brazil (where *Herbaspirillum* was first isolated) have shown that crops with only half of the total fertilizer nitrogen requirement and a mixture of biofertilizers produced the same yields as crops which were fed on totally synthetic fertilizers. The total nitrogen requirement is commonly taken as 275 kg/hectare. The biofertilizer mixture, in the experiment contained *Acetobacter diazotrophicus*, *A. lipoferum* and *Herbaspirillum* spp.

The rate of nitrogen fixation depends on the sugar available in the plant (predominantly in the leaves). It has been found that 30% of the total sugar produced by the sugar cane crop would be used to fix 200 kg nitrogen per hectare.

Herbicides

Herbicides, also known as **weedicides**, can be applied to soils or sprayed on weeds to kill them. These chemicals, being dangerous to humans and animals must be used with great care. Till 1924, inorganics such as sodium chlorate, sodium chloride, arsenic and boron compound were used as herbicides. Currently, more specific organics like 2,4 - dichlorophenoxyacetic acid (2,4-D), phenols, carbamates and urea derivatives are used.

Herbigation

Application of herbicides through irrigation water is known as herbigation. The application of pesticides or fertilizers through irrigation waters in open or closed systems is called **chemigation** or **fertigation**. Depending on the nature of the pesticide, such applications are also called **herbigation**, **insectigation**, **fungigation** and **nemagation**.

Heterocyst

Heterocysts are nitrogen-fixing sites of aerobic, filamentous cyanobacteria.

They are large, thick-walled cells that grow between pigmented cells on the algal filament (Fig.H.6). The vegetative cells and heterocyst cells depend on each other for fixing nitrogen. Heterocysts derive an enzyme reductase in the form of D-glucose-6 phosphate, pyruvate or isocitrate from photosynthesising vegetative cells. The vegetative cells depend on heterocysts for nitrogen nutrition in the form of glutamine, glutamate and other amino acids (Fig.H.7).

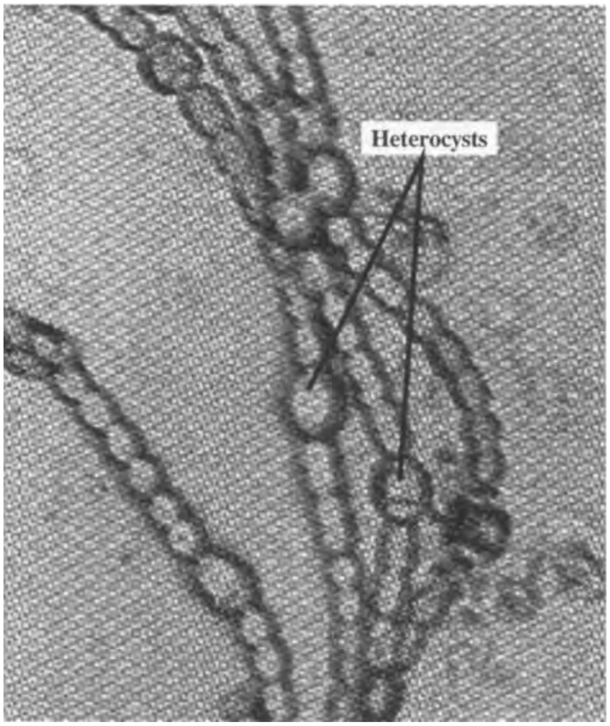


Fig.H.6: Heterocysts of Anabaena azollae, a cyanobacterium.

Heterogeneous catalyst

Catalysts that are present in the same phase as the reactants are known as **homogeneous catalysts**, and those existing in a different phase are called heterogeneous catalysts.

Heterogeneous catalysis involves the adsorption of gaseous reactants on the surface of a solid catalyst. An example is the oxidation of gaseous sulphur dioxide to gaseous sulphur trioxide in the manufacture of sulphuric acid using vanadium pentoxide catalyst.

Heterogeneous catalysis is also used in the catalytic converters of automobile exhaust systems.

Heterogeneous mixture

In nature, there are very few 'pure' materials; almost everything is a mixture of pure substances. Wood, gasoline, wine, soil and air are all mixtures. They can be described as either homogeneous or heterogeneous. In a heterogeneous mixture, different regions have differing properties. Sand in water, dust suspended in air and tea with ice cubes are examples of heterogeneous mixtures. Heterogeneous mixtures can usually be separated into two or more homogeneous components or pure substances. (See also Homogeneous mixture.)

Hetero-polysaccharides

Polysaccharides are non-sugars. The examples are starch, dextrin and cellulose, which on hydrolysis yield a large number of monosaccharide molecules. Polysaccharides are amorphous, tasteless, non-reducing, mostly insoluble in water, and are classified into **homo-polysaccharides** and hetero-polysaccharides.

Hetero-polysaccharides are combinations of two or more different types of monosaccharides joined together by glycosidic bonds. Polysaccharides are branched and may have a molecular weight of several thousands. Amylopectin is an example of this class.

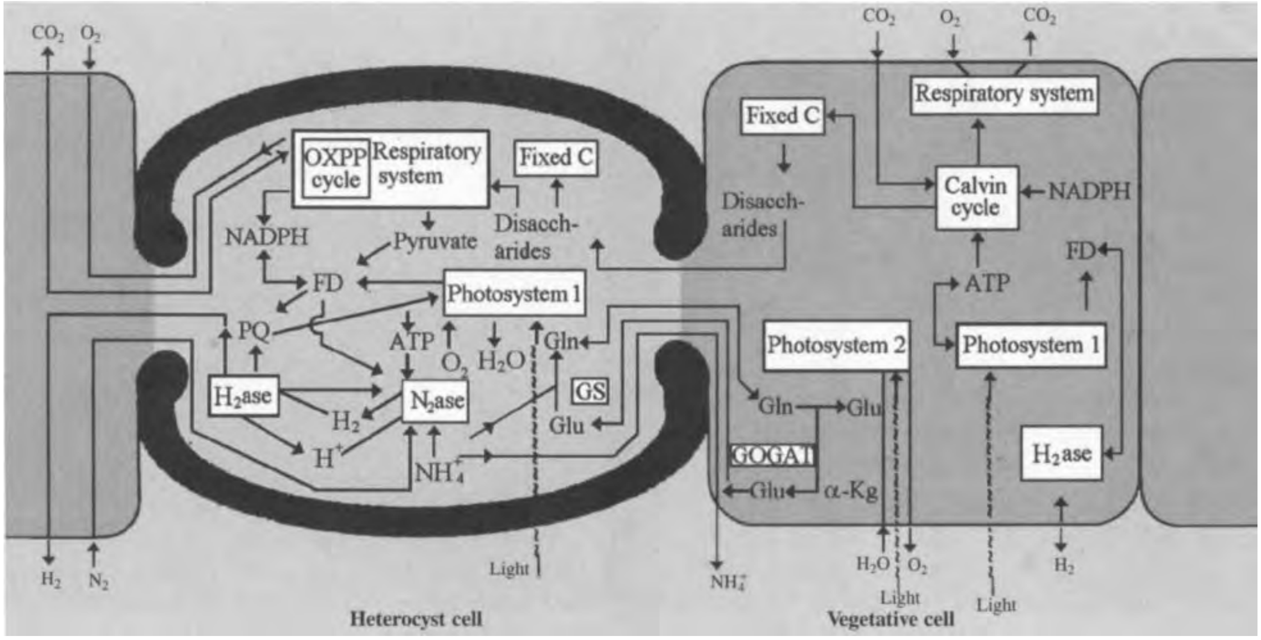


Fig.H.7: Cells of blue-green algae and nitrogen fixation.

Heterosis: See Hybrid

Heterotrophic bacteria

Heterotrophic bacteria are those that manufacture food from organic matter.

Hexadentate ligand

Ligand is an ion or a molecule that can attach itself to a metal atom by coordinate bonding. Ligands, also called **complexing agents**, donate a pair of electrons to a metal atom or ion forming coordination complex. Ethylenediaminetetra-acetic acid (**EDTA**) is a hexadentate ligand. Hexadentate ligands are used to make fertilizers, especially for micronutrients. Zinc-EDTA is used as a foliar spray on plants to overcome zinc deficiency.

Hibernation

Hibernation is the slowing down of metabolism of an organism. Some animals spend the winter in a dormant state and remain inactive. Hybernation is a form of diapause commonly witnessed in regions where there is a well defined cold season. Although the lowering of temperature is generally the immediate cause of dormancy, in many insects there appears to be an innate rhythm connected with an increase and decrease in the secretion of certain hormones.

Hidden hunger

Hidden hunger indicates instances when a crop shows no obvious nutrient deficiency symptoms although the deficiency exists. Fertilization with more than the bare economic minimum, helps to overcome the hidden hunger and obtain profitable yield.

Hide meal

Organic manure can be acquired from animal wastes or by-products at butcher shops, slaughterhouses and carcass disposal plants. Skin and hair are the main constituents of hide meal which provides a slow nitrogen supply to the crops. Sometimes, hide meal is contaminated with toxic chromium salts in the tanning process.

High analysis fertilizer

High analysis fertilizer is an arbitrary term used in the fertilizer industry for fertilizers containing more than 25% of one or more of the major plant nutrients, namely, nitrogen (N), phosphorus (as P_2O_5) or potassium (as K_2O). Urea, potassium chloride and triple superphosphate are examples of high analysis fertilizers.

High calcium limestone

High calcium limestone or **calcitic limestone** is made mainly of calcium carbonate.

High-octane gasoline: See Gasoline

High pressure injection

A high pressure injection is a method of applying gaseous fertilizers like unhydrous ammonia. (See also Fertilizer placement.)

High yielding variety

Over thousands of years, men have practiced some form or other of plant breeding, resulting in the selection of certain plant species based on the qualities desired of them. The favored attributes could, for instance, be tolerance to salinity, resistance to pests, and so on. In the modern age, plant breeding techniques have created the most desired genotypes and phenotypes. **Phenotype** is the unique physical appearance or a specific attribute like color or size of an individual.

Genetic engineering has revolutionized plant breeding and has resulted in genetically enhanced cultivars which are high yielding. These are called high yielding varieties (HYV). The thinking right now is that breeding high yielding crops is the key to food security the world over. Research has yielded many HYV of rice, wheat and maize which lay the foundation of the **Green revolution**.

HYV are preferred over traditional varieties for two reasons. HYV tend to be physiologically more suited for higher yields. They produce an increased rate of harvestable plant product, such as grains. They have shorter stems than the traditional cultivars, ensuring an increased nutrient flow toward grain production. This feature, in turn, prevents problems of **lodging**. HYV also focus more on photosynthetic material than on the production of woody structure. Hence, HYV witness much more vegetative growth than normal cultivars.

Homogeneity is the second distinguishing feature of HYV. Since these cultivars are a result of inbred lines, they share the same genotype. **Genotype** is the specific genetic makeup of an individual, in the form of DNA. Such a feature enables uniform management practices (such as pesticide application, irrigation, etc) throughout the field. HYV can also be made disease resistant for uniform protection of a crop.

High yielding varieties of wheat developed in the USA in recent times include Alamo, Crown, Platinum, Ria, Topper, Brooks, Cavalier, etc., and those developed in India include Sonalika, Kalyansona, Chotiberma, etc. Among the HYV of barley are Barcott, Baretta, Max, Mucho. While indigenous varieties of HYV of rice have produced yields that are much higher than traditional varieties, (that too, by consuming lesser quantities of fertilizers and pesticides), there are also encouraging results seen in the case of certain fruits and vegetables. Modern varieties of strawberries can now bear fruits for an extended period, are resistant to root weevil infestation, are tolerant to harsh winter conditions, etc. Such HYV are Benton, Independence and Rainier. Similar HYV in raspberries have also yielded rich economic returns. Research on developing local maize population in Burundi in Africa resulted in new cultivars that were both resistant to the African maize streak virus and yet, high yielding. Similar results were seen in the case of the Mexican black beans in a certain field trial which yielded 1,500 kilograms per hectare without the use of pesticides, compared to the average bean yield, for that region, of 400 kg per hectare with pesticides. This was achieved by a process of **horizontal resistance**.

Modern plant breeding (either by conventional types or by genetic engineering) has been a subject of continuing debate ever since these techniques came to be used for commercial exploitation. Besides the moral question of whether human interference in a natural phenomenon is good or not, there is also a debate on whether one would stand to lose, nutritionally, by suppressing some aspects of a plant in preference to some other aspects. Studies are carried out to verify if genetically modified food is nutritionally adequate and safe. One such study, entitled "Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999", published in the Journal of the American College of Nutrition, in 2004 found a substantial decrease in 6 out of 13 nutrients (including protein and ribloflavin) in the sampled crops. The study suggested that the decline could be due to changes in the cultivated varieties, indicating a possible emphasis on and preference of the yield over the nutrient content in the given period (between 1950 and 1999).

High yielding varieties also have certain weaknesses. Abundant vegetative growth encourages pest attacks and certain fungal diseases, which can spread at alarming rates, in the absence of genetic variations. HYVs are highly dependent on fertilizers, pesticides, herbicides, water supply and management practices. While these inputs result in high yields, they are said to cause irreparable damage to the environment. Some of the disadvantages would need to be confirmed by further studies.

Hillel definition of field capacity: See Field capacity

Hill placement

When fertilizers are placed in raised bands between the (and close to) plants that have a distance of about 1 meter or more between them, the practice is known as hill placement.

Hill placement is practiced for fruit plantations like orange, banana, papaya, apple, pear, coconut, cashew, etc. with nitrogenous and phosphatic fertilizers. Hill practice is also common in vegetable farming.

Hill reaction: See Hill reaction inhibitor

Hill reaction inhibitor

In **Hill reaction**, the isolated chloroplasts are capable of releasing oxygen in the presence of an electron acceptor (oxidizing agent). The reaction is named after Robert Hill. Substances that block the transport of electrons thus are called Hill reaction inhibitors. Triazine, which is an example of the Hill reaction inhibitor, is an organic heterocyclic compound containing a six-member ring formed from three nitrogen atoms and three carbon atoms. Because of its high nitrogen content and low solubility in water, triazine is used as a slow-release nitrogen fertilizer. Some examples of triazines used as photosynthesis inhibitors are atrazine, simazine and cyanazine. These materials are commonly called Hill reaction inhibitors because they block electron transport in photosystem II, the latter being one of the stages in photosynthesis.

Histels

Histels are one of the suborders of the soil order **Gelisols**. They are characterized by organic soil material which accounts for almost 80% of its content, up to a depth of around 50 cm, unless confronted by a glacic layer or a permafrost table.

Histels have permafrost within 2 meters from the soil surface. In terms of the components of the organic matter content, histels are similar to histosols.

Histic horizon

Histic horizon is a surface horizon or a subsurface horizon of a shallow depth. It consists of organic matter which is saturated with water for at least one month in a year, hence making it less aerated.

Histic horizon is at least 20 cm thick. Its distinguishing feature relates to the proportion of clay to organic matter which must be around 30% if the clay content in the mineral fraction is around 60%. If, however, the clay content in the mineral fraction is absent, the organic matter must account for 20% or more (or organic carbon must be 12% or more). Another measure of distinguishing the histic horizon is that it should contain 14 to 28% of organic matter if the land is plowed, and 20 to 30%, if not plowed.

Histosols

Histosols is one of the 12 soil orders occurring in humid and cold climates, stagnant marshes and swamps. It comprises less than 1% of the world's soils. These soils have large quantities of organic material (commonly known as peat) present in at least half of the first 80 cm of their profile. The organic material includes peat (fibric soil material), mucky peat (hemic soil material) and muck (sapric soil material). The land covered by histosols is known as **peat land**. **Mire**, a synonym of peat land, is a more commonly used term in Europe. **Irish bogs** are well-known histosols.

A property that makes histosols unique is the proportion of organic carbon content to clay. Histosols must have a minimum organic carbon content of 12% when the mineral portion has no clay, and a carbon content of 18% if the mineral portion has 60% or more clay. When soils are formed on lithic contact, the organic carbon in histosols must be 20% or more. Because of the high carbon content, many histosols have been used as a combustible energy source since prehistoric times. Mankind has mined and burned peat which, although having a lower calorific value than oil or coal, is still an important fuel.

Histosols usually have a high water retention capacity, low bulk density and high **cation exchange capacity**. They are generally deficient in nutrients like nitrogen, potassium and copper. Despite major constraints relating to subsistence, nutrient deficiencies and wind erosion, histosols serve extensively for cranberry, citrus, vegetables, rice and sugar cane production.

Based on the specific physical and chemical properties histosols are divided into four suborders. These are **fibrists**, **folists**, **hemists** and **saprists**. They critically limit construction activity because of their low soil strength and low load-bearing capacities. Histosols are important habitats for wildlife.

Hocking sprayers

The Hocking sprayer consists of a lever operated pump assembly which rests on a wooden platform. The rocking (forward and backward) movement of the handle operates the lever attached to the pump. Such sprayers are used for spraying tall trees like coconut and arecanut, and sugar cane plants.

Hoe

A hoe is a long handled tool with a thin horizontal metal blade (30 cm × 24 cm), used for weeding and cultivating soil between rows of crops with a view to controlling weeds (Fig.H.8). Tractor hoes, steerage hoes and front - or mid-mounted hoes are connected to a tractor and raised or lowered hydraulically.

Gardeners use hand hoes made of a thin metal blade attached to a long handle for loosening the soil and chopping and removing weeds (Fig.H.9).

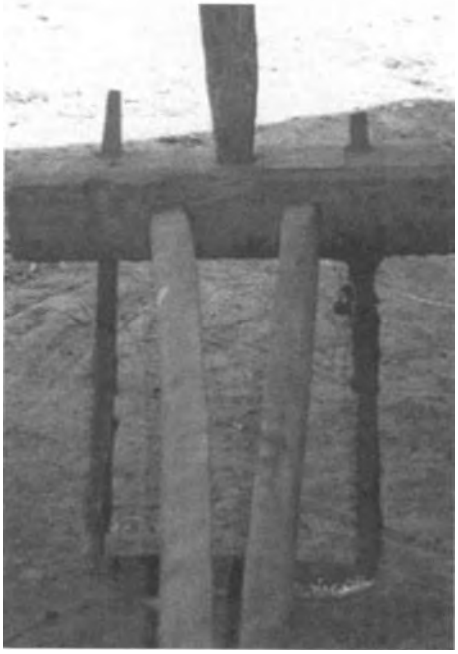


Fig.H.8: A wooden hoe with an iron blade.

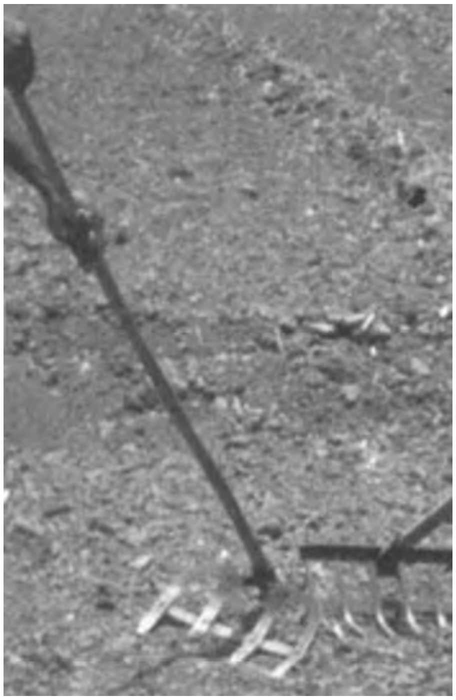


Fig.H.9: A hand hoe with thin metal blades being used for loosening the soil.

The African hoe has a curved wooden handle on which a steel blade is mounted. When the blade is small, it is used for weeding; when large, it is used for digging.

Dutch hoes have long straight handles and are used for light weeding. They are of three types which are (a) the swan-necked blade, an all-purpose weeding hoe, (b) the inverted-end blade, and (c) a wide-angled 'V' blade for careful weeding near the base of crops. The draw hoe resembling the Dutch hoe is used for digging up root crops set in shallow trenches.

Hog

A **clamp** is the traditional form of storing potatoes or other root crops which are neatly piled and covered with earth and straw. It has now been mostly replaced by indoor storage, known as hog, **bury**, **grave**, **pie** and **pit**.

Hollow cylinder type auger

The **soil auger** is a tool with a pointed tip used for collecting soil samples for analysis. There are two types of augers: the worm-type, and the hollow cylinder type. The hollow cylinder type auger has a cutting edge or a screw at one end.

Holtz and Gibbs' free swell test for clay suitability assessment

The suitability of a given clay for cultivation, or any other purpose can be evaluated on the basis of some simple empirical tests, called **puddle tests**. Puddle tests require no equipment and can be performed even by village artisans. One such puddle test is the free swell test, designed by Holtz and Gibbs. In this test, the change in the volume of dry soil is expressed as a percentage of the original volume. About 425 mg oven dried soil in 10 ml of water, is slowly drizzled into 50 ml of distilled water and then allowed to settle. The settling time may range from a few minutes to a few hours. Depending on the swelling capacity of the clays, the volume of the settled soil solids increases (from the original volume of 10 ml). If the free swell value is more than 100%, it is an indication of the clay being the expanding type. Bentonites show very high free swell values of up to 2000%.

Homogeneous catalysis

A catalytic reaction where the reactants and the catalysts exist in the same phase is known as homogeneous catalysis. **Catalysts** that share the same phase as the reactants are called **homogeneous catalysts**. An example of a homogeneous catalyst is an acid solution catalyzing ester hydrolysis. Another example of homogeneous catalysis is the unusual catalytic behavior of nitric oxide toward ozone. In the troposphere (the part of atmosphere closest to the earth), nitric oxide catalyzes ozone production, but in the upper atmosphere it catalyzes the decomposition of ozone. Both of these effects are not good for the environment.

$$\mathrm{NO(g)} + \tfrac{1}{2}\,\mathrm{O_2(g)} \longrightarrow \mathrm{NO_2(g)}$$
$$\mathrm{NO_2(g)} + \text{light} \longrightarrow \mathrm{NO(g)} + \mathrm{O(g)}$$
$$\mathrm{O_2(g)} + \mathrm{O(g)} \longrightarrow \mathrm{O_3}$$

Homogeneous catalysts: See Homogeneous catalysis

Homogeneous mixture

In nature, there are very few 'pure' materials; almost everything is a 'mixture'. Mixtures contain elements and/or compounds in variable proportions. Mixtures can be either homogeneous or heterogeneous. A system is said to be homogeneous when it is completely uniform throughout. For example, pure water is homogeneous, as it contains no other substance than is indicated by the formula H_2O. A homogeneous mixture is called a **solution** and has uniform properties throughout the sample. Thus, a homogeneous system consists of only one phase. For example: (i) A sugar solution is uniformly sweet throughout the solution. (ii) While ordinary air is a mixture of several gases, air as such is homogeneous at a given place and time. (iii) Sea water is a homogeneous system of various miscible salts and other compounds.

A homogeneous mixture can be separated into its components by appropriate physical methods. Most of the fertilizers are homogeneous mixtures of N, P and K, such as, ammonium sulphate [$(NH_4)_2SO_4$], calcium phosphate [$Ca_3(PO_4)_2$] and potassium chloride (KCl).

The reacting substances are in the same phase (i.e., solid, liquid or gaseous) when a chemical reaction takes place. In a catalytic reaction, the reactants and the catalysts are in the same phase; for example, an acid solution catalyzing ester hydrolysis is known as **homogeneous catalysis**. (See also Catalyst.)

Homogenization

Homogenization is the process used to delay the separation of fat in milk, an unstable emulsion containing fat globules that tend to coalesce. In homogenization, milk is heated to 60°C and then passed through small apertures under pressure. The fatty clusters break under pressure by shearing as they pass through the holes, and by impact with the homogenizer components.

Homo-polysaccharides

Non-sugars like starch, dextrin and cellulose, which on hydrolysis, yield a large number of monosaccharide molecules, are called **polysaccharides**. They are amorphous, tasteless, non-reducing and mostly insoluble in water and are classified as homo-polysaccharides and **hetero-polysaccharides**. Homo-polysaccharides contain only one type of monosaccharide.

Hoof meal

Hoof meal or **horn meal** is a manure, rich in proteins. It is made up of dried and ground animal hooves or horns or both. It contains 12 to 14% nitrogen which is rapidly released in warm soil, and 2 to 3% phosphorus which takes 4 to 6 weeks to release. Horn meal is normally added to soil before planting or sowing and is good for perennials planted in autumn.

Horizons: See AB horizon; Soil horizons

Horizontal resistance

Horizontal resistance is a term used to describe a kind of genetic resistance introduced into modern cultivars. Genetic engineering attempts to evolve breeding techniques that will yield long term benefits. Horizontal resistance is an unconventional technique which involves transferring multiple resistance genes into a cultivar. This may be done by breeding the best individuals from each generation of a certain crop. Such a process enables protection against a range of pathogens.

Horizontal resistance breeding carried out by researchers have yielded encouraging results. In comparison, vertical resistance involves a single gene that renders the cultivar resistant to a particular pathogen associated with that gene.

Since horizontal resistance aims to cover a broader spectrum of resistance traits, it contrasts with the classic Mendelian breeding techniques which enhance a cultivar's vertical resistance.

Hormone

Hormone is an organic substance that stimulates specific cells or tissues to act in a regulatory mode. It is produced and secreted in minute quantities in one part of the organ and transported in tissue fluids (like blood) to other parts through the circulatory system.

Hormones are sometimes called '**chemical messengers**' because they regulate such physiological processes as metabolism, growth, reproduction, moulting, pigmentation and osmotic balance. For example, the hormone insulin controls the rate and manner in which glucose is used by humans and animals. **Semiochemicals**, like pheromones, are produced within the body and are emitted externally to elicit a response or attract an organism to a point source.

Hormones vary widely in chemical nature. Some are steroids (estrogen, progesterone, cortisone, etc.), while others are **amino acids** (thyroxin), polypeptides (vasopressin, insulin) and conjugated proteins. Peptide and steroid hormones have been isolated and many others are synthesized and manufactured for medical purposes. Hormones are being used to regulate the growth and moulting of insects; the semiochemicals elicit a sexual response or attract an insect to a point source where it can be trapped.

Hormones, which play a prominent role in plant growth, are called **phytohormones**. Their mode of transportation in a plant is not as yet fully understood. The movement of **auxins** in young stems is not merely a simple diffusion process. It is an active process and is controlled by living cells, being directed away from the stem tip.

An important recent concept relates to the action and interaction of different types of phytohormones. For example, alteration in the ratio of kinetin and **indoleacetic acid** can change the relative amount of leaf and root formation in tissue culture.

Horn meal

Horn meal is another word for **hoof meal**.

Horse manure

Horse **manure** is coarse, light and dry. This manure has a loose structure. It is only half as dense as other manures. It is regarded as a fast acting substance that stimulates growth. It is generally added to cow manure or in combination with other manures.

Horse manure contains 0.65% N, 0.25% P and 0.5% K. If incorporated exclusively, around 91 kg is required to be added to 93 sq. m. It is believed by some farmers that work-animals pass most of the nutrients in the feed, through their excreta. This has prompted them to include a few working horses in their farm.

Horsepower

Horsepower is the common unit of power employed in agriculture, as elsewhere. Different types of horsepower used are: engine horsepower, brake horsepower, drawbar horsepower or power take off horsepower.

The concept of horsepower (hp) was conceived by James Watt, while developing his famous steam engine. He watched horses pulling loads out of mine shafts and assumed that one horse is equal to the work performed at the rate of 33,000 foot pounds per minute, that is,

$$1 \text{ Horsepower (hp)} = \frac{\text{Power (p)}}{33{,}000}$$

Thus one horsepower is equal to 745.7 watts or 550 foot-pound force per second. Since power is work (w) divided by time (t), and work is force (f) multiplied by distance (d), horsepower (hp) is commonly shown mathematically as:

$$\text{hp} = \frac{f \times d}{33000 \times t}$$

Horticulture

Horticulture refers to gardening or to the scientific cultivation of fruit, vegetables, flowers and shrubs. Many horticultural crops have been domesticated and brought under regular cultivation in many parts of the world.

Horticulture in the tropics can be broadly divided into subsistence horticulture, home gardening, commercial horticulture (like floriculture) and landscape horticulture.

Though horticulture generally refers to a specialized holding, it also relates to the commercial production of crops on a farm, where the soil, climate, skilled labor and irrigational facilities can be used for maximizing the yield of high quality crops. A suitable infrastructure, like good roads, helps in accessing the market and getting better prices for the product. Widespread use of appropriate machinery has increased the per unit area output of horticultural products.

The subdivisions of horticulture are (a) **olericulture** dealing with the production of vegetable processing and storage (Fig.H.10), (b) **pomology** dealing with the art and science of fruit crop production (Fig.H.11), and (c) **floriculture**, dealing with the cultivation of ornamental and flowering plants for aesthetic purposes (Fig.H.12).

Horticultural plants are classified according to their life cycles, growth patterns and, more commonly, according to their use. The classification on the basis of use is considered practical and useful to the producer, dealer or consumer. Banana and plantain belong to the same genus. However, a banana is classified as a fruit because when ripe, it is consumed directly whereas plantain is regarded as a vegetable because it has to be cooked before eating.

Fig.H.10: Production of vegetable crops (Olericulture). A crop of snake gourd is seen in the picture.

Fig.H.11: Science of cultivation of fruit crops is termed as pomology.

Vegetable crops are classified as (a) salad vegetables (lettuce, celery, cucumber, radish), (b) **pot herbs** (amaranthus, telfairia, talinum, ocimum), (c) **fruit vegetables** (squash, pumpkin, tomato), (d) vegetable legumes (garden pea, garden bean, cowpea, lima bean), (e) **root vegetables** (carrot, beetroot, Jerusalem artichoke), (f) **cole crops** (cabbage, cauliflower), (g) **bulb vegetables** (onion, shallot, leek, garlic), and (h) **condiments and spices** (sesame, chili, pepper, ginger, black pepper).

Vegetable gardening requires a small land area and a small capital investment in comparison to field or plantation crops and can, therefore, be a rewarding hobby as well as a full-time occupation.

Fig.H.12: A field of tuberose in blossom, an example of floriculture.

Host

A **parasite** is an organism that lives on a plant or an animal. The host is the organism infected by a parasite. Some parasites require only one host while others need two; sexual maturity is reached in the **primary** (or **definitive**) **host** while the rest of the life cycle is completed in the **secondary** (**alternate** or **intermediate**) **host**; for example, the liver fluke is a parasite that enters a mud-snail, the primary host, through water and later installs itself in the liver of a sheep through vegetation or water.

Hot mix liquid fertilizer plant

A liquid fertilizer plant is classified according to the type of operation it carries, whether hot mix or cold mix. A hot mix liquid fertilizer plant uses phosphoric acid and ammonia.

Hot water insoluble urea formaldehyde products

Hot water insoluble (HWI) is one of the three fractions of slow releasing nitrogen fertilizers like urea-formaldehyde products. The other two are **CWS** or **cold water soluble** (at 25°C) and **HWS** or **hot water soluble** (at 100°C). Based on these fractions, the activity index of slow releasing nitrogen fertilizers is evaluated.

Hot water soluble urea formaldehyde products: See Hot water insoluble urea formaldehyde products

Human intervention in agricultural systems: an environmental perspective

Modern agricultural systems depend, to a great extent, on advanced technological innovations, to achieve desired crop yields. Farm production figures have continually been increasing to cater to the increased needs of the society. Technological advances like appropriate machinery, disease-resistant seeds, effective chemigation and the introduction of specific fertilizers have made it possible to achieve good yields from limited resources.

The process of **chemigation** is the introduction of synthetic chemicals to the crop through the medium of irrigation water. These chemicals may be pesticides, fungicides or fertilizers. This way, specific doses of fertilizers are added at the pre-planting stage, growth stage, flowering stage, etc. Foliar sprays are also required to be applied for most crops.

While such intervention helps the production of high quality crops, often, little attention is paid to its effects on soil, water and the surrounding fauna and flora. Thoughtless application of synthetic chemicals has at many places poisoned the surroundings of several farming communities.

Changes in the pH of water and soil endanger the natural balance of nature. Unless one is extremely careful, extensive use of macronutrients like N, P and K can increase the levels of silicofluoride complexes, gaseous fluorides, nitrates, chlorides, soil acidity, phosphogypsum, arsenic, uranium, etc. Needless to say, that these have long term effects on the environment.

Mindless production and use of pesticides the world over has caused much damage to animal and human life. Most of the pesticides and some chemical fertilizers contain organophosphates, carbamates and chlorides that affect the nervous system, and cause damage to the reproductive organs.

Ground waters may also be contaminated by a host of factors. Pesticide run-off from farms is one such factor polluting ground water. Poor management of wastes from synthetic fertilizer plants is also a serious issue. In short, ground water contamination is brought about by **persistent organic pollutants** (POPs) which include harmful chemicals in industrial plants and agricultural pesticides. Many fertilizers are high in chlorides which prove toxic to soil micro-organisms.

One estimate is that only 10 to 20% of the total fertilizers applied to the soil gets absorbed by the plant. The remaining is tied up in organic matter, leached away into the water, or lost to the atmosphere.

Humic acid

Humic acid is a partially decomposed aromatic, organic matter that originates from terrestrial vegetation. It is made up of dark colored amorphous materials and is the end-product of the action of bacteria and certain enzymes. Most of the humic acid has a large fraction of carboxylic functional group which enables the humic acid molecule to chelate with positively charged multivalent ions (Mg^{++}, Fe^{++}, etc). The action of chelation helps plants to absorb the nutrients effectively. This function is one of the most important roles of humic acid. Humic acid also contains the phenolic functional group.

Humic acids are derived from peptide, lipid and carbohydrate precursors. Peat, lignite coal, leonardite, decomposing driftwood and fish excreta are rich in humic acids. Leonardite is a highly oxidized form of organic matter and is technically known as a low rank coal which is between peat and sub-bituminous coal. Most of the humic acid found in rivers, lakes and even oceans has flowed from land over long periods of time. In the aquatic media, humic acid molecules develop unique characteristics.

Humic acid can be broken down into two groups, based on the size and polarity of the individual components. The smaller, more polar fraction is called **fulvic acid** and the larger, non-polar fraction is the humic acid. The acids are soluble in sodium hydroxide.

Humic acids are soluble in alkaline solutions. But on acidification of the alkaline extracts, they precipitate (Fulvic acid, on the other hand, remains soluble on acidification of the extract). Their molecular weight is in the range of tens of thousands to a million. They are believed to be polymerization products of fulvic acids and their decay products.

The three main components of **humus** are **humin**, humic acid and **fulvic acid**.

Humic coal

Humic coal, also called **woody coal**, is a type of **coal** derived from plant remains.

Humidity

Humidity refers to the amount of water vapor in the air. Absolute humidity measures the mass of water per unit volume of air. Saturation or the dew point occurs when the water vapor pressure reaches a certain pressure at the temperature concerned. This rises rapidly with temperature. Relative humidity (RH), expressed as a percentage, is the amount of water in the air at any given time compared with the amount the air can hold at the temperature before becoming saturated. Humidity interferes with the storage of grains and fertilizers. The higher the humidity, the greater the chance of fertilizer caking, or of fungal growth in grains. Humidity inhibits body cooling by impeding the evaporation of sweat. The physiologically tolerable humidity level falls rapidly with the rise in temperature.

Humification

Humification is the process in which organic matter decomposes into humus.

Humin

Humin is one of the three components of soil humus. It is that fraction of the soil organic matter which does not dissolve in dilute alkali. The other components of humus are **fulvic acid (FA)** and **humic acid (HA)**.

Humus

Humus is a dark-colored, amorphous, colloidal, biochemically stable, complex end product of microbial decomposition of organic matter in soil. Humus is resistant to further microbial breakdown, and has a low bulk density (0.2 to 0.49 g/cm^3). The process of decomposition of the organic matter into humus is called **humification**. The nature of soil humus is extremely complex; it contains **humin**, **humic acid** and **fulvic acid** and accounts for 60 to 70% of the organic carbon in the soil.

Chemically, the humus is composed of carbohydrates, proteins and small amounts of organically bound sulphur and phosphorus. It can hold water (5 to 7 times as much as clay) and, therefore, improve the water-retaining properties of soil. It also enhances soil fertility and workability. The carbon to nitrogen ratio of humus ranges between 10:1 and 15:1 and its carbon-nitrogen-phosphorus-sulphur (C:N:P:S) ratio is about 100:10:1:1. It has a relatively high molecular weight and a high cation exchange capacity (~200 meq/100 g compared to 1 to 100 meq/100 g for clays). Fig.H.13 shows the schematic of humus formation in soils.

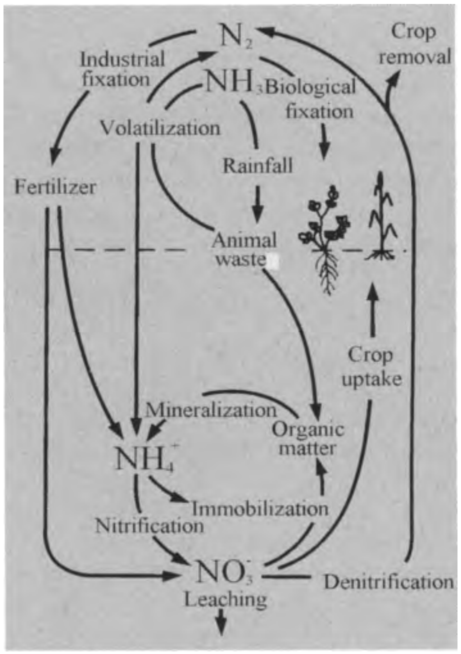


Fig.H.13: Cycle of humus formation in soils.

Humus plays an important role in the formation and stabilization of soil aggregates, controlling soil acidity, cycling of nutrient elements and the detoxification of toxic substances like heavy metals and pesticides. Also soluble humus compounds like fulvic acid can form complexes with organic compounds which move along with percolating water. Thus, a pesticide deposited on the soil surface, does not stay there, but moves; and may contaminate the environment as well as the groundwater.

Acid humus (**mor**) is found in coniferous forests where the decay is brought about mainly by fungi. Alkaline humus (**mull**) found in grassland and deciduous forests, supports abundant micro-organisms and small animals.

Highly decomposed small particulate organic material (colloidal size) is called **amorphous humus**. **Peat** is a type of humus that is formed by the decomposition of plant material under conditions of excessive moisture or in areas submerged in water.

Dauer humus is a kind of humus that is resistant to attacks by micro-organisms.

Humus-clay complex: See Clay-humus complex

Humus micelles

The aggregates of humus molecules are humus micelles, which are electronegative, and cannot be held directly on to clay. The association between clays and humic components of the soil due to electrostatic or other bonds results in a clay-humus complex.

Humus rich fen land soils

The humus rich fen land soils, also called **black land**, are in low-lying areas with slightly acidic to alkaline peat soils. Agriculture is intensively carried out on these fertile soils with vegetables, fruits and wheat being grown on a large scale.

Hundred-grain weight

The hundred-grain weight, a measure of the grain yield, denotes the weight of 100 grains of the test material. Sometimes 1000 grain weight is also considered in small-sized grains. In bigger-sized grains, a lesser number of seeds are considered. For example, say 100 grains of cowpea whereas 1000 grains of rice are considered for the test weight.

Hungry soil

A soil which is barren and low in fertility is called a hungry soil. Soil becomes 'hungry' owing to nutrient exhaustion and lack of organic matter. A hungry soil requires abundant supplies of plant nutrients through manuring and fertilization to produce good quality crops.

HWI

HWI is short for **hot water insoluble**.

HWS

HWS is short for **hot water soluble**.

Hybrid

The word hybrid originates from Latin *hybrida* meaning cross. A progeny or offspring of two or more individuals, plants or animals of different genetical constituents, obtained after crossing, is called a hybrid.

A cross-breed is also a term synonymously used for hybrid. The method of crossing plants or individuals is called **hybridization**, and is used especially for crop improvement. In this, two or more plants of dissimilar genetic constituents with one or more different characters are crossed together. Hybridization is practiced for inducing in plants (a) resistence to pests and diseases, (b) resistence to drought, (c) improved grain or fruit size, and (d) higher productivity, etc.

The important steps in hybridization are the (a) selection of parent material, (b) selfing or self-pollination of parents, (c) emasculation (meaning, removal of stamens from the female parent before they shed their pollens), (d) bagging, (e) cross-pollinating genetically unlike plants and proper labelling, (f) harvesting hybrid seeds and raising the first generation after hybridization (F1 generation), (g) handling of F1 and subsequent generations using different selection methods of hybridization, and (h) conducting trials, multiplication and distribution of hybrid seeds.

The **hybrid seed** exhibits increased vigor, growth and yield than the parents, a condition called **heterosis** or **hybrid vigor**. It acts as a catalyst in bettering agricultural yield, provided it maintains its purity, high germination percentage and productivity.

Fig.H.14: Cotton Magic AAC-1 is highly tolerant to drought and sucking pest, has good seed cotton retention even after delayed picking and bears medium to big sized bolls. (Courtesy: Mahyco Seeds Ltd., Mumbai, India).

There are renowned organizations involved in producing hybrid seeds or plant varieties with improved characteristics. For example, Magic AAC-1 is a variety of hybrid cotton (*Gossypium arboreum*) developed by MAHYCO (India), for its high tolerance to drought and resistence to sucking pests, better seed cotton retention in case of delayed picking, big boll size, etc. (Fig.H.14). Such organizations are involved in genetic improvement and development of hybrids of economically important fruit and vegetable crops and have created a vast range of hybrid products. The illustrations (Fig.H.15 and H.16) exhibit major hybrid crops developed for their specific characteristics.

Hybridization: See Hybrid

Hybrid seed: See Hybrid

Hybrid vigor: See Hybrid

Fig.H.15: 1. Purple Panther, a variety of brinjal is a long cylindrical blackish purple fruit, borne solitary. 2. Green Glory okra is dark green and longer than the variety Green Energy and tolerant to yellow vein mosaic virus. (Courtesy: Mahyco Seeds Ltd., Mumbai, India).

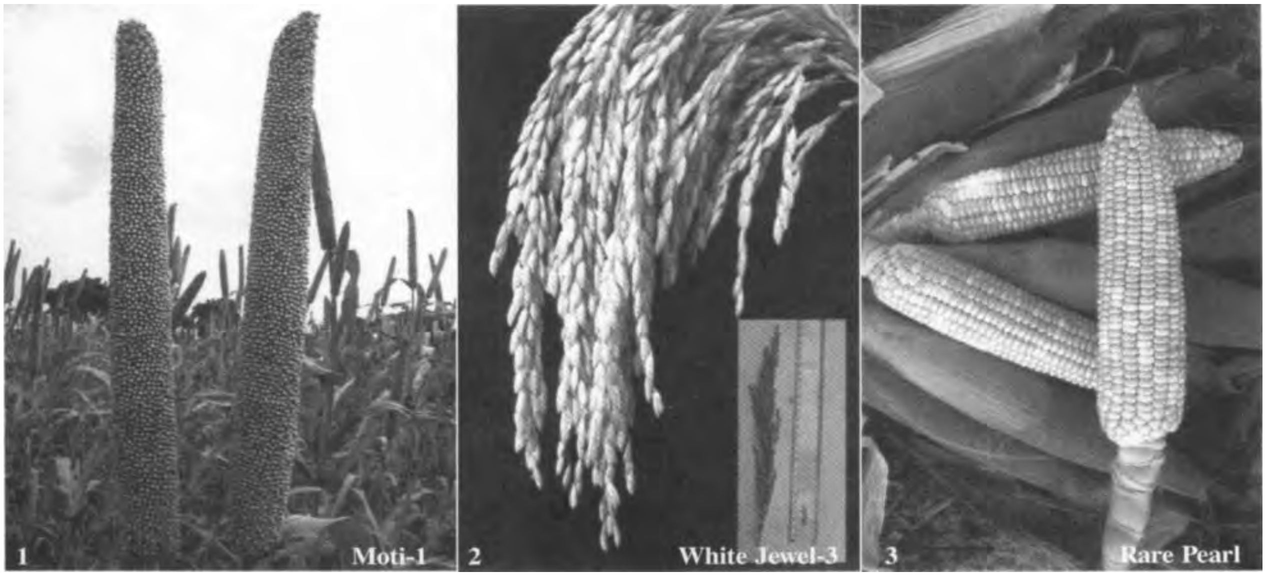


Fig.H.16: 1. Moti-1 variety of pearl millet is a medium maturity hybrid, with round bold whitish grey grains, a long cylindrical, semi compact ear head and tolerant to Downey mildew. 2. White Jewel-3 rice is a medium maturity hybrid, resistant to Blast, with excellent tillering habit, more grains per panicle and medium size translucent grains, 3. Rare Pearl corn is very sweet, having cylindrical ears with plumpy bicolored grains. (Courtesy: Mahyco Seeds Ltd., Mumbai, India).

Hydrated lime

Calcium hydroxide $Ca(OH)_2$, also called **slaked lime** or **hydrated lime**, is a white solid which dissolves sparingly in water. It is used as an acid neutralizing material and has an efficiency of 135% compared to 100% for calcium carbonate.

Hydrates

Hydration is the reaction of water molecules with a substance in such a way that the H-OH bond is not broken. The association of one or more water molecules with an ion or a molecule is called **hydration**. The products of hydration are called hydrates; for example, in $FeSO_4 \cdot 7H_2O$, ferrous sulphate has seven water molecules associated with it to give **green vitriol**. Water thus retained by a hydrate is known as **water of crystallization** or hydration. The number of water molecules associated with an ion or a compound is called the degree of hydration. The degree of hydration in $FeSO_4 \cdot 7H_2O$ is 7. As the water is removed by heating, most of the hydrates change their structure and color. The compound without any water molecule attached to it is called anhydrous.

$$CuSO_4 + 5H_2O \longrightarrow CuSO_4 \cdot 5H_2O$$

Many compounds form more than one hydrate. For example, hydration of sodium sulphate gives $Na_2SO_4 \cdot 10H_2O$, $Na_2SO_4 \cdot 7H_2O$ and $Na_2SO_4 \cdot H_2O$. Heat removes this water, yielding anhydrous compounds.

When an ionic substance dissolves in water, the ions adjacent to one another in the solid separate and get surrounded by water molecules. Such a substance is said to be hydrated. This process is also called hydration. For example, the dissociation of sodium chloride, which occurs when NaCl is dissolved in water, is represented as:

$$NaCl_{(s)} \longrightarrow Na^+_{(aq)} + Cl^-_{(aq)}$$

The surrounding water molecules in the immediate vicinity of a positive ion, are oriented so that the negative ends of the water molecules' dipoles point toward the positive charge. Water molecules surrounding a negative ion have their positive ends directed toward the ion. An ion enclosed within this 'cage' of water molecules is considered hydrated. In general, when molecules of a solvent surround a solute particle, it is referred to as solvated; hydration is a special case of the more general phenomenon of **solvation**.

The layer of oriented water molecules surrounding an ion helps to neutralize the ion's charge and keeps ions of the opposite charge from being attracted toward each other over large distances in the solution. The solvent thus insulates ions. Non-polar solvents do not dissolve ionic compounds because they can neither tear apart the ionic lattice nor offer any shielding for the ions. Thus, substances with similar intermolecular attractive forces tend to be soluble in one another because like dissolves like. Thus, non-polar substances are soluble in **non-polar solvents**, whereas polar or ionic compounds dissolve in **polar solvents**.

The term hydration is used in paper industry to describe the combination of water with wood pulp in a beater, so that the fiber-to-fiber adhesion is increased by hydrogen bonding.

Hydrates of carbon

In olden times, glucose, fructose, cane sugar, starch and cellulose were considered as hydrates of carbon, $C_x(H_2O)_y$ and were called **carbohydrates**.

Hydration: See Hydrates

Hydraulic energy sprayers

Sprayers in which hydraulic pressure is thrust upon the liquid by hand operated pumps are called hydraulic energy sprayers. As a result, the liquid is forced through the nozzle in the form of a spray of droplets which are mostly 300-400 $m\mu$ in diameter. Sprayers of this type are for small volume and high pressure, and are suitable for complete coverage of field crops.

Hydric soil

A soil saturated and flooded with water long enough during the growing season to create anaerobic conditions in its upper part is called a hydric soil.

Hydro agri-neutralization process for ammonium nitrate production: See Ammonium nitrate production processes

Hydrocarbon gases

Hydrocarbon gases are gases consisting exclusively of carbon and hydrogen, and are derived principally from petroleum, coal tar, etc. They are divided into two classes - aliphatic and aromatic, in which carbon atoms are arranged in chains and rings, respectively. Aliphatics are further divided into subgroups according to the way the carbon atoms are bonded together.

Hydrocracking

Hydrocracking, also called **cracking**, is used in dissociating naphtha and making new products, in the presence of hydrogen and special catalysts.

Hydrogen

Hydrogen, a non-metallic element, is a colorless odorless, tasteless gas occurring in water combined with oxygen, and in all organic compounds (for example, hydrocarbons and carbohydrates). It is produced by electrolysis of water and is used in the **Haber-Bosch process** for producing ammonia - a major raw material for nitrogenous fertilizers.

Large quantities of hydrogen are utilized in catalytic hydrogenation of unsaturated vegetable oils to make solid fats and petroleum refining. Large quantities of hydrogen are also used as a propulsion fuel for rockets in conjunction with oxygen or fluorine. Being flammable, it is used with helium for filling balloons and airships.

Hydrogen (Fig.H.17) is the lightest of all the elements holding position in Group 1 of the Periodic Table. It is abundant in the universe. There are three hydrogen isotopes namely hydrogen-1, deuterium and tritium. The first two are naturally occurring stable isotopes and the third being radioactive, is made artificially.

Fig.H.17: Position of hydrogen in the Periodic Table.

Hydrogen bond

Hydrogen bond is a weak electrostatic interaction between an electronegative atom and a hydrogen atom bonded to a different electronegative atom. It is an attractive force, or bridge, occurring in polar compounds such as water, in which a hydrogen atom of one molecule is attracted to two unshared electrons of another. The hydrogen atom is the positive end of one polar molecule and forms a linkage with the electronegative end of another such molecule. In the formula below, the hydrogen atom in the center is the 'bridge'.

$$\begin{array}{ccc} H\ddot{O}: & H\ddot{O}: & H\ddot{O}: \\ H & H & H \end{array}$$

Hydrogen bonds are only one tenth to one thirtieth as strong as covalent bonds, but they have pronounced effects on the properties of substances in which they occur, especially as regards melting and boiling points and crystal structure. They are found in compounds containing such strongly electronegative atoms as nitrogen, oxygen and fluorine. They play an important part in the bonding of cellulosic compounds (e.g., the paper industry) and occur also in many complex structures of biochemical importance (e.g., adenine-uracil linkage in DNA).

Hydrogenic soil

Hydrogenic soil is a soil developed under the influence of water standing in the profile for a long period, mainly in wet and cold climates.

Hydrogen ion concentration: See pH

Hydrogen production by coal gasification process: See Ammonia production processes

Hydrogen production by electrolysis for ammonia synthesis: See Ammonia production processes

Hydrogen production by partial oxidation process: See Ammonia production processes

Hydrogen sulphide

Hydrogen sulphide (H_2S) is a colorless, poisonous, flammable gas with an odor of rotting eggs. It is found in cesspools and mines and is a by-product of decomposed substances containing sulphur. It is one of the gaseous end-products of the reduction of sulphate in highly degraded paddy fields. Hydrogen sulphide is also produced in the laboratory for use as an analytical reagent.

Hydrological watershed

Watershed is a region or a ridge of land that separates waters flowing to different rivers, basins or seas. It is the dividing line between catchment areas. A hydrological watershed is concerned with properties of the earth's water, particularly in relation to the land.

Hydrologic cycle: See Hydrology

Hydrology

Hydrology is a branch of science that studies **water table** which is the level below which the land is saturated with water. Hydrology is concerned with the movement and properties of the earth's water.

The **hydrologic cycle** is the circulation of water on the earth between land, oceans and atmosphere. Water evaporates from the oceans to form clouds. Much of this water is precipitated back on the earth's surface as rain, snow, sleet or hail. Some of the water is returned to the atmosphere by transpiration of plants, some eventually enters the sea via lakes or rivers and some evaporates back into the atmosphere from the surface of the land or from rivers, lakes, etc. Over 97% of the earth's water is in the oceans.

Hydrolysis

In hydrolysis, a substance reacts with water, gets ionized and broken down into two or more new substances.

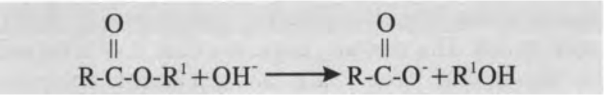
Although 'hydrolysis' means decomposition by water, cases in which water alone brings about effective and unaided hydrolysis are rare. High temperatures and pressures are needed to bring about hydrolysis.

Some examples of hydrolysis are as follows:

(i) Inversion of sucrose. Acids catalyze this type of hydrolysis.

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{[H^+]} \underset{\text{Dextrose}}{C_6H_{12}O_6} + \underset{\text{Glucose}}{C_6H_{12}O_6}$$

(ii) Alkaline hydrolysis of ester produces alcohol and salt of carboxylic acid.



$$R\text{-}\overset{\overset{\displaystyle O}{\|}}{C}\text{-}O\text{-}R^1 + OH^- \longrightarrow R\text{-}\overset{\overset{\displaystyle O}{\|}}{C}\text{-}O^- + R^1OH$$

(iii) In the acid hydrolysis of proteins the long chains are first broken into peptides which are further hydrolyzed to produce amino acids.

Through hydrolysis, a wide range of silicate minerals (including feldspars and micas) are broken down as

$$KAl\,Si_3O_8 + H_2O \longrightarrow HAl\,Si_3O_8 + KOH$$
$$2HAl\,Si_3O_8 + 8H_2O \longrightarrow Al_2O_3 \cdot 3H_2O + 6H_2SiO_3$$

The released potassium is soluble and is taken up by the plants, or leached out or adsorbed by soil colloids; aluminum and silicon may recrystallize into clay, remain in the soil as oxides or may be leached. Free movement of underground water provides the best environment for hydrolysis.

Hydromagnesite

Hydromagnesite is a magnesium ore which occurs as a carbonate. Magnesium carbonate occurs in a mixed salt dolomite ($CaCO_3 \cdot MgCO_3$) and as basic magnesium carbonate in two minerals, namely, artinite ($MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O$) and hydromagnesite ($3MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O$).

Hydromorphic sandy soils: See Hydromorphic soils

Hydromorphic soils

Soils that exist in areas of water regime (like flat marshy zones, swamps, coastal areas, beach ridges and tidal zones) are called hydromorphic soils. These soils are saturated with water for most parts of the year and hence lack oxygen. In these soils, decomposition of organic matter is very slow except for the action of anaerobic bacteria responsible for some degree of mineralization. As a result, a thick layer of organic matter gets accumulated which may be up to 1 meter in depth. This peaty matter gives the soil a dark appearance. Iron oxides in permanently wet soils get reduced and give the soil a grey color.

When these water laden hydromorphic soils are sandy and course textured, they are called **hydromorphic sandy soils**. These soils have lesser organic matter content. Any mineral and organic matter present in these soils can get leached away. As a result of the loss of iron oxides, these soils get a whitish look. However, since these hydromorphic sandy soils are also in the same water regime, they may be mistaken for hydromorphic soils.

Hydromulching

Hydromulching, also called **hydroseeding**, is a method of planting and growing grass on vast level surfaces and slopes. It is considered to be a fast and economical way of covering the given land with grass.

The process of hydromulching begins by mixing the seed with the required fertilizer, water and a specially made mulch. This mixture, made in a tank, is then spread on the desired area. Such an application enhances sustained growth of the grass, owing to the nature of the mulch material. The mulch material is made of wood pulp or recycled paper, reduced to a fibrous material. The mulch sometimes also acts as a kind of glue that helps to hold it to the soil. A hydromulching mixture, when spread on the ground, helps to conserve water, thus providing the ideal warm and moist conditions for the seed to germinate. However, the mixture should not be applied as a very thick layer, as otherwise the seed will not receive the required warmth. When slopes are covered with grass, the roots hold the soil and prevent run-off, erosion and soil pollution of streams. Hydromulching finds suitable applications on golf courses, mine sites, land reclamation sites, homes, etc.

Hydrophilic colloids

Colloids are either hydrophilic (**lyophilic**) or **hydrophobic (lyophobic)**. **Hydrophilic substances** or colloids (or **lyophilic colloids**) are those having a tendency to mix with, dissolve in or be wetted by water (solvent).

Hydrophilic substances: See Hydrophilic colloids

Hydrophobic colloids

Colloids are either **lyophilic (hydrophilic)** or hydrophobic (lyophobic). **Hydrophobic substances** or **lyophobic colloids** are those having a tendency to repel or fail to mix with water (solvent). Such colloids are stabilized by the adsorption of ions. They coagulate when the charge is neutralized.

Hydrophobic substances: See Hydrophobic colloids

Hydrophytes

A plant that is fully or partially submerged in water is called a hydrophyte. Rice, water caltrop and water lilies (Fig.H.18) are examples of hydrophytes. Structural

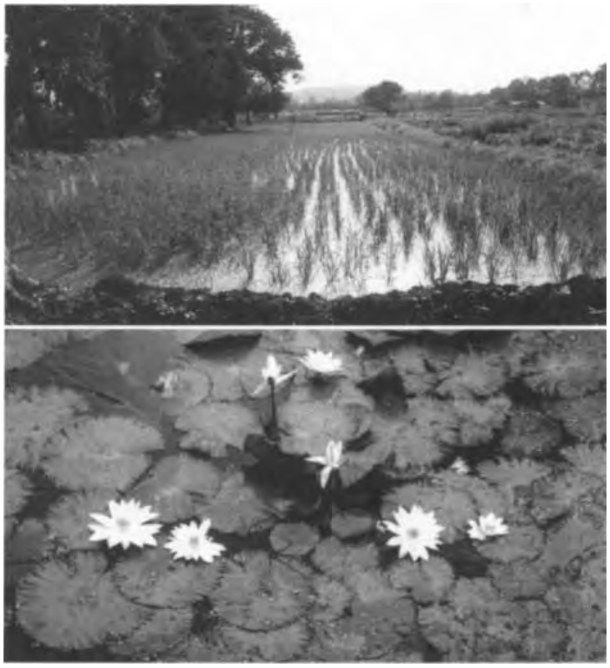


Fig.H.18: Rice and water lilies are hydrophytes.

modifications of hydrophytes lead to reduction of supporting and vascular tissues. The root system is also reduced. The stems, leaves and roots have air spaces inside them, which help them not only to float but to exchange gases. The (near) absence of cuticles helps plants to absorb minerals and gases directly from water. These plants generally have a rooting depth of 50 cm. So the water table has to be at a depth of less than 50 cm or at least 50 cm.

Hydroponics

Hydroponics refers to the practice of growing plants (like tomato) without soil (soil-less culture), in nutrient solutions with or without an artificial medium such as sand or gravel.

In hydroponics, the roots of a plant are immersed in an aerated solution containing the correct proportions of essential mineral salts. This technique is based on various laboratory water culture methods used to assess the effects of certain mineral elements on plant growth. In **aeroponics**, plants are suspended in air and the roots coated with nutrient solutions.

Hydroseeding

Hydroseeding is the method of broadcasting seeds in an aqueous suspension, usually containing plant nutrients.

Hydrous mica

Hydrous mica (illite) is a 2:1 type clay of silica and alumina sheets. Water cannot penetrate between these layers because the potassium ions in mica hold the layers very tightly.

Hyetograph: See Rain gauge

Hygrometer

Hygrometer is a device that measures humidity (the amount of water vapor the air holds). Usually hygrometers measure relative humidity, the amount of moisture as a percentage of the saturation level at that temperature. The hair hygrometer, which is of limited accuracy, measures the increase in the length of human hair with increase in relative humidity.

The wet and dry bulb hygrometer has two thermometers mounted alongside each other, with the bulb of one thermometer covered by a damp cloth. Air is moved across the hygrometer by evaporating water from the damp cloth which takes the latent heat for the evaporation from the bulb. Comparison of the temperatures of the two thermometers and the use of tables give the relative humidity. The dew point hygrometer comprises a polished container cooled until the dew point is reached. This temperature gives a measure of relative humidity. The electric hygrometer measures changes in electrical resistance of a hygroscopic strip.

Hygroscopic: See Hygroscopicity

Hygroscopicity

Hygroscopicity is the property (of a substance) to absorb moisture from the air. Calcium chloride, ammonium nitrate, zinc chloride for instance, are **hygroscopic** substances because they readily absorb moisture from the air. A hygroscopic substance (like silica gel) used as a drying agent is called a **desiccant**. Hygroscopic chemicals should be kept in tightly closed bottles. The hygroscopic nature of fertilizers interfere with fertilizer application and storage.

Hygroscopicity varies under specified conditions of humidity and temperature. Water absorbed to a surface from the atmosphere is called **hygroscopic water**. Paper and cotton fabrics are hygroscopic, normally containing 5 to 8% water after standing in normal atmospheric humidity.

Most fertilizers are hygroscopic because of their high affinity for water, leading to problems during storage and handling. Fertilizers like calcium ammonium nitrate, sodium nitrate, ammonium nitrate, ammonium chloride and urea, absorb moisture from the air and become sticky. Hygroscopicity of fertilizers depends on factors like the (a) chemical composition, (b) moisture content, (c) ambient temperature, (d) relative humidity, (e) particle structure and porosity, (f) exposure time, and (g) particle surface area.

Hygroscopic properties of a substance can be quantified by measuring the critical relative humidity and its moisture absorption-penetration characteristics. In fertilizers, these properties are as follows:

(i) **Critical relative humidity** (**CRH**): The CRH of a material is defined as the relative humidity of the atmosphere at which (and not below) the material begins to absorb moisture from the atmosphere.

CRH is that humidity of air at which partial vapor pressure of water in the air equals the equilibrium water vapor pressure above a saturated solution of the salt at a given temperature.

The chemical composition, ambient air temperature, and humidity of the atmosphere are the major factors that dictate the CRH of a fertilizer.

A material with a high CRH is advantageous because it can then be exposed to, and handled in, humid conditions without the risk of its getting damaged or caked. The CRH of a fertilizer affects the (a) wetting of bulk pile surfaces, (b) mass transfer of moisture within a pile or bag, (c) sticking and building up of hygroscopic materials (fertilizer) on equipment, (d) compatibility in bulk blends, and (e) choice of handling - whether in bulk or in bag, and if in bag, the type of bag required.

CRH is sometimes wrongly considered as a universal measure of the caking tendency of fertilizers. When a fertilizer is stored in a moisture-resistant bag or protected in a plastic sheet, atmospheric humidity is effectively excluded and CRH is of little importance. If caking still occurs, it is related to factors such as the fertilizer moisture content, chemical reactions, ambient air temperature, storage pressure, presence of fines and the efficiency of any conditioning treatment. CRH is strictly a quantitative measure indicating whether or not a material will absorb moisture at a specified relative humidity and temperature.

The simplest method of measuring CRH is to gradually expose a sample to increasing relative humidity at a predetermined temperature. The lowest relative humidity at which a significant amount of moisture is absorbed, is taken as the CRH. The significant amount of moisture for a fertilizer can vary depending on its type and nature of material being tested. A moisture level, which is significant for one fertilizer may not be so for another.

CRH is determined in laboratory in a temperature humidity chamber equipped with a forced air circulation and mechanical refrigeration for humidity control.

In one experiment, it was found that for prilled urea at 70% relative humidity (RH), the moisture was not absorbed over a three-hour period, while it was continuously absorbed at 75% RH. For diammonium phosphate, the CRH is between 70 and 75% at 70% RH. In this condition, a maximum of 2% moisture would be absorbed, which is insufficient to cause inter-granule transfer of moisture or agglomeration.

CRH of a fertilizer mixture is lower than that of its constituents. The effect of mixing fertilizers is most dramatic for ammonium nitrate (CRH of 55 to 60% at 30°C) and urea (CRH 70 to 75% at 30°C). The CRH of this mixture is approximately 18%. The CRH of most fertilizers decreases with an increase in temperature.

Table-H.1. gives the critical relative humidities of some fertilizers.

(ii) **Moisture absorption-penetration characteristics**: Though CRH defines the humidity, above which a substance absorbs moisture from the atmosphere, it neither indicates how rapidly the moisture is absorbed, nor the effect of absorption on its physical condition.

Fertilizers vary considerably in their ability to tolerate the absorbed moisture. Factors affecting the moisture absorption-penetration characteristics of a fertilizer include chemical composition, particle porosity, particle surface area and degree of crystallinity. Moisture absorption-penetration characteristics are important for the fertilizer storage conditions and to predict its free flowability during handling and movement for field application. These characteristics give an idea of how rapidly and to what depth, the wetting will induce physical deterioration of the fertilizer.

The laboratory absorption-penetration test involves exposing a bulk fertilizer surface of known area. The exposure should be for a long period to moving air in a chamber with constant temperature and humidity. In the test, samples are placed in 20 cm tall glass cylinders which have an internal diameter of 6.8 cm. These samples are evaluated by measuring (a) the rate of moisture absorption per unit of the fertilizer surface, (b) the depth of moisture penetration into the fertilizer, (c) the moisture holding capacity of individual fertilizer particles, and (d) the integrity of the wetted granules. Typical data from this type of tests for some common fertilizers are given in Table-H.2.

Table-H.1. Critical relative humidities of fertilizer products.

Fertilizer	Grade	CRH (30°C)
Ammonium nitrate	34-0-0	55-60
Ammonium sulphate	21-0-0	75-85
Ammonium sulphate, ammonium phosphate, potassium chloride, sand	10-10-10	65-75
Ammonium sulphate, ammonium phosphate, potassium chloride, sand	8-32-16	65-75
Ammonium sulphate, phosphate rock, potassium chloride, kieserite	10-5-18-2MgO	60-70
Diammonium phosphate	18-46-0	65-75
Potassium chloride	0-0-60	70-80
Monoammonium phosphate	12-50-0	70-75
Nitrophosphate	12-12-17-2MgO	60-65
Potassium sulphate	0-0-50	75-80
Potassium nitrate	13-0-44	80-85
Triple superphosphate	0-46-0	75-85
Urea	46-0-0	70-75
Urea, ammonium sulphate, diammonium phosphate, potassium chloride	17-17-17	45-55
Urea, ammonium polyphosphate	28-28-0	55-65
Urea, ammonium polyphosphate, potassium chloride	19-19-19	50-60
Urea, diammonium phosphate, potassium chloride, sand	15-15-15	45-50
Urea, diammonium phosphate, phosphate rock	20-20-0	50-60
Urea, diammonium phosphate, phosphate rock, potassium chloride, neem cake, filler	18-18-10	45-55
Urea, potassium chloride	16-0-30	45-55
Urea, phosphate rock, potassium chloride, kieserite	12-12-17-2MgO	40-50

Source: "Fertilizer Manual" 1998, UNIDO, IFDC and Kluwer Academic Publishers. With permission.

Neither the rate of moisture-absorption nor the depth of moisture penetration correlates with CRH; the depth of moisture penetration also does not correlate with the rate of moisture absorption. This is due to differences in the moisture-holding capacity which represents the maximum amount of moisture that a granule can absorb before it becomes wet enough to transfer the moisture to the adjacent granules by capillary action.

A high moisture-holding capacity is desirable as it can offset the effects of a high rate of moisture absorption, *Table-H.2: Moisture absorption-penetration characteristics of granular fertilizer products.*

Grade	Composition[a]	Moisture absorption-penetration characteristics (30°C, 80% relative humidity for 72 h)			
		Moisture absorption (mg/cm²)	Moisture penetration (cm)	Holding capacity (%)	Granule integrity[b]
46-0-0	Urea	350	15	3	Fair - good
21-0-0	Ammonium sulphate	100	0	-	Excellent
18-46-0	DAP	175	2	12	Fair - good
0-46-0	TSP	235	2	12	Excellent
0-0-60	KCl	135	3	5	Good
6-24-24	Ammonium sulphate, ammonium phosphate, KCl, sand	280	2	15	Fair
10-10-10	Ammonium sulphate, ammonium phosphate, KCl, sand	270	4	7	Poor
13-13-13	Ammonium sulphate, ammonium phosphate, KCl, sand	365	4	9	Fair
28-28-0	Urea, APP	370	3	15	Poor
17-17-17	Urea, ammonium sulphate, MAP, KCl	580	6	12	Poor
12-19-9	Urea, phosphate rock, KCl	450	5	8	Poor
15-15-15	Urea, phosphate rock, KCl, sand	490	6	8	Poor
12-12-17-2MgO	Urea, phosphate rock, KCl, kieserite	445	5	7	Poor

a. DAP = diammonium phosphate; TSP = triple superphosphate; KCl = potassium chloride; APP = ammonium polyphosphate; MAP = monoammonium phosphate.

b. Granule integrity is a qualitative observation based on the strength of the top layer (surface) of granules after exposure for 72 hours.

Source : "Fertilizer Manual", 1998, UNIDO, IFDC and Kluwer Academic Publishers. With permission.

and may be related to both the chemical composition and the porosity of the granules. Pure crystalline materials like ammonium nitrate and urea have low moisture holding capacities. Impurities from the wet-process acid like iron and aluminum phosphates are beneficial as they decrease the crystalline phase and increase the amorphous phase in fertilizers increasing their moisture-holding capacity.

Hygroscopic water

Water adsorbed on a dry soil from an atmosphere of high relative humidity is called hygroscopic water. It is the water that forms a thin film around individual soil particles by powerful molecular attraction, such that it is not available to plants. This water may also be bound by adhesive forces that exceed 31 bars and may be as great as 10,000 bars. This non-mobile water can be removed from the soil through heating.

Hygroscopic water is one of the subdivisions of soil water, the others being **capillary water** and **gravitational water**. Capillary water is held by cohesive forces between hygroscopic water films. This water is not so tightly held and can be extracted by plants, until the soil capillary force equals the plant root extractive force, after which point the plant wilts (the **wilting point**). Gravity water is the water moved through soil by the force of gravity.

Hyperaccumulator plants

Plants that absorb disproportionately large amounts of toxic metals or metalloids throughout their lives are called hyperaccumulators. It is not very clear yet whether, and to what extent, such accumulations prove useful to such plants. But evidence suggests that hyperaccumulation represents a breakdown of the homeostatic mechanism and does not symbolize a normal growth process.

Hyperaccumulators exist throughout the plant kingdom. Hyperaccumulators are commonest among the Brassiceae. These plants accumulate such metals as nickel, copper, cobalt, lead, zinc, manganese, etc. The accumulation rates are around 1000 g of Ni, Cu, Co, Pb per gram of dry weight in their leaves, 100 g cadmium per gm dry weight, etc. However, these metals are available to the plants only in the form of free ions, soil soluble complexes and when they are adsorbed to inorganic soil constituents at ion exchange sites.

Phytomining with hyperaccumulators and **indicator** plants can help to restore heavy metal sites without employing traditional decontamination techniques. Hyperaccumulators can also be commonly used for extracting nitrogen compounds, chlorinated solvents, BTEX compounds (benzene, toluene, ethylbenzene and xylenes), etc., so as to restore the soil.

Hypha

The vegetative structure of majority of fungi consists of more or less elongated, septate or aseptate, branched filaments. The individual filament is called hypha (plural-hyphae) and a group of **hyphae** is called **mycelium**.

Hyphae: See Hypha

Hypocotyl necrosis, bean

Calcium deficiency is rare in vegetables; however, it is seen as a disorder in their storage tissues. Hypocotyl necrosis in beans is the result of calcium deficiency.

Hypomagnesemia

Hypomagnesemia is another word for **grass tetany**.

Hysteresis

Hysteresis is a phenomenon in which the value of a physical property lags behind the changes in the effect causing it. For example, in magnetism, the magnetic induction lags behind the magnetizing force. For some specimens, the measurements of stress and strain leading to a stress-strain diagram is a closed loop, indicating the occurrence of hysteresis.

Hysteresis is analogous to mechanical inertia; the energy lost is analogous to that lost in mechanical friction.

The phenomenon of hysteresis has to be taken into consideration, while designing electrical machines like transformers, rotating armatures, etc.

Hysteresis is observed during drying (desorption) and moistening (sorption) of soils. Measurements of sorption/desorption produce a graph that has the shape of a closed loop, called **hysteresis cycle** (Fig.H.19).

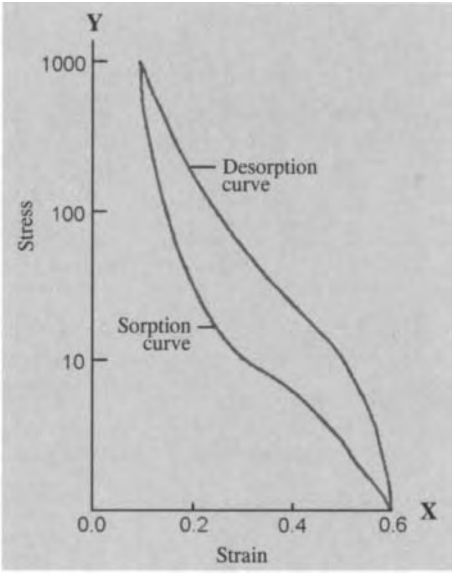


Fig.H.19: Hysteresis cycle, observed during drying and moistening of soil.

The vulcanized rubber stress-strain curves also display hysteresis, where strain (elongation, crystallization) persists when the deforming stress is removed. This produces a hysteresis loop instead of a reversible pathway of the curve. This loop indicates the loss of **resilient energy**.

Hysteresis cycle: See Hysteresis

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

I

IAA

IAA is short for **indoleacetic acid**.

IBA

IBA is short for **4-indole-3-butyric acid**. It is a naturally occurring auxin, which gets synthesized in the plant shoot-tips and is an important growth regulator. (See also Auxins.)

IBDU

IBDU is short for **isobutylidene diurea**. Such urea fertilizers are coated with a water insoluble material, such as isobutylidene diurea (IBDU, 30% N), in order that they release the nitrogen slowly over an extended period.

Icelandspar

Icelandspar is a transparent variety of **calcite** ($CaCO_3$) which is crystalline calcium carbonate. It crystallizes as a colorless or white crystalline material in a rhombohedral system with a hardness of 3 on the Mhos' scale. It exhibits double refraction, which is apparent in icelandspar.

Ideal solutions: See Solution

Illite

Illite is a mica-type clay mineral with a lattice structure, which does not expand on absorbing water. The illite group of clays are used in the manufacture of structural clay products, such as bricks and tiles. Some degraded high plastic illites are used for bonding or moulding sands.

Illite has a 2:1 layer structure and resembles montmorillonite. It has a high concentration of potassium ions which hold the adjacent layers so tightly together that the water cannot penetrate between the layers. The swelling capacity of illite (hydrous mica) is, therefore, slight to moderate, depending on the number of weathered potassium ions. In such a case, the clay expands, somewhat like montmorillonite. Illite is believed to be formed by limited alteration of primary mica.

Hydrous mica is found in soils that are high in primary minerals. Both hydrous mica and montmorillonite may occur in similar and slightly leached environments. Because of its stability, illite is often found in ancient sediments. It is common in recent sediments and is abundant particularly in deep-sea clays.

Illuvial horizon

Soil particles, clay and minerals get translocated by the movement of water through a soil profile. The process of deposition of these materials in a deeper layer is called **illuviation**. The B-horizon or the mineral horizon is an illustration of illuviation.

Illuvial horizon or **illuvial layer** is the horizon enriched by the addition of materials from overlying (**eluvial**) horizons or layers. The horizon has an accumulation of clay, iron, aluminum, humus, sesquioxides, carbonates and their mixtures in the form of coatings or nodules, distributed more or less uniformly throughout the horizon.

Illuvial layer: See Illuvial horizon

Illuviation: See Illuvial horizon

Imbalance of plant nutrients

When plant nutrients are not in the proportion required by the plant, they are said to be in imbalance. The condition could be due to antagonism or **negative interaction** among the nutrients in the plant, and is generally brought about by too much or too little of one nutrient compared to the other. For example, excessive potassium can reduce magnesium availability and hinder plant growth.

Imbibition of water

Imbibition of water refers to the absorption of water by substances that swell, without dissolving. Many biological substances, such as starch and some proteins, cellulose and other constituents of the plant cell walls exhibit imbibition. Dry seeds imbibe before they germinate and, together with osmosis, take up water during the growth of the plant cell. The moisture imbibed by the **clay-humus complex** in a soil is called imbibitional water. Capillary imbibition leads to the saturation of soil.

Imhoff tank

Imhoff tank is a reinforced concrete structure (about 12 m length) designed for sewage clarification. It has (a) an upper or sedimentation compartment in which the inflowing sewage deposits its suspended solids by gravity (residence time 2 to 3 hours), the free water being drawn off through an outlet, and (b) a separate lower compartment in which the accumulated sediment (sludge) gets digested. The sludge is passed from the upper compartment to the digestion chamber through an inclined slot or channel. Here, decomposition takes place by anaerobic bacteria for a period of 6 to 9 months, after which it is removed with the help of pipes for further disposal. The gases generated by digestion are released through suitably located vents.

The digested sludge, called **Imhoff tank sludge**, is removed through the outlet pipes at an interval of about six months. The dried sludge contains 2 to 3% ammonia and about 1% phosphoric acid, which makes it suitable as a soil conditioner and as land fill. Thus, imhoff tank sludge is the result of a process that can be carried out on municipal waste.

Imhoff tank sludge: See Imhoff tank

Immobilization of nutrient

Immobilization of a nutrient means that the nutrient is made unavailable (or less available) to the plant. In immobilization, the soluble nutrient element is converted from an inorganic to organic form. This takes place in microbial mass or plant tissues. Large amounts of N, P, K and S get tied up in this manner, temporarily or for long periods.

When large quantities of carbon rich materials are applied to the soil, the soil nitrogen gets immobilized. The immobilization process is the reverse of the mineralization process which involves conversion of organic nitrogen to its inorganic form.

In soil, some organisms mineralize the nitrogen while others immobilize it, depending on the following two factors: (a) the type and amount of organic matter that has entered the soil, and (b) the relative contributions of the two acts (of mineralization and immobilization) to the decomposition of the incoming fresh material, and to the pre-existing humus. Field studies with ^{15}N show that inorganic nitrogen is more immobilized with the ammonium (NH_4^+) than with the nitrate (NO_3^-) fertilizers. This is because the quantity of energy (soluble carbon) needed to incorporate one unit of nitrogen into plant protein is greater with the nitrate than with an ammonium fertilizer.

Immobilization of sulphur

Immobilization of sulphur is the conversion of the sulphate ion into organic sulphur.

Impact resistance of granule

The impact resistance of a granule is the resistance to breakage upon impact against a hard surface. The knowledge comes in handy when (a) fertilizer spreaders are to be used, (b) the material is required to be discharged from an overhead point (such as loading into a ship), or (c) the handling entails dropping of fertilizer bags. (See also Granular strength of fertilizer.)

Impact strength

Impact strength is the ability of a material to accept a sudden blow or shock without fracture or other substantial damage, measured by standard impact testing equipments. It is the property of hard, friable material.

Impact strength is determined by measuring the energy required for breaking a granule after subjecting the sample (say, of a fertilizer) to a standardized impact. Dropping a sample from a given height or impinging a sample on to a steel plate can show the impact. The measurement is very similar to the impact strength measurement of an explosive.

Impalpable powders

Powders that are so fine that their particles cannot be detected by rubbing them between one's thumb and forefinger are called impalpable.

Impeded drainage

Drainage is the removal of excess gravitational water from soil by natural or artificial means. If the downward flow of matter by gravity is impeded, the result is waterlogging which leads to anaerobic conditions, called impeded drainage.

Imperfectly drained soil

Among the soil drainage classes is an imperfectly drained soil which is considerably gleyed with reduction.

Impermeable soils

Some dense soil horizons that do not let water transmit through them, or do so very slowly are called impermeable soils. A soil in which water, air or roots do not penetrate is termed **impervious soil**.

Impervious soil: See Impermeable soils

Impurity

In the context of chemical analysis or phenomenon, the presence of one substance in another is often in such a low concentration that it cannot be measured quantitatively by ordinary analytical methods. Such a substance is called an impurity. It is impossible to prepare an ideally pure substance. In certain metal crystal lattices, foreign substances can exist in as low a concentration as one millionth of an atomic percent. For example, arsenic atoms are present in germanium crystals in this order of percentage. Biuret is present as impurity in urea. In the air, trace amounts of sulphur dioxide and carbon monoxide are present in concentrations of about 5 ppm and 50 ppm, respectively.

Inbreeding

Inbreeding is the breeding of individual plants or animals that are closely related. Inbreeding tends to bring together recessive genes, usually with deleterious effects.

Inceptisols

Inceptisols is one of the 12 soil orders, representing moderately developed soils of the humid region. They typically show little evidence of **eluviation**, **illuviation** or extreme weathering. Inceptisols occur in all climatic zones where there is some leaching.

Incomplete disinfectants: See Disinfectant

Incrustation

Incrustation, also called encrustation, is the process of forming a crust or hard coating, especially of a fine material. In soil science, incrustation refers mainly to calcareous material which slowly accumulates on the soil, forming a hardened mass. It gives a chalky, tuff-like appearance to the soil.

Incubation

Incubation is the act of incubating which means keeping eggs, cells, bacteria, embryos, etc. in a laboratory at a certain temperature so that they develop.

Incubation involves keeping the micro-organisms in an appropriate medium and maintaining conditions to promote their growth. Specialized incubation permits the control of humidity, light and temperature, and incubation is usually achieved within closed, thermostatically insulated, controlled chambers, called **incubators** (Fig.I.1).

Incubation period is the period of time for which sample is incubated. The period between exposure to an infection and the appearance of the first symptoms is also called incubation period. The incubation period may be helpful in diagnosis and in determining length of quarantine periods.

Fig.I.1: An incubator.

Incubation period: See Incubation

Incubators: See Incubation

Independent variable: See Regression

Indian Bureau of Standards: See AFNOR

Indicator

Indicator is an organic substance (usually a dye or intermediate) which indicates, by a change in its color, the presence or absence or concentration of some other substance, or the degree of reaction between two or more other substances. The most common example is the use of acid-base indicators such as litmus, phenolphthalein and methyl orange to indicate the presence or absence of acids and bases, or the approximate concentration of hydrogen ion in a solution. Their chief use is in analytical chemistry.

The pH ranges of several typical indicators are given in Table-I.1.

Table-I.1 : pH range and reaction color of some common indicators.

Indicator	pH	Color
Alizarin yellow	10.1-2.0	yellow to red
Methyl orange	3.1-4.4	red to yellow
Phenolphthalein	8.3-10.0	colorless to pink
Phenol red	6.8-8.4	yellow to red
Litmus	4.4-8.3	red to blue
Congo red	3.0-5.2	blue to red

Indicator plants

Indicator plants are the plants that show symptoms of deficiency of one or more nutrients. The extent of deficiency symptoms depends on its severity. A few plant species, because of their sensitive nature, indicate the deficiency (Table-I.2).

Table-I.2: Sensitivities of plant nutrients in selected crops.

Deficient element	Indicator plants
Nitrogen (N)	Apple, citrus, maize, mustard, Non-leguminous small grains
Phosphorus (P)	Barley, lettuce, maize, tomato
Potassium (K)	Beans, clover, cotton, cucurbits, lucerne, maize, potato, tobacco, tomato
Calcium (Ca)	Lucerne, other legumes
Magnesium (Mg)	Cauliflower, ground cherry, potato
Sulphur (S)	Clover , lucerne, rye
Iron (Fe)	Barley, cauliflower, citrus, peach, sorghum
Zinc (Zn)	Citrus, maize, onion, peach, rice
Copper (Cu)	Apple, apricot, barley, lettuce, maize, oats, onion, tobacco, tomato
Manganese (Mn)	Apple, apricot, beans, cherry, citrus, maize, oats, pea, radish, wheat
Boron (B)	Apple, cauliflower, lucerne, peach, turnip
Molybdenum (Mo)	Cauliflower, citrus, legumes, mustard, oats, spinach
Chlorine (Cl)	Lettuce

Source: "Handbook on Fertiliser Usage" 1994, S. Seetharaman, et al., (Ed). The Fertilizer Association of India (FAI), New Delhi. With permission.

Some indicator plants grow well in certain soil conditions and act as indicators for that soil type. For example, sage (*Salvia officinalis*) indicates wet soils, bilberry plants (*Vaccinium myrtillus*), acid soils, and cogon grass or blady grass (*Imperata cylindrica)*, a degrading soil.

Indicator plants also indicate the presence of a certain toxic element. For example, there are toxin-tolerant species, which indicate the toxin. Indicator plants thus provide a clue to implement **phytoremediation** techniques. For instance, some mosses indicate high metal concentrations in water and Prince's plume indicates the presence of selinium. Indicator plants have helped miners since ages, to decide where to dig.

Indirect allelopathy

Indirect allelopathy is the inhibition of intermediate organisms (often a bacterium, alga or fungus) on which the plant depends for nutrients or water. Consequently, the plant becomes inhibited.

Indirect fertilizer

An indirect fertilizer is the one that does not contain any essential nutrients but still has a beneficial influence on the plant. **Stimulant fertilizer** and **catalytic fertilizer** are the other names for an indirect fertilizer.

Indirect method for recovery of ammonia or ammonium sulphate: See Ammonium sulphate recovery by the indirect method

Indoleacetic acid

Indoleacetic acid (**IAA**), synthesized in the plant shoot tips, is a naturally occurring auxin. It is a plant growth promoter.

4-indole-3-butyric acid

4-indole-3-butyric acid (**IBA**) is a naturally occurring auxin. It is synthesized in the plant shoot-tips and is an important growth regulator. (See also Auxins.)

Indurated soil

An indurated soil layer is hard and brittle even when wet. Some cementing substances like calcium carbonate, oxides of silica, iron and aluminum or humus, cause an indurated soil layer.

Industrial neutralization processes for ammonium nitrate: See Ammonium nitrate production processes

Ineffective nodule

Root nodules are tumor-like swellings on the roots of certain plants, formed by symbiotic bacteria such as rhizobia and actinomycetes. Nodules are the sites for nitrogen fixation. The nodules with white or pale green centers, scattered over the entire root system are ineffective nodules. Such nodules may be large and numerous, but they fix very little nitrogen.

Inert powders: See Anti-caking agent

Infection thread

At a very early stage of plant growth, bacteria can penetrate plant roots through root hairs. A thread-like structure, which is the infection thread, carries rod shaped bacteria that spread themselves between the root cortex cells. As a result, these cells swell and form knob like structures or nodules on the roots (Fig.I.2). The infection threads are present in *Rhizobium*-inoculated leguminous crops. Cells, in the zone of infection thread called **infection thread zone**, multiply actively and are contaminated with *Rhizobium*, but without the nitrogen fixation.

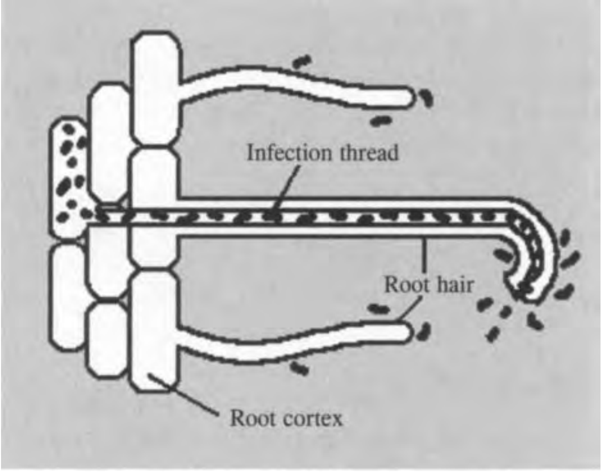


Fig.I.2: Infection thread of Rhizobium bacteria entering the root cortex.

Infection thread zone: See Infection thread

Infertile soil

Infertile soil is the soil deficient in plant nutrients and requiring a large number of fertilizer applications before it can produce good crops.

Infiltration

Infiltration refers to the movement of water into the soil under the influence of gravity. This phenomenon is different from **percolation** which is the movement of water through a soil profile. Infiltration precedes filtration and percolation.

Infiltration is important in agriculture because if water is to be conserved in soil in order to make it available to plants, it must first pass through the soil surface. When the infiltration rate is high, less water passes over the soil surface, thereby reducing the run-off and overflow of water (soil erosion).

Soils with a high percentage of clay have a very low infiltration rate while sandy soils have a high infiltration rate. Infiltration rates are medium in loamy soils and silts, and high in well-aggregated silts or soils with high porosity. According to a study, the infiltration rate recorded for clay soil is 5.0 to 12.5 mm/hr, for clay loam - 12.5 to 25, for silt loam - 25 to 30, for sandy loam - 30 to 45 and for sand - 45 to 75 mm/hr.

Generally, clays swell when wet, reducing the pores and the water movement. The loose flowing particles block the pores and obstruct water infiltration. For example, 60 mm of rain or irrigation may take about 12 hours to soak a unit area of clay soil.

Infiltration is the sole source of soil water and ground water supply to wells, springs and streams. The movement of water into the soil by infiltration is limited by any restriction to the flow of water through the soil profile.

The rate of filtration depends on the (a) physical characteristics of the soil, (b) soil surface cover, (c) soil water, (d) temperature, and (e) rainfall intensity. The **infiltration rate** of soil is a measure of water the soil can soak up in a given period. It is the highest in dry land, takes place either at the start of precipitation or irrigation application and decreases as the topsoil is saturated, to stabilize at a particular level, depending on the particle size or the texture of the soil.

The infiltration rate is measured in terms of the volume per unit time per unit area, and is reduced simply to the depth per unit time. The **Darcy equation** computes the one-dimensional flow of water through a saturated homogeneous soil.

$$q = khA/L$$

where q is the flow rate (L/T), k is the hydraulic conductivity of the flow medium, h is the head or potential causing flow, A is the cross-sectional area of flow and L is the length of the flow path.

The infiltration rate determines the time taken for rain or irrigation water to soak a unit area of land having a particular soil. The infiltration character of a soil is an important consideration in irrigation. When irrigation is in excess of the infiltration rate, water may be wasted and the flowing water may cause erosion or form puddles and evaporate.

Infiltration rate: See Infiltration

Inhibitor

An inhibitor is a substance that considerably reduces or stops an undesired reaction. For example, nitrapyrin acts as an inhibitor in ammonia nitrification and reduces fertilizer loss. Coating urea with a neem seed extract inhibits or reduces the solubility of urea in water and the leaching resulting in its longer availability. Biological antagonists retard the growth of pests and insects by the use of chemicals known as inhibitors.

The mechanism of inhibition varies. An inhibitor may work by inactivating the catalyst, which would otherwise cause undesirable reactions. In chain reactions, an inhibitor can act as a scavenger of free radicals, eliminating the propagation cycle. The reaction of an inhibitor with a reactive free radical gives rise to a radical of a lower reactivity, which is capable only of termination.

Some inhibitors are consumed in the course of reactions and prevent development of the chain mechanism. Such reactions are characterized by a longer induction period as the concentration of the inhibitor in the reaction system is increased (e.g., amine and phenolic inhibitors in radical polymerizations). Other inhibitors are regenerated in the course of reaction by some side-processes and thus exhibit a permanent retarding effect.

In enzyme-catalyzed reactions, several types of inhibition take place. In competitive inhibition, the molecule attaches to the active site of the enzyme that is otherwise occupied by the substrate. Increasing the concentration of the substrate reverses the inhibition process. In **non-competitive inhibition**, the inhibitor molecule changes the activity without blocking the active site.

Heterogeneous reactions may also be inhibited as is done by an anti-corrosion inhibitor. The latter acts by passivating the metallic surface through its oxidation potential. Alternatively, the anti-corrosion inhibitor may protect the metallic surface mechanically or slow down the course of some partial reaction of the corrosion. The inhibitor may also enable the formation of corrosive products with a stronger protective action.

Inoculant

Inoculant is an artificial substance introduced along with seeds, for protecting them from pathogens. It is placed in the root zone for better growth of seedlings. An inoculant is also used for the growth and proliferation of micro-organisms or cells by placing a small sample of micro-organisms or cells into a culture medium under aseptic conditions in an inoculation chamber (Fig.I.3).

Fig.I.3: Inoculation of microbial cultures on different culture media is done in an inoculation chamber.

The process of introducing a small sample of micro-organisms, or any other type of cells into a culture medium for their proliferation is called **inoculation** (Fig.I.4).

Inoculum is the substance containing a small amount of viable micro-organisms used for inoculation.

Inoculant quality details the effectiveness and population of micro-organisms in the inoculant. An inoculant is good for use when it contains a minimum of 10^8 viable rhizobia per gram. A best quality inoculum contains 10^9 to 10^{10} viable bacterial cells per gram. Only fresh inoculants are effective.

There are different types of inoculants such as granular, agar based, peat based, carrier based, freeze dried, etc.

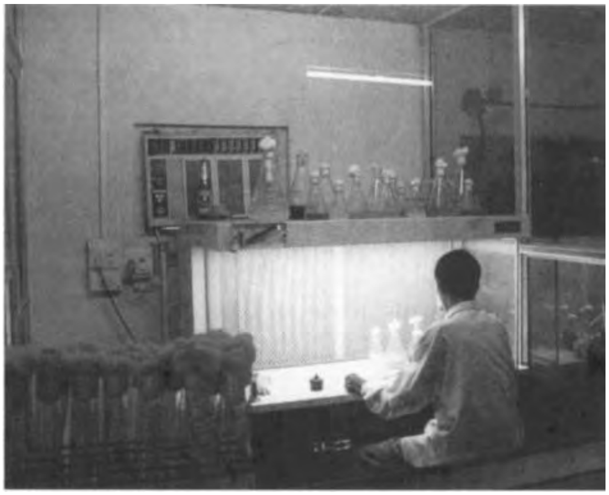


Fig.I.4: Inoculation of microbial cultures being done under aseptic conditions.

Agar based inoculants contain agar in their medium as a solidifying agent. In granular inoculants, an adhesive binds a pulverized peat inoculant and sand together so that the inoculant distributes uniformly for use in broadcasting. Mixing a liquid inoculant with carriers such as peat, lignite or charcoal makes a **carrier-based inoculant**. This inoculant has a short shelf life, but when fresh, it can support a billion cells per gram for up to 6 months after production.

Trichoderma viride is a mycoparasitic fungus. An inoculum of this fungus is introduced along with seeds or without them in the root zone. It protects seedlings from attack by soil-borne pathogens and promotes healthy growth in the early stages of crop. *Pseudomonas syringae* is a non-virulent bacterium, which is also used as a biocontrol agent against various fungal diseases. It produces potent anti-fungal metabolites that protect plants from infection by soil-borne fungal pathogens. Mycorrhizal spores are also used as inoculants where they improve nutrient availability to plants.

Inoculant pellet

An inoculant pellet is a modified pellet in which the seed, coated with a peat-based inoculant is placed. It is used when a large quantity of *Rhizobium* or any other inoculum is required. One third of the inoculum is applied as gum Arabic slurry on the seed and the remaining two third quantity is mixed with the seed. This system is useful for seeds planted in hot and dry soils or where soils are heavily infested with native ineffective rhizobia.

Inoculant quality: See Inoculant

Inoculant supplement

Inoculant supplements are adhesion promoters that improve the adhesion between the micro-organisms and the seeds. Such a supplement aims to prolong the viability of micro-organisms on the seeds. Gum Arabic and methyl or ethyl cellulose are good adhesive promoters.

Inoculation: See Inoculant

Inoculum: See Inoculant

Inoculum size

The inoculum size is the minimum quantity of inoculum necessary to initiate a culture growth due to diffusive loss of the cell materials into the medium. The inoculum size depends on the volume of the growth medium and size of the culture vessel. The use of a conditioned medium decreases the minimum inoculum size. Generally, it is up to 10% in a medium sized culture vessel.

Inorganic fertilizer

An inorganic fertilizer contains nutrients in the form of salts obtained by extraction and other physical or chemical processes of organic minerals. These do not have carbon as an essential component of their basic chemical structure. Ammonium nitrate, potassium chloride, diammonium phosphate, borax, copper sulphate, rock phosphate, etc. are among inorganic fertilizers. (See also Artificial fertilizers.)

Inorganic forms of phosphorus

An inorganic form of phosphorus is the phosphorus present as phosphates, salts of orthophosphoric acid, and other phosphoric acids of potassium, ammonium or calcium. (See also Phosphorus, inorganic forms.)

Inositol phosphate

Inositol, a cyclic molecule with six hydroxyl groups, forms the hydrophobic head group of membrane inositol phospholipids. Inositol phosphates are intracellular second messengers in eukaryotic cells. The most studied of them is inositol 1,4,5 triphosphate (IP3) which is said to play an important role in releasing calcium ions from intracellular stores in endoplasmic reticulum.

Inositol phosphate is considered to be of microbial origin and its various forms are characterized in soil. It can exist in several stereoisomeric forms (a isomeric forms) such as myo, scyllo, neo and chrio.

Inositol hexaphosphoric acid, known as **phytic acid**, occurs in nature in the seeds of many cereal grains as insoluble calcium or magnesium salts. It inhibits the absorption of calcium in the intestine.

Intolerant tree: See Forest

In-place parent material

The material that has not changed its original location is in-place parent material. Bedrock is an example of the in-place parent material. (See also Parent material.)

Insecticide

Insecticide is a substance which is toxic to insects and hence used to control them. Insecticides are used where insects cause economic damage or endanger the health of man and his domestic animals.

The broad types of insecticides are: (i) Inorganic insecticides: arsenic, lead and copper compounds and their mixtures, the use of which has diminished sharply in recent years because of the development of more effective types that are less toxic to man. (ii) Natural organic compounds: rotenone and pyrethrins (which are relatively harmless to man), nicotine, copper naphthenate and petroleum derivatives. (iii) Synthetic organic compounds: (a) chlorinated hydrocarbons, such as DDT, dieldrin, endrin, lindane, chlordane and p-dichlorbenzene, (b) organic esters of phosphorus, and (c) imidazole and its derivatives which act on the principle of metabolic inhibition. Besides direct application, these can be fed to growing plants, with the result that the plants can no longer serve as nutrient for the specific insect.

There are three main types of insecticides based on their mechanism of action. They are (a) stomach insecticides which are ingested by the insects with their food, (b) contact insecticides which penetrate the cuticle, and (c) fumigant insecticides which are inhaled. Stomach insecticides are used to control chewing insects like caterpillars and sucking insects like aphids. They may be applied to the plant (in anticipation) where they remain active for a considerable time. Polychlorinated biphenyls (PCBs) are added to some insecticides to increase their effectiveness and persistence.

Insecticides must be used with considerable caution on food plants or animal forage. For example, arsenic compounds are absorbed by the plant and transported to all its parts. Contact insecticides (like nicotine, derries and pyrethrum), and some synthetic compounds such as DDT and other chlorinated hydrocarbons, organophosphates (Malathion) and carbamates are quickly broken down, and have lasting presence on the plants.

Highly persistent insecticides may be concentrated in food chains and exert harmful effects on other animals such as birds and fish.

Insectigation

Chemigation is the application of any chemical through irrigation waters and includes **fertigation**, **herbigation**, insectigation, **fungigation**, etc. When insecticides are applied in this manner, the operation is called insectigation.

Drip irrigation and micro-irrigation are the commonly preferred vehicles of chemigation of any kind. Insectigation in particular, is ideal for row crops like vegetables and strawberries.

In situ water harvesting

In situ water harvesting is a technique where water is stored in the soil profile for plant uptake.

Instant white rice

Rice is categorized based on its size, variety and the way it is processed. Instant white rice which is a type of processed rice, is dehydrated, pre-cooked, milled, polished and can be enriched with nutrients as required.

Institute of mineral fertilizers process, nitric acid: See Environmental impact of nitric acid industry

Integrated nutrient management

Integrated nutrient management involves the maintenance and adjustment of soil productivity and plant nutrient supply in order to achieve a given level of crop production. This is achieved by optimizing the benefits from all possible sources of plant nutrients. (See also Soil nutrient index.)

Integrated pest management

The widespread application of a cheap and effective insecticide was once considered a quick solution to every insect pest problem. However, almost each eradication program failed because of the resistance the pests developed to insecticides. Such programs were also responsible for the destruction of wildlife and widespread environmental pollution. The initial reaction to any failure was to develop a new insecticide of a different chemistry and character. The indiscriminate use of broad-spectrum insecticides over the past 40 years has not controlled the insect pest nuisance. The costs involved in conducting pest control activities have steadily decreased, but the non-target effect of pesticides on environmental quality has continued to rise. A variety of techniques, as well as chemicals are used in integrated pest management (**IPM**) to keep pest population under control. The approach is far more promising than simple biological control programs.

In IPM, chemicals are used only when the population density reaches a certain level and, if possible, selective acaricides are chosen so as not to harm beneficial insects and predatory mites. IPM involves the assessment of pest problem and the judicious use of an appropriate and compatible combination of control methods (parasitoids, chemical insecticides, predators, pathogens, hormones, semiochemicals, plant resistance and culture practices) that would reduce the pest population to an acceptable level. At all times, attention is paid to using sound ecological principles so as not to disturb the beneficial regulatory factors present in nature.

Generally, IPM envisages the use of pesticides during emergencies and aims to avoid exclusive reliance on toxic chemicals by optimizing pest control tactics in an economically and ecologically sound manner.

The following are the goals of IPM: (i) Determine how the life cycle of the pest must be modified to reduce its numbers below the economic injury level. (ii) Use the knowledge of biology and current technology to achieve the desired modifications (biological control). Selective use of the refugia technique, (refugia being areas in which a population of organisms can survive through a period of unfavorable conditions, especially glaciation) is an example. Another example is that the crop is interspersed with a susceptible cultivar, which permits the pests to attack it and reproduce, leaving the main crop unharmed. Hence, the susceptible cultivar serves as a refuge for pests. The use of certain fungi like *Verticillium lecani*, *Paecilomyces variotii*, *Beauveria bassiana*, etc., for controlling certain insect pests is also common. (iii) Devise procedures for pest control compatible with economic and environmental control aspects and their integrated use toward the management of pests.

Insecticides are important in any IPM program. Their management is concerned with their safe, efficient and economical handling during manufacture, utilization and disposal. The program involves the selection of proper insecticides, the mode, timing and dosage of application and selection with regard to resistance and resurgence.

Insecticides or **pesticides** must be short-lived so that they do not accumulate in the food chain. They must not be mutagenic and carcinogenic, must be safe to handle and yet, effective in controlling pests.

Development of pest-resistant genes through plant breeding (to incorporate genetic factors to deter insect pest attack) is considered the most important technology for integrated pest management, although this has to be a continuous process.

Integrated pollution control system for urea plant: See Environmental impact of fertilizer industry

Integrated plant nutrient supply

Integrated plant nutrient supply is an approach in which the external needs of nutrients required for the plant are supplied appropriately by fertilizers, organic manures, plant residues, biofertilizers and recyclable wastes.

Integrated weed management

Integrated weed management is a system that takes care of all compatible methods to reduce weed population, and maintain weeds at an acceptable level of safety. The management is a combination of manual, chemical and biological methods.

Intensive farming

Intensive farming method aims at producing maximum number of annual crops of high yield from the available land, and maintaining a high stocking rate for livestock.

In intensive farming, crop yields are raised through increased inputs of labor and capital (by mechanization), use of nutrients and irrigation methods, protection against pests, etc. The level of nitrogen input has been used as a measure of intensity.

Intensification of agriculture is beneficial for biodiversity, because it reduces the pressure to convert natural areas to farmland. Intensive (high-yielding) agriculture has been successful in increasing food production to meet the rising demand, at prices affordable to most people, without significant expansion of the cultivated area. However, since intensive farming often involves mono-cropping, it results in narrowing the genetic base with a consequent large-scale loss of vertical diversity.

Intentional ageing of fertilizer

The process of retaining a fertilizer deliberately in a storage pile for some time prior to bagging or shipping is called intentional ageing of the fertilizer or **fertilizer curing**. Such storage allows any incomplete chemical reactions to complete and any caking or bonding to take place so that further caking may not occur after bagging. In the case of superphosphate, for instance, pile curing for 30 days is frequently resorted to at the factory site to help further improve its physical properties. (See also Fertilizer conditioner.)

Interaction between nutrients

The effect of two or more parameters on the performance of each other is known as interaction. The interaction can be positive (**synergistic**), negative (**antagonistic**) or **neutral** (absent).

Interactions between nutrients are often described in terms of physicochemical phenomena. The phenomena relate to adsorption (competitive sites), ion exchange (competitive exchange, e.g., K x Mg, Zn x Cu, Ca x Mg), precipitation (e.g., Zn x P), complexation (e.g., Zn, Cu, Fe and/or Mn with organic molecules), etc. In addition to these physico-chemical phenomena, it is important to know the biological significance of interaction, as plants need all of them and take them up simultaneously for their growth and development.

Interaction of macro and micronutrients: See Macro and micro elements, interaction of

Intercropping

Intercropping is a cropping system in which two or more different crops are grown together in different rows and in a definite pattern to get the best out of the existing conditions. Growing of sorghum and pigeon pea in the same place is an example of intercropping.

Intermediate host

An organism that hosts a parasite from the time the parasite attains sexual maturity is known as an intermediate **host** (or a **secondary host**).

Intermediate wheatgrass

Intermediate wheatgrass, known as *Thinopyrum intermedium* (or *Agropyron intermedium*) is a native of the region covering Central Europe, Russia, the Balkans and Asia Minor. This species has been introduced into many countries, especially the USA, by virtue of its useful and beneficial properties.

Intermediate wheatgrass is a cool season, sod-forming grass plant, best used as pasture and hay. Its growth starts in early spring. It grows best on well drained soils in irrigated regions, and dry land areas with rainfall of at least 35 cm. Hence, it is commonly planted in mountainous regions, high valleys and meadows. This grass starts growing in early spring and matures latest by August. It generally takes two growing seasons to get perennially established. It is propagated best by seeds, but also by tillers and rhizomes.

The highlight of this grass is its vigorous growth. With glabrous and somewhat pubescent leaves, the plant grows to a height of up to four feet. With its extensive and deep rooting system, it easily covers the area around it. This makes it a good cover crop.

Intermediate wheatgrass is relatively tolerant to drought and alkaline soils. In moderately dry areas, it produces more forage yields than other grass varieties (like crested wheatgrass known for drought tolerance and smooth bromegrass), for upto three crop years, subject to the severity of the drought. However, productivity falls significantly after that period.

Intermediate wheatgrass is winter hardy and the foliage does not easily freeze with an early frost. The plant foliage is ideal for all classes of livestock and wildlife. Under favorable conditions, it outperforms most other grass species, as a pasture crop.

When intermediate wheatgrass is grown along with legumes, especially alfalfa, it produces high amounts of foliage which is of excellent quality. When cut early, it makes good to excellent hay. This crop mixing practice is beneficial because this grass species responds favorably to nitrogen from the legumes.

This grass is a good contender to control erosion because of its vigorous growth, sturdy roots and perennial life. It is also widely grown along the river banks or in waterways. Some varieties of intermediate wheatgrass include amur, greener, slate and **tegmar**.

On the other hand, intermediate wheatgrass does not grow in conditions of extreme salinity or drought. Persistently wet or waterlogged conditions are very unfavorable to its growth.

Internal browning of lettuce

In salty soils, calcium precipitates as insoluble carbonate or sulphate causing calcium deficiencies. This calcium deficiency is seen as internal browning of lettuce and as **blossom-end rot of tomato**. (See also Salt tolerance.)

Internal conditioners of fertilizers

Internal conditioners are types of anti-caking agents added to the fertilizer during processing. They act internally as hardeners or crystal modifiers and improve storage properties. For example, formaldehyde (0.3 to 0.5%) and magnesium nitrate (1.8%) are added to urea and ammonium nitrate, respectively, as internal conditioners. (See also Anti-caking agent.)

Internal respiration

The process of oxidation of sugars to form carbon dioxide and water, resulting in energy is respiration. At the cellular level, respiration is known as internal (or **tissue**) respiration operating in two stages, namely, the processes of **glycolysis** and the **Krebs cycle**. These two are common to all plants and animals that respire aerobically. (See also Respiration.)

International pipette method for soil texture

Soil texture can be determined by the international pipette method. The method considers the rate of fall of solid particles in a liquid medium as per **Stokes' law**. Assuming the average particle sizes of sand, silt and clay as 50, 5 and 2 μm, respectively, the quantities of particles are calculated and the textural class determined. (See also Soil texture.)

Inter row placement

Inter row placement is the method of applying fertilizers in bands, usually in wide row crops, midway between the two rows or between every other row. This method is generally adopted for cotton, sugar cane and sorghum.

Interveinal chlorosis

When the iron content in soil is below 50 ppm, plants exhibit iron deficiency. As a result, interveinal chlorosis (green vein color and yellow interveinal areas) is seen on young leaves, which spreads rapidly to the entire green foliage.

In the furrow

A completely plowed field, before cultivation, is said to be in the furrow.

Inverted wells

Inverted well is a type of a **sub-surface drainage system** with a hole in the ground, through which excess water goes down. Each inlet may be around 2½ meters deep and less than thirty centimeters wide.

This subsurface drainage system works best when soil has low permeability. In addition, the surrounding areas should not be contaminated with harmful organisms or chemical toxins lest water seeps in and pollutes the ground water. Such a system is also ideal for areas with stagnant water.

Investigational allowance for fertilizer

Investigational allowance means the variations that are permitted while drawing, preparing, sampling and analyzing a fertilizer. (See also Tolerance limits in fertilizer composition.)

In vitro experiments

In vitro refers to biological experiments performed in a test tube or other laboratory glassware.

In vivo testing

In vivo testing refers to testing within living organisms.

Ion

An atom or radical that has lost or gained one (or more) electron and has thus acquired an electric charge is called an ion. **Positively charged ions** are **cations** and they have fewer electrons. Ions having a negative charge are **anions** and they have more electrons than needed for electrical neutrality. An ion has properties different from the element or atom from which it is formed.

In sodium chloride solution, sodium exists as sodium ion (Na^+) (sodium atom has lost one electron) and chlorine is present as chloride ion (Cl^-), that is chlorine atom has gained one electron. Copper sulphate contains copper ions (Cu^{2+}) and sulphate ions (SO_4^{2-}).

Ions occur in water solution or in fused state (except in glass). Compounds that form ions are called electrolytes, because they conduct electricity in solution. The ion formation causes an abnormal increase in the boiling point of water and also lowers the freezing point, its extent depending on the concentration of the solution. Ions are also formed in gases as a result of electrical discharge.

The number of electronic charges carried by an ion is called its **electrovalence**. The charges are denoted by superscripts consisting of a sign and a number. For example, Na^+ denotes a sodium ion, which carries a positive charge, and a sulphate ion, which carries two negative charges, is denoted by SO_4^{2-}. The energy required for the formation of ions from the neutral atom is the **ionization energy**.

Salts, also known as **electrolytes**, are usually composed of orderly arrangements of ions which are not free to move easily in the solid. However, when the salt is fused or dissolved in a solvent, the ions become free and in an electric field, the positively charged cations move toward the cathode and negative ones toward the anode. At electrodes, ions lose their charge by **electrolysis**. Plants take up nutrients in ionic form.

Ion exchange

The exchange between ions of the same charge in a solution (usually aqueous) or a solid in contact with it is termed as ion exchange. Ion exchange occurs widely in nature, especially during adsorption and retention of water-soluble fertilizers by soil. If a potassium salt is dissolved in water and applied to soil, potassium ions are adsorbed on the soil ion-exchangeable sites or negatively charged exchange capacity. Thus, the soil acts as an ion-exchanger.

A synthetic ion-exchange resin consists of a variety of copolymers with a cross-linked three-dimensional structure to which ionic groups are attached. An anionic resin with negative ions built into the structure, exchanges positive ions. Similarly, cationic resin with positive ions in its structure exchanges negative ions. In anion exchange, anions X^- are attached to the side groups such as $-NH_3^+$. Similarly, in cation exchange, resins with ionized acidic side groups (e.g., $-COO^-$, $-SO_2O^-$) exchange with the attached positive M^+ ions.

Ion exchange also occurs with inorganic polymers such as zeolites and montmorillonites in which positive ions are held at sites in the silicate lattice. These are used for water softening wherein calcium and magnesium ions (Ca^{2+} and Mg^{2+}) in solution displace sodium ions (Na^+) in **zeolite**. A zeolite can be regenerated by sodium chloride solution.

Ion-exchange membranes are polymeric films having sulphonic acid, carboxylic acid, or substituted amino groups that give membranes the property of combining with, or exchanging ions between the film and the solution. Ion-exchange membranes are used as separators in electrolytic cells to remove salts from sea water. In modern high-performance liquid chromatography, ion exchange is used extensively to analyze amino acids.

Ion exchange is used frequently for deionization of water, separation of different salts from solutions, isolation of pure unstable acids and catalysis in esterification and dehydration reactions.

Ion-exchange membranes: See Ion-exchange

Ion exchange resins

Ion exchange resins are synthetic resins containing active groups, generally, sulphonic, carboxylic, phenolic or substituted amino groups that give the resins the property of combining with or exchanging ions with a solution. Thus, a resin with active sulphonic acid groups can be converted to the sodium form and will then exchange its sodium ions with the calcium ions present in the hard water or potassium present in the soil solution.

Ionic potential

Ionic potential (**IP**) is the ratio of the ionic charge (z) to the ionic radius (r) of an ion expressed in nanometers (nm or 10^{-9} m). Thus, the IP of calcium ion (Ca^{2+}) with $z = 2$, and ionic radius of 0.106 nm is 19 per nm.

An ionic potential facilitates the understanding of the behavior of elements in soil solutions. In a soil solution, elements with $IP > 100/nm$ (such as B, C, N, P, S and Mo) exist as oxyanions, whereas elements with $IP < 30/nm$ (such as Mg, K, Ca, Mn, Fe, Cu and Zn) exist as solvated cations. Elements such as Al (III), Ni (II), Hg (II), Cd (II), etc. for which $30 < IP < 85/nm$ are potentially phytotoxic in the dissolved ionic form.

It is possible that during the process of evolution, plants developed detoxifying mechanisms to protect themselves against insoluble toxic elements and are obliged to live with these elements introduced into the environment by man. The biological significance of these attributes of essential elements is best understood by an examination of the **Banin-Navrot plot** which is a log-log graph of the biological enrichment factor against the ionic potential.

Ionic surfactants

Ionic surfactants are those that contain either cationic and anionic molecules or groups in their structure. The best known surfactant is alkylbenzene sulphonate. (See also Anti-caking agent.)

Ionization energy

The energy required for the formation of ions from the neutral gaseous atom is the ionization energy. (See also Ion exchange.)

Ion pump

Ion pump is a naturally occurring process, in which ions are transported across the cell membrane against the concentration gradient. The energy compounds used for transporting ions across the cell membranes are known as ion pumps. The ion pump theory is a new theory put forth for explaining ion transport across the membrane in plants.

In physics, ion pump is a vacuum pump that passes a beam of electrons through the residual gas to reduce the pressure in a container to about 1 nanopascal. The gas is ionized and the positive ions are attracted to a cathode in the container where they remain trapped. The ion pump is useful only at a very low pressure, that is below 1 micropascal, and has a limited capacity because the adsorbed ions eventually saturate at the cathode surface. A more effective pump can be made by sputtering simultaneously a film of metal so that a fresh surface is produced continuously. The device is then known as a **sputter-ion pump**.

Ion uptake, active and passive

Plants take up nutrients predominantly in ionic form. Ions move first along the surface of the plant roots by diffusion, passively, and then enter the plant cells by active or passive processes.

In **passive ion uptake**, ions move from a higher to a lower concentration, or down the chemical gradient of potential energy.

A considerable root volume is accessible for the passive absorption of ions which enter the root tissue through diffusion and an ion exchange process. The uptake is controlled by ion concentration (diffusion) and electrical gradients (ion exchange). These processes are non-selective and do not require energy produced from metabolic reaction within the cell. A passive uptake occurs outside the casparian strip in the cortex and plasmalemma, which are the boundary membranes for diffusion and ion exchange.

From the roots, most ions reach the outer space of leaves through the xylem. Nutrient ions from rain, irrigation water and foliar applications penetrate the leaves through the stomata and the cuticle to reach the interior of leaves where they are absorbed by the mesophyll cells.

Once the ions reach the surface of roots, they enter the cells by three mechanisms. First, they diffuse through hydrophilic 'channels' present in membrane protein complexes. Secondly, the ions attach themselves to a carrier-protein which undergoes a change and transfers the ions to the inner surface. The roots can absorb ions selectively, some ions being more preferred to others. The preferred ions are absorbed even against the concentration gradient – they are absorbed from a low concentration soil solution to a higher concentration in the plant cell. The uptake against a concentration gradient (or strictly speaking, against the electrochemical gradient) requires metabolic energy, and the process is commonly termed **active uptake** or transport. Carriers may show active or passive transport of ions. Pumps are mainly for active transport, where membrane-bound ATPases use up the energy from ATP to transport ions across the membranes. Such pumps may transport two ions in the same direction or in opposite directions. Due to selective ion transport, the concentration of ions inside and outside the cell differs leading to the development of membrane potential.

In addition, electrochemical potentials are established across membranes by equal charge distribution. The difference between the membrane potential and the actual potential created by the non-equilibrium distribution of ions is a useful measure to predict whether an ion undergoes active or passive transport. The **Nernst equation**, which is given below, relates to the difference in electric potential inside and outside the cell.

$$Y = \frac{RT}{ZF}\,\text{In}\ a_i/a_0$$

where Y is the electrochemical potential difference between the root cells and the external solution (in millivolts), R is the gas constant, T is the absolute temperature, Z is the net charge on the ion, F is the Faraday constant, and a_i and a_0 are the activities of the ion inside and outside the tissue, respectively.

For passively transported ions, the potentials predicted by the Nernst equation and by experimental determination are similar. For actively transported ions, the experimentally determined electrochemical potential is greater than that predicted by the Nernst equation.

At present, there are two theories of ion transport across the membrane: the carrier theory and the **ion pump** theory.

IP

IP is short for **ionic potential**, the ratio of the ionic charge to the ionic radius of an ion.

IPM

IPM is short for **integrated pest management**.

Irish bogs

Bog is an area of wet muddy ground that is too soft to support a heavy mass. Irish bogs are natural peat lands of Ireland which are suited to its wet and cool climate. They receive over 1000 mm of rain, out of which only one-third is evaporated, leaving the whole area poorly drained. A gradual decomposition of vegetation has led to peat formation over thousands of years.

Bogs, although **wetlands**, are considered as an example of **histosols**. Irish bogs present a unique biotic environment, with sphagnum moss as its special feature.

Bogs have been part of the Irish heritage over the ages, with peat providing a source of fuel and bog wood being a valuable raw material for artefacts.

Iron

Among the common and familiar metals, iron (Fe) is one of the essential plant nutrient elements. It has the atomic number of 26 and belongs to Group 8 of the Periodic Table (Fig.I.5).

Fig.I.5: Position of iron, an essential micronutrient element, in the Periodic Table.

Iron is required in plants at the rate of 50 to 250 ppm and is, therefore, a micronutrient. It is mainly involved in biochemical processes which are mostly enzymatic oxidation-reduction reactions. In these reactions electrons are transferred from an electron donor to an electron acceptor.

Iron is also involved in respiration and photosynthesis. Some of the enzymatic involvements of iron are in (a) nitrate reductase activity, (b) reducing cytochrome-C by flavin enzyme, and (c) a protein (derived from iron ferridoxin) participating in photosynthetic electron transport.

Iron is a structural component of porphyrin molecules like cytochromes, hemes, hematin, ferritin, ferrichrome and leghemoglobin. The **heme** in hemoglobin is also a porphyrin derivative. Physiological processes of plants have shown that chlorophyll is formed from protoporphyrin by removing iron from hemin, whereas in other organisms, iron is introduced into protoporphyrin to form heme.

Iron is necessary for chlorophyll synthesis in plants. As much as 75% of cellular iron is associated with chloroplasts. Iron, which can replace molybdenum, is absorbed by the plant roots as ferrous ions or as complex organic salts and is absorbed by the leaves when applied as foliar sprays. It takes part in the plant's oxidation-reduction reactions and activates several enzyme systems such as fumaric hydrogenase, catalase and oxydase.

Iron oxide is one of the least soluble minerals in aerated soils. In highly weathered soils, like oxisols and some ultisols, soluble materials leach out whereas the resistant hydrous iron oxides remain. Some oxisols contain up to 80% iron hydrous oxides as clay. Iron is not very soluble in soil solutions or water and, therefore, does not become easily available to plants. In strongly acidic solutions, however, iron is increasingly solubilized and becomes available to plants. In anaerobic conditions, ferrous iron is formed which is more soluble than ferric iron. Therefore, in the **iron cycle**, iron solubilizes in aerobic conditions and precipitates in anaerobic conditions.

Although soluble mineral iron is barely sufficient in soil, most plants get enough iron through decomposition of organic substances (like humic materials), exudative products from the root and microbial cells, animal manures and polyphenols extracted from leaf surfaces. These react and bind with iron, and facilitate iron solubility, making it more mobile in the form of solution.

The soil type, its characteristics, the nature of extractants used and the agro-ecological conditions dictate the availability of iron. The amount of iron in soils varies from as low as 200 ppm to more than 10% as oxides, hydroxides, phosphates or silicates. In Indian soils, for instance, the available iron varies from traces to 386 ppm. The soil iron is progressively depleted by such factors as (a) intensive cultivation (with and without high yielding varieties), (b) adverse nutrient interaction, and (c) a decreased use of animal manures.

When the iron content falls below 50 ppm, plants exhibit **iron deficiency**. This results in **interveinal chlorosis** (green vein color and yellow interveinal areas) in young leaves, which spreads rapidly to all the green foliage (Fig.I.6). In severe iron deficiency, the leaves turn completely white. Fruit trees, ornamentals and grain sorghum show comparatively stronger symptoms than other crops.

Fig.I.6: Interveinal chlorosis in citrus due to iron deficiency.

In calcareous soils, the deficiency disease is called **chlorosis**. Acid forming fertilizers used on such soils overcome iron deficiency. Soluble salts of iron added to soils get converted to insoluble hydroxides, oxides and phosphates, and do not assist in correcting iron deficiency. Some other causes for chlorosis are (a) imbalance of the metal ions such as copper and manganese, (b) excess of phosphorus in soils, and (c) a high pH level, lime content, soil moisture, bicarbonate in the rooting medium and cool temperatures.

In alkaline soils, iron forms insoluble salts like phosphates, whereas in acid soils iron salts are soluble, thus becoming available to plants.

In waterlogged soils, oxygen is depleted and ferric compounds are reduced to a more soluble ferrous form. The presence of organic matter in the soil also assists in creating a reducing environment which allows a periodic increase in the ferrous content of the soil. The longer the period of submergence in water, the greater the amount of ferrous iron formed. More than 300 ppm of iron is toxic and causes nutritional disorders such as **bronzing in rice**, which is predominant when rice is grown in a poorly drained submerged soil.

Prolonged spray applications of Cu, Mn or Zn salts on poorly buffered soils can cause **iron deficiency**; the main cause being dilution of iron with respect to other metals (Cu, Zn, Mn). The iron deficiency in plants can be corrected by applying iron compounds (except ferrous sulphate which is not very effective as it gets oxidized to a ferric form) to the soil or by spraying aqueous salts on leaves. Alternatively, foliar sprays or direct injections of iron salts into the trunks and limbs of plants (iron medicaps) are found to be effective in controlling iron chlorosis. A ferrous sulphate aqueous solution of 4 to 6% at the rate of 30 to 50 g/acre in the spray can control chlorosis. The remedial chemicals most widely used to control chlorosis are iron chelates containing 6 to 12% iron. For instance, ferrous oxalate, though expensive, is used in the overall improvement of crops, as the quantity required is small.

Soluble iron compounds, diluted in water, are good for soil applications and spraying on foliage. Basic slag, (a by-product of the steel industry, which has oxides of phosphorus, calcium and magnesium as principal constituents) as well as soluble oxides of iron and manganese in small amounts, have a good effect on soil when added directly, in quantities of 560 to 1,120 kg/ha. **Ferrous sulphate** ($FeSO_4 \cdot 7H_2O$), a by-product of the steel industry contains 19% Fe and is the most commonly used iron salt in plant nutrition. In an experiment, when 802 kg/ha of it was used on alkaline soils, it increased rice yield from 4,530 to 6,042 kg/ha. NPK fertilizers contain iron in the range of 23 ppm to 1.19%. Many chelated products are also available as fertilizers. The iron deficiency can be improved by the addition of organic matter to well-drained soils. The improvement may be due to a better aeration and acceleration of iron reduction from the ferric to the ferrous form.

Iron chelate

Iron chelate is a complex in which a ferric or ferrous ion is linked through an organic ligand like EDTA (ethylenediaminetetraacetic acid) to form a ring structure. This complex, commonly used for soil application, increases the quantity of iron transported to the plant roots by mass flow and diffusion. It can be sprayed on foliage. Fe-EDDHA (iron-ethylenediamine di-o-hydroxyphenylacetic acid) can be used as an iron fertilizer because of its affinity to iron.

The chemical structure of EDDHA is given in Fig.I.7. (See also Iron).

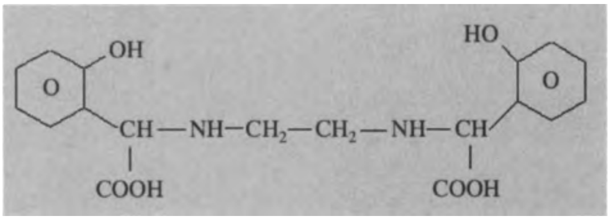


Fig.I.7: Chemical structure of EDDHA.

Iron chlorosis: See Iron deficiency symptoms

Iron cycle: See Iron

Iron deficiency: See Iron deficiency symptoms

Iron deficiency symptoms

When iron, which is a micro-nutrient, is not made available to plants, either naturally or by means of fertilizers, it results in an **iron deficiency**. Iron deficiency occurs when this nutrient is below 50 ppm in the soil. Iron deficiency may manifest itself in many ways and almost always results in the loss of productivity.

Iron deficiency in the plants shows up in a variety of ways. It manifests itself by a slow and low activity of catalase and peroxidase in crops. Iron deficiency disturbs the balance between the total and the reducing sugars. Iron deficient plants show a considerable accumulation of nitrates, amino acids, amides as well as lowered protein content. In some crops, the level of enzymatic activity indicates the iron deficiency.

Berries, citrus, grapes, groundnuts, rice, soybeans, sorghum, sugar cane and field beans are iron sensitive crops. Plants of the genus *Brassica* are also very susceptible to iron deficiency.

A major symptom of iron deficiency is the extensive **chlorosis** (whitening) of leaves. It shows up first on the younger and lower leaves (Fig.I.8) as iron cannot be

Fig.I.8: Severe iron deficiency leads to extensive chlorosis (whitening) of young leaves.

mobilized in younger tissues from the older ones. In severe cases of iron deficiency, new or young leaves turn pale yellow (Fig.I.9). In rice, the yellowing of the newly emerged leaf is an early symptom of the deficiency and in the absence of a preventive measure, the plant may ultimately die. In soybean, the whole leaf area turns yellow except for the veins. In fruit bearing trees, the younger leaves shrink in size, become thin and develop reddish-brown necrotic areas along the margins; when iron deficiency is severe, young shoots show dieback symptoms and chlorophyll is absent in these leaves.

Fig.I.9: Iron deficiency symptoms in citrus showing interveinal chlorosis.

Iron chlorosis is caused, principally because the level of ferrous (Fe^{2+}) ions in a plant is lower than the loss of the total iron. The deficiency is seen particularly in upland green crops in calcareous soils and in less aerated compact soils. It is also seen in soils low in iron and high in bicarbonate, phosphorus and copper, and in soils which are permeable, coarse-textured and low in organic matter. The extent of iron deficiency varies from one country to another.

Iron chlorosis reduces pods in groundnut to about 32% and in fodder to 18%. It reduces 25% of the total dry matter. The yield reduction is also substantial in ornamentals and fruit plants.

The preferred option for managing iron is repeated foliar sprays of the ferrous sulphate solution at the mid bloom stage and the sowing and reproductive stage for field crops. In the case of sugar cane, 3 to 4 sprays of the 2% ferrous sulphate solution are recommended every week. Alternatively, soil applications of 20 kg ferrous sulphate/ha can completely control iron chlorosis. This measure also improves the sugar cane growth and the quality of its juice. In calcareous and moderately alkaline soils, a foliar spray of iron sulphate continues to be the preferred option. (See also Iron.)

Iron frits

When iron salts are fused with glass or glass components, iron frits are formed. The frits are powdered before mixing with a fertilizer. Iron frits are a slow-release source of the micronutrient ions. (See also Frits.)

Iron pan

Iron pan refers to a dark brown horizon of accumulation, consisting of sand cemented by inorganic matter (mainly by iron oxide and sometimes by oxides of manganese and aluminum) forming a thin coating around the soil particles. Such compact coatings make the soil impermeable and are partly responsible for indurations of the iron pan. The iron pan is formed in humic ferruginous podzols and in the podzols of sandy plains.

If iron pan is cemented by plain plinthite, it is called **ironstone**.

Iron pyrite

Iron pyrite, also called **fool's gold** because of its superficial resemblance to gold, is a brassy-yellow or brown tarnished mineral with metallic luster. It is iron disulphide, crystallizing in the cubic system, occurring in octahedral, pyritohedra, etc. Iron pyrite is used in the manufacture of sulphur, sulphuric acid, sulphur dioxide, ferrous sulphate and cheap jewelry.

Iron solubilization

Iron is not easily absorbed in plants, unless it is in the form of ferrous ions or organic compounds. It is made soluble by a process called iron solubilization. For instance, in strongly acidic solutions, iron is increasingly soluble and becomes available to plants. In anaerobic conditions, ferrous iron is formed which is more soluble than the ferric iron. Iron also becomes soluble when it is exposed to organic substances like animal manure, root exudates, humus, etc.

Ironstone: See Iron pan

Iron toxicity

Iron becomes toxic in plants when plants contain more than 300 ppm iron on dry weight basis. The toxicity manifests itself by 'bronzing' of leaves. In rice, for instance, the yield is subsequently decreased. Bronzing entails the appearance of many tiny brown spots from the tips of green leaves and then a general browning of the leaf blades followed by the death of the lower leaves. Sometimes, the leaves become orange-yellow from the tip and later dry up. These symptoms are of toxicity although they appear like those of **iron chlorosis**.

A toxic iron concentration of higher than 300 ppm is most common in flooded rice grown in acid soils. The flooding creates conditions where ferric iron (Fe^{3+}) is increasingly reduced to ferrous iron (Fe^{2+}) enabling increased uptake.

Fatal toxicity is expressed directly and indirectly. Direct toxicity occurs when an excess of the element is absorbed and becomes lethal to the plant. On the other hand, toxicity can be related to a nutritional imbalance. When excess iron is present in the growth medium, it may inhibit the uptake, transport and utilization of many other nutrients and induce a generalized nutritional deficiency as happens in flooded rice grown in acid soils. Unlike deficiency symptoms, toxicity symptoms first appear in old leaves. In rice, brown spots characterize iron toxicity.

Irreversible desertification: See Desertification

Irrigation

With the spread of agriculture arose the need for irrigation. Variants of irrigation systems developed throughout the world. Construction of tanks, wells and dams for storing water, and the digging of canals or channels to distribute or drain water seemed common even hundreds of years ago. In Egypt and the surrounding regions, China, parts of South East Asia, the erstwhile Roman Empire and in India, different systems of irrigation were devised. These primitive and crude irrigation works of antiquity served the peasant community perfectly. Today, they have even survived some modern irrigation projects and a remarkable fact is that they served the purpose of irrigation without harming the environment.

Irrigation supplies water to land or crops through channels to help crops grow during times of little rains. Quantity of water for irrigation is measured in mm/hectare, and amount and frequency decided by soil moisture, rainfall pattern, evapotranspiration rates, etc.

Agriculturists decide the irrigation pattern and timing based on (a) simple measurements, (b) careful estimates of the consumptive use, and of course (c) the art learned over the years. The recent trends in irrigation frequency are based partly on the crop's moisture condition which is the petiole moisture content or the leaf moisture potential.

The border strips, check basins, furrows, corrugations, sprinklers, drip and sub irrigation are some of the irrigation methods that have their own special advantages and disadvantages. Among these, the surface flow methods (border, basins, corrugations, cablegation and furrows) are the simplest, cheapest and most frequently used except when the land is sandy, steep or uneven. The surface flow methods, based on gravity are mechanically simple, have low energy requirements and can be adapted to small holdings. But these methods suffer from a low application efficiency, high conveyance losses and water wastage, all of which may cause waterlogging and salinization.

The **sprinkler method of irrigation** is a time saving irrigation method now in vogue at many places, in which the water outflow can be closely controlled. Sprinklers facilitate fertigation, even when the land does not have a uniform slope. However, the sprinkler systems are expensive and often ineffective in windy conditions.

The most efficient irrigation system with minimum water wastage is **drip irrigation** or **trickle irrigation**. It is particularly useful when water is in short supply or when the entire field is not required to be wet, for example, orchards or vineyards. It should be ensured, however, that the water emitters are not clogged. In another technique, called **sub-irrigation**, water is applied in open ditches or in tile lines to raise the water table sufficiently to wet the plant root zone. The irrigation techniques are modified in special circumstances. For instance, when water is too scarce even for drip irrigation, farmers resort to irrigating alternate furrows and irrigating only once or twice at the most critical growing stage. The two other modified irrigation techniques, **micro sprayers** and low-head bubbler irrigation, are also used advantageously.

In all irrigation methods, the **water use efficiency** is calculated as the yield divided by the water used. The irrigation efficiency – that is the amount of water added to the root zone divided by the amount of water drawn from the source – is always below 50%. The factors that must be taken into account while considering the suitability of water for irrigation purposes are (a) the chemical composition of irrigation water, (b) crops and soils to be irrigated, (c) climate, and (d) management of irrigation and drainage. The interaction of these parameters can modify the contours of irrigation limits and methods.

Irrigation efficiency

Irrigation efficiency is the output divided by the input, usually expressed as a percentage, and can be meaningful only when the output and the input are clearly defined. Three irrigation-related concepts must be understood while defining irrigation efficiency. These are water conveyance efficiency, water application efficiency and water use efficiency.

(i) **Water conveyance efficiency** (E_c) is defined as the ratio of the quantity of water present in a system to the quantity of water introduced into that particular system. This is expressed as:

$$E_c = 100 \times \frac{W_d}{W_i}$$

where W_d is the volume or quantity of water in a distribution system, and W_i is the volume or quantity of water introduced into the distribution system.

(ii) **Water application efficiency** (E_a) is defined as the ratio of the volume of water stored in the soil root zone by irrigation to the volume of water delivered at the farm. It is expressed as:

$$E_a = 100 \times \frac{W_s}{W_d}$$

where W_s is the volume or quantity of water stored in the soil root zone by irrigation and W_d is the volume or quantity of water delivered to the area being irrigated. This efficiency may be calculated for an individual furrow or border, for an entire field or for an entire farm. When applied to areas larger than a field, it overlaps the definition of conveyance efficiency.

(iii) **Water-use efficiency** (E_u) is the yield of crop produced per unit of water. It is expressed in units of water depth for unit weight of crop.

$$E_u = 100 \times \frac{W_u}{W_d}$$

where W_u is the volume of water used beneficially and W_d is the volume or quantity of water delivered to the area being irrigated. The amount of water required for producing the yield includes water loss in transpiration, evaporation and drainage, and that required in plant growth.

Normally, the water stored in the plant zone is considered beneficial water. Sometimes, water use efficiency is also understood as the dry plant weight produced by the unit volume of water.

Another useful measurement of the effectiveness of irrigation is the **uniformity of water distribution**. It is described by the uniformity coefficient (UC) as:

$$UC = 1 - \frac{y}{d}$$

where y is the average volume of the irrigation infiltrated or caught, and d is the average depth of water infiltrated or caught. This coefficient indicates the degree to which water has been applied and has penetrated uniformly throughout the field. When each value represents an equal area and when deviation from the average depth is zero, the uniformity coefficient is 1.0, but UC values above 0.8 are acceptable.

Irrigation methods

A variety of methods are used to irrigate fields at different intervals. The following are the most common irrigation methods: (i) In **border strip method of irrigation** (Fig.I.10), water is applied at the upper end of the strip with soil ridges helping to prevent water from flowing away. However, in this method 25 to 45% of applied water is lost. (ii) In **check basin irrigation** or **basin irrigation method**, water is applied rapidly to relatively level plots surrounded by levees, thereby forming a basin of water in the field or around each tree in an orchard. This method is unsuitable for highly permeable or irregularly sloped soils. (iii) In **sprinkler method of irrigation** (Fig.I.11), pressurized water is sprayed over the soil surface through nozzles. This method is used for irrigating all kinds of lands. A measured quantity of water, mixed with fertilizers, insecticides, herbicides, etc. can also be sprayed in the sprinkler method. However, this method is costly and requires maintenance, as sprinkler nozzles can get clogged. (iv) In the **flooding method**, water released from the field ditches is allowed to flood over the land, whereas in **furrow irrigation**, water is applied between the rows of the crops in small ditches. (v) In **corrugation method of irrigation** (Fig.I.12), water is applied to small, closely packed furrows to keep water flowing in one direction. This method is useful for grain, pastures and forage crops. (vi) In **sub-irrigation method**, water is applied in open ditches or tile lines so that the water table is raised sufficiently to wet the root zone of the soil. This form of irrigation is effective on land with sand peat or muck. (vii) In **wild flooding method of irrigation** (Fig.I.13), water is released at high points in the field without controlled distribution. (viii) Irrigation through cables or pipes is called **cablegation**; the pipes or tubes have gates for opening and closing. (ix) In **drip irrigation**, water drips slowly on the soil through small water emitters or outlets, from a plastic tubing line placed along the soil surface. Drip irrigation can be used advantageously as a means of economizing water on orchards, vineyards, etc. The capital costs of a drip irrigation system are high. The method needs rigorous scheduling and maintenance. A microprocessor-based drip irrigation system is considered to be ideal in developing countries and is now commercially available. This method of irrigation is also known as **trickle irrigation**. (x) **Micro sprayers** have

Fig.I.10: Border strip irrigation method.

Fig.I.11: Sprinkler method of irrigation.

Fig.I.12: Corrugation method of irrigation.

several advantages over drip systems, in that water is applied only to a fraction of the ground surface. Also, high frequency irrigation is possible and fertilizers can be injected. The advantages of micro sprayers over the drip system are that they (a) have larger nozzle orifices and hence there is no clogging of nozzles nor is there a need for water filtration, (b) are operated at a pressure of 2 atmospheres, which is lower than in the drip systems, and (c) can be scaled down for small farms. The disadvantages of micro sprayers are that they (a) cannot use brackish water as wetting of leaves is involved, and (b) encounter evaporation losses, as the area to be wetted is larger than the drip systems. (xi) A low head **bubbler irrigation system** is a closed conduit irrigation system. It has two advantages, namely that it (a) avoids conveyance losses and maintains uniformity in application, and (b) requires no pump or nozzle. In this arrangement, water is simply allowed to bubble out from open vertical standpipes. The system is suitable for widely spaced crops such as fruit trees and grapevines. It allows low volume, high frequency and partial area irrigation. The initial cost is comparable to the other systems. It has no energy costs as it works on gravity and lasts a long time because it is buried in the soil.

Fig.I.13: Flooding, a method of irrigation in rice fields.

Irrigation of clayey soil

Irrigation of clayey soil is difficult because of its high stickiness, plasticity, high water retention capacity and volume changes when the clay is wetted or dried. The other factors rendering irrigation of clayey soil difficult are inadequate aeration of the soil when wet, its slow water infiltration and an excessively large moisture range for tilling. When fully wetted, the clayey soil absorbs no further water and lets all additional rainwater run-off the surface unless there are open ditches to drain out the clays. A dry and cracked clayey surface absorbs several centimeters of rain and the evaporation loss in it is 12 to 30% more than found on non-cracked surfaces.

The rate of water infiltration is a major problem in irrigating clayey soils. Wherever deep and extensive cracks occur, wetting to capacity is easy. However, the surface mulch of the organic residue and tillage also help wetting. Tillage forms mulch and prevents the moisture rising from the subsoil to the surface.

Water can be held on the soil for longer periods by lengthening the rows (serpentine pattern), using check furrows, slow rate sprinkling and drip irrigation. **Serpentine schemes of irrigation** are made by cutting passageways across the furrow to connect several channels, so that water flows back and forth like a snake's trail. It is also known as **dead-end serpentine scheme** or **block serpentine scheme** and **meander furrows scheme**. A longer furrow allows water to stay on the soil for a longer period. To reduce the evaporation losses and improve the water retention capacity, measures must be taken to reduce the cracking of the soil surface.

Irrigation water quality criteria

The chemical character of water determines its suitability for irrigation, depending on the concentration of (a) the total soluble salts, (b) potentially toxic elements, (c) sodium to other cations, and (d) bicarbonate *vis-à-vis* calcium plus magnesium.

The total soluble salts are commonly characterized by electrical conductivity of water and expressed as deci Siemens/meter (dS/m). The sodium hazard or the proportion of sodium to other cations in water is given by the sodium adsorption ratio (SAR).

$$\mathrm{SAR} = \frac{\mathrm{Na^+}}{\sqrt{\dfrac{\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}}{2}}}$$

where Na^+, Ca^{2+}, Mg^{2+} are the concentrations in milliequivalent per liter of the saturation extracts.

Boron, though essential for normal growth of plants, may become toxic in concentrations of as low as 0.33 ppm. A high concentration of bicarbonate ions may result in the precipitation of calcium and magnesium bicarbonates from the soil solution, increasing the relative proportions of sodium and thereby increasing the sodium hazard. Many plants are sensitive to chloride ion concentrations and to high sodium levels in their leaves.

Many classification systems of irrigation waters have been proposed, based on conditions like the quantity applied, drainage, texture, crop tolerance, etc. A widely used classification system is the one proposed by the U.S. Salinity laboratory to which modifications have been made depending upon the local conditions. The salinity diagram for the classification of water is given in Fig.I.14.

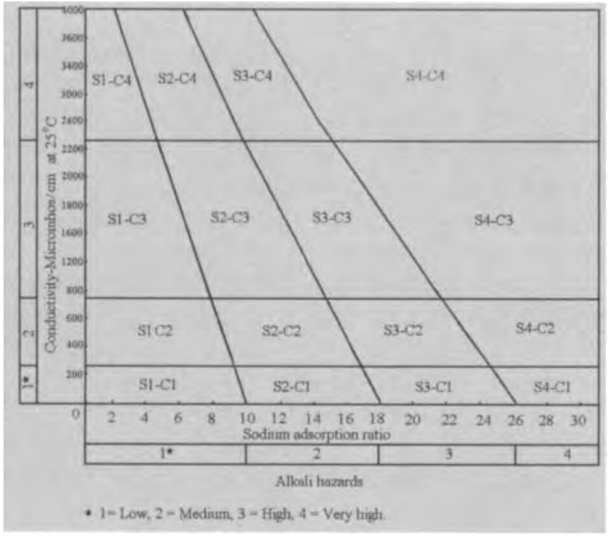


Fig.I.14: US Salinity staff diagram for classifying irrigation waters. (Source: Richards (1954). Adapted from "Soil Salinity and Water Quality", 1996, by R. Chhabra. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi. With permission.)

The S-C surface (where it is sodium adsorption ratio - conductivity) is divided into 16 zones corresponding to all possible S-C combinations.

The US classification system is based on the values of C (electrical conductivity, EC in μS/m) and S (**sodium adsorption ratio, SAR**) of the irrigation waters, using the following equations.

$$S = 43.75 - 8.87 \log C \text{ (upper)}$$

$$S = 31.31 - 6.66 \log C \text{ (middle)}$$

$$S = 18.87 - 4.44 \log C \text{ (lower)}$$

Keeping in view the soil texture, the following water classes can be useful for irrigating various types of crops (Table-I.3).

Table-I.3: Water quality class and its suitability for crops grown in soils of different textures.

Soil texture	Water quality class for		
	Sensitive crops	Semi-tolerant crops	Tolerant crops
Clay	C_2S_1	C_3S_1 C_1S_2	C_4S_1 C_2S_2
Loam	C_2S_1 C_2S_1	C_3S_1 C_2S_2 C_1S_1	C_4S_1 C_3S_2 C_2S_3
Loamy sand	C_3S_1 C_2S_2 C_1S_3	C_4S_1 C_3S_2 C_2S_2 C_1S_4	C_4S_1 C_4S_2 C_3S_3 C_2S_4
Sandy loam	C_2S_1 C_2S_2 C_1S_3	C_4S_1 C_3S_2 C_2S_3	C_4S_1 C_4S_2 C_3S_2

Source: Kanwar and Kanwar (1969). Adapted with permission from "Soil Salinity and Water Quality", 1996, by R. Chhabra. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.

On the basis of major components, (for example, salinity and sodicity hazards), irrigation water can be grouped into two categories: (a) low-salinity water (C_1), medium-salinity water (C_2), high-salinity water (C_3) and very high-salinity water (C_4), and (b) low-sodium water (S_1), medium-sodium water (S_2), high-sodium water (S_3) and very high-sodium water (S_4). The classification of irrigation water is given in Table-I.4.

Table-I.4: Classification of irrigation water.

Water quality	EC, dS/m	SAR	RSC, meq/l
Good	<2	<10	Nil
Marginal	2 to 4	<10	<2.5
Saline	>4	<10	Nil
Sodic	<4	>10	Usually >2.5

Source: "Soil Salinity and Water Quality", 1996, by R. Chhabra. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi. With permission.

Based on the total dissolved solids, SAR (sodium adsorption ratio) and RSC (residual sodium carbonate) of

Table-I.5 : Criteria for use of groundwater for irrigation purposes.

Soil texture	Other conditions	Maximum limits for safe use		
		TDS mg/l	SAR	RSC meq/l
Coarse	Good water management and leveled lands	1500	12	5.0
Medium	Adequate water supply and fairly leveled lands	800	10	2.5
Fine	Leveled lands, low management level and poor water supply	500	5	1.25

Source: Haque (1989). Adapted with permission from "Soil Salinity and Water Quality", 1996, by R. Chhabra. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.

the water, and considering the degree of management and texture of soil, the safe limits for the use of ground water for irrigation purposes are given in Table-I.5.

Irrigation with salty water

Shortage of fresh water forces farmers to irrigate their lands with salt water. But this affects the osmotic relationship because of the high content of sodium, chloride and salt in the water. In such a case, the irrigation techniques used must ensure that the soil holds water near the full field capacity in order to keep the salt as dilute as possible. In addition, foliage wetting should be avoided to prevent leaf damage and the accumulated salts should be leached periodically. This is achievable by (a) applying water at or below the soil surface, and (b) adding enough water continuously at or below the field capacity to keep the salts moving downward. This is not easy to accomplish, except by some form of drip irrigation. Sandy soil is most amenable to irrigation with salty water, whereas clayey and salty soils are less suitable to it.

ISI

ISI is short for Indian Standards Institution. It is the custodian of all standards for and on behalf of the Government of India. It is charged with the responsibility of ensuring that all Indian products comply with the quality standards set out for them. The sieves used for particle analysis follow the ISI standard. Currently ISI is known as **BIS** or Bureau of Indian Standards. For example, the ISI standard for *Azotobacter* biofertilizer is IS: 9138-1979.

Isobaric process: See Isobar

Isobar

The term isobar is used in many contexts. The following are some examples:

(i) Isobars are atomic substances that have the same mass but different atomic numbers. In other words, the nuclei of the isobars contain the same total number of nucleons (protons plus neutrons) but an unequal number of protons (Table-I.6).

Table-I.6: Common examples of isobar elements.

Element	Atomic weight	Atomic number
Ar	40	18
K	40	19
Ca	40	20

Although isobars have approximately equal mass, they differ in chemical properties, as they are atoms of different elements.

(ii) Isobars also mean a line on a map or chart that joins points or places that have the same atmospheric pressure. A curve on a graph representing readings taken at constant pressure is also known as isobar. Obvious examples of its use are in weather forecasting and meteorology. The most common weather maps are charts of weather conditions at the earth's surface and mean sea level, and they contain isobars as the principal information.

(iii) **Isobaric process** is a thermodynamic process in which heat transfer to or from the gaseous system causes a volume change at a constant pressure. The system is then capable of doing an amount of work on its surroundings, for instance, heating the surrounding.

Isobutylidene diurea

Isobutylidene diurea (**IBDU**) or **isobutylidene urea**, shown in Fig.I.15, is a condensation product of isobutylaldehyde and urea.

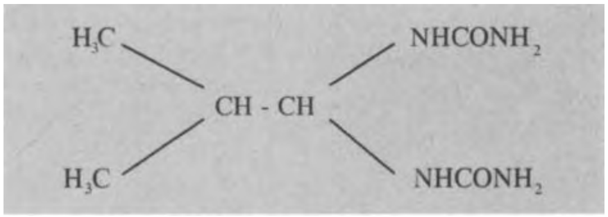


Fig.I.15: Chemical structure of isobutylidene diurea.

Unlike urea-formaldehyde, isobutylidene diurea gives a single oligomer. It is a white crystalline solid, containing 32.18% of nitrogen, with 90% solubility in cold water and 100% in hot water. Its **activity index (AI)** value is 90 to 99 compared to 55 to 65 for urea-formaldehyde. Hydrolysis of this product releases nitrogen, the rate of which is dependent on the particle size - the finer the particles the faster the decomposition.

Isobutylidene diurea decomposes into starting reactants in acid media. The safety margin and the agronomic response from IBDU are good with turf. IBDU is suited to low temperature applications and is independent of the microbial activity.

For urea fertilizers to release nitrogen slowly over an extended period, they are coated with a water insoluble material like isobutylidene diurea (IBDU, 30% N). (See also Sulphur-coated urea.)

Isobutylidene urea: See Isobutylidene diurea

Isomorphism

Isomorphism is the formation of crystals from different compounds or minerals which have similar external forms and lattice structures. Isomorphous compounds have similar chemical compositions, ions of similar sizes with the charge and ionization potential being substituted for each other, and forming mixed crystals, for example, Ag_2S and Cu_2S.

The replacement of one metallic ion by another without breaking or changing the structure is known as **isomorphous substitution** and occurs predominantly in the 2:1 clay minerals. For example, in the structure of clay minerals, Al^{3+} or Fe^{3+} can replace some Si^{4+} ions and Mg^{2+} by Li^{+}. A mineral series showing a continuous isomorphous change between the end members constitute a solid solution as in plagioclase feldspars, where sodium and calcium are the cations involved. (See also Exchangeable elements.)

Isomorphous substitution: See Isomorphism

Isotherm

The line joining different points of equal temperature is called an isotherm. (In such a condition, no heat can flow between any two such points and the system is in equilibrium.)

Isotones

Atoms with an equal number of neutrons in their nuclei but different mass numbers are termed isotones. Their mass numbers differ owing to the presence of an unequal number of protons (atomic numbers). Thus, the number of naturally occurring isotones provides useful evidence concerning the stability of particular neutron configurations. For example, a relatively large number of naturally occurring 50 and 82 neutron isotones (6 and 7, respectively) suggests that these nuclear configurations are especially stable.

Isotones with different numbers of neutrons show different physical and chemical properties. Some examples of isotones are 3014Si, 3115P, and 3216S, each containing 16 neutrons in its nucleus. 146C, 157N, 168O is another set of isotones containing 8 neutrons.

Isotope

Isotope is a member of the chemical element family that has two or more nuclides with the same number of protons but different number of neutrons so that they have the same chemical attributes, but display different physical attributes. For example, we have ^{15}N and ^{14}N for nitrogen or ^{31}P and ^{32}P for phosphorus.

Isotopes of any element are identical in their chemical properties. The existence of isotopes is a common phenomenon, and most elements occur naturally as a mixture of the isotopes.

On the earth, all oxygen atoms with 8 protons are distributed in a proportion of 99.763% as ^{16}O, 0.375% as ^{17}O and 0.1995% as ^{18}O with 8, 9 and 10 neutrons respectively, in their nuclear shell (number of neutrons = A - Z and number of protons = Z). Twenty one elements consist of just a single type of atom and, therefore, do not have isotopes. Aluminum, for example, has only one isotope, ^{27}Al.

The occurrence of isotopes among the 83 most abundant elements is widespread, but their separation is tedious and costly. Some elements have from 2 to 10 isotopes. The heavier isotopes usually occur very rarely in the atomic population (1 part in 4500 for hydrogen 2, 1 part in 140 for U-235). There are three kinds of isotopes: (a) natural, non-radioactive, (b) natural, radioactive, and (c) artificial radioactive.

Isotopes of certain elements possess unique or peculiar properties and their separation or enrichment is desirable. **Deuterium**, ^{2}H, which occurs with an abundance of about 0.16% in terrestrial hydrogen, is useful in moderating neutrons in heavy water reactors and is expected to form the fuel of fusion reactors. Very large quantities of deuterated water are produced by a variety of distillative, exchange and electrolysis processes.

Among biologically important elements, only carbon, phosphorus, sulphur and hydrogen have radioisotopes of sufficiently long half-life for use in tracer studies in living organisms. Studies of metabolism, drug utilization and other reactions in living organisms are best done with stable isotopes like ^{13}C, ^{15}N, ^{18}O, ^{2}H, ^{3}H, ^{32}P and ^{35}S.

Isotopic exchange

A few elements have natural radioactive isotopes. The exchange between two isotopes of an element is known as an isotope exchange. For example, we can have an exchange between ^{31}P and ^{32}P.

The fate of phosphorus in plants can be studied by the incorporation of ^{32}P in a fertilizer and following its pathway in plants. These are used widely for research purposes in order to understand the mechanism of the absorption of elements. They are used as the tracers of a process, since they may be detected in very small amounts and may behave virtually identically to other atoms of the same element. They may also be used to label particular atoms in complex molecules, in an attempt to work out the mechanisms of chemical reactions.

Isotropic

Substances whose physical properties are the same in all directions are isotropic. In addition, the substances in an amorphous state are called **isotropic substances**. Cubic crystals have this property of transmitting light equally in all directions. Liquid, gases and most glasses show this property.

Isotropic substances: See Isotropic

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J

Jacobs dihydrate phosphoric acid process: See Phosphoric acid production processes

Jacobs-Dorrco industrial process for granular diammonium phosphate

Granular DAP (diammonium phosphate) is commonly produced by a slurry process, called Jacobs-Dorrco industrial process. Fig.J.1 shows the flow chart of the Jacobs-Dorrco granulation process for DAP production. The process was originally known as Dorr-Oliver slurry granulation process for DAP production, and resembles the process developed by Tennessee Valley Authority (TVA) with two exceptions. The first is that, in the Jacobs-Dorrco process, the ammoniation is carried out in three reaction vessels, operated with the $NH_3:PO_4$ ratios of 0.6, 1.4 and 1.85; secondly, the slurry granulation with recycle is carried out in a blunger. In the TVA process, however, the ammoniation is carried out in a pre-neutralizer, and granulation in a granulator.

Japanese method of paddy cultivation

The availability of water largely determines the method of rice cultivation. Rice cultivation is broadly classified into four categories - dry cultivation, semi-dry cultivation, wet cultivation and intensive method of cultivation. The intensive method was once popularly known as the Japanese method of paddy cultivation.

Each region develops its own cultivation practice, based on its soil, moisture, unique pattern of terrain, etc. Such local solutions may not be exactly suitable elsewhere, but may be adapted to suit similar situations. For instance, Indian farmers may not be able to transplant rice seedlings into the flooded fields when the seedlings are 3 weeks old (which is considered ideal) because the monsoon often gets delayed. To tide over this situation and yet maintain high yields, Indian agriculture has to depend heavily on irrigation systems.

The Japanese method of cultivating rice has been hailed worldwide as an innovative solution to Japan's typical local environment. Japan has limited flat land, extremely cold and long winters and heavy rainfall. So, farmers generally get only small stretches of level lands to cultivate rice on. This has resulted in the practice of labor intensive farming, where personal attention is given to the crops. At the same time, they use small machines appropriate for their field, indicating that mechanized farming can be carried out on small paddies too. This choice helps reduce costs and yet maintain efficiency. Thirdly, Japanese farmers do not commonly plant rice seeds directly in the field in the harsh winter, since seeds do not germinate easily in winter and may die causing substantial delays and losses. So, the farmers plant these seeds indoors till they germinate, before transplanting them in the field. As an alternative, the seeds are coated, before planting, with calcium oxide which reacts with water, releasing oxygen (along with calcium hydroxide) which helps the seeds to survive in water and then germinate. Transplanting of seedlings is done in straight columns, thus enabling better management of the crop. Rotation of wetland rice with upland crops, including legumes, on the same paddy fields is also gaining

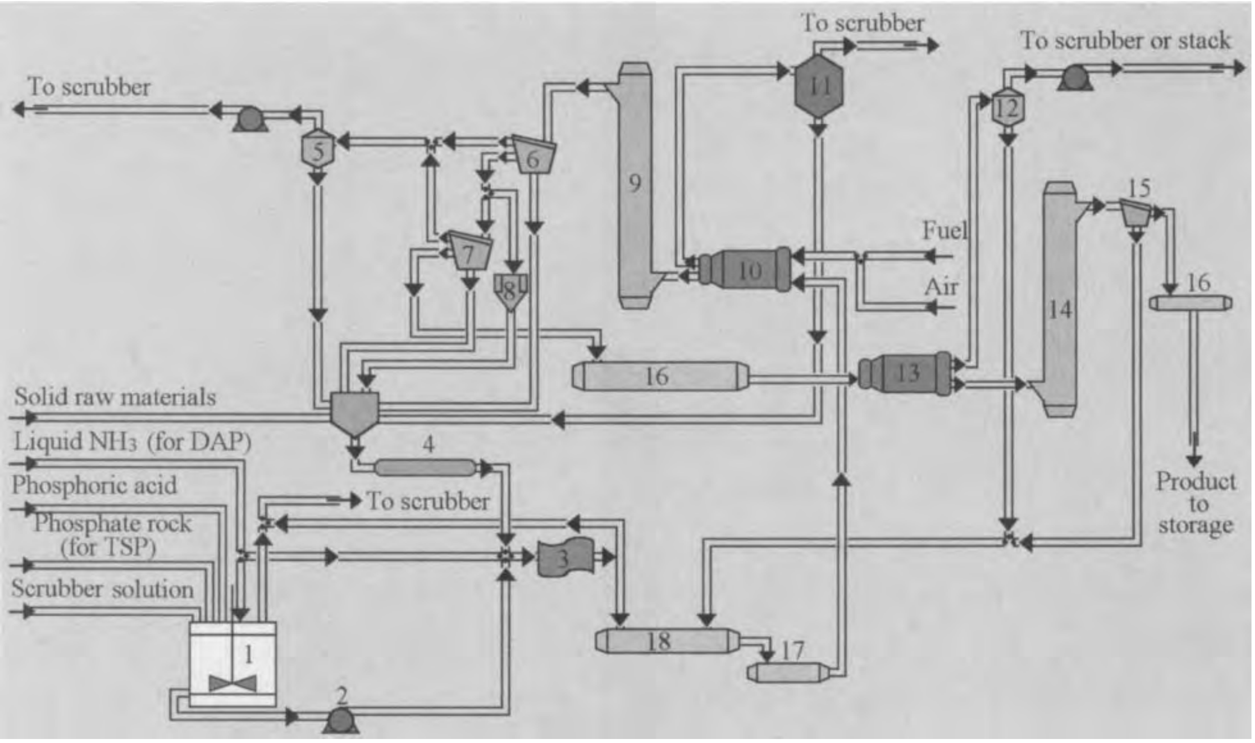

Fig.J.1: Jacobs-Dorrco slurry granulation process for DAP production. 1. Reactor, 2. Slurry pump, 3. Granulator, 4. Fines conveyor, 5. Dust cyclone, 6. Oversize screen, 7. Screen, 8. Crusher, 9 and 14. Bucket elevators, 10. Dryer, 11. Dryer cyclone 12. Cooler cyclone 13. Cooler, 15. Polishing screen, 16 and 17. Belt conveyors, and 18. Aging conveyor. (Source: "Fertilizer Manual", 1998. UNIDO, IFDC and Kluwer Academic Publishers. With permission.)

popularity, and is seen as a means to utilize the available land to the optimum level.

However, since this rotation system is observed to deplete the organic matter levels of the soil and cause moisture excess to upland crops, minimum tillage without puddling is becoming popular leading to improved drainage.

Another practice followed in Japan is the **parachute technique of transplantation**. Here, a cluster of rice seedlings are flung up in the air and allowed to fall in the flooded fields. The weight of the soil clumps attached to the roots enables the seedlings to get rooted neatly in the soil. Although a slightly unscientific method (*vis-à-vis* the systematic row and column method), the parachute technique saves labor and time needed for transplanting by hand.

Joulie's solution

The European Union specifies some solvents for evaluating phosphate fertilizers. Joulie's solution is one of the solutions for all straight and compound fertilizers of alumino-calcic form. (See also Nutrient availability.)

Justus von Liebig's law of minimum

The Justus von Liebig law states that if a deficient element is supplied, the plant growth increases in proportion to the amount supplied upto a point after which the supply of that element is no longer the limiting factor. The law also states that if one of the nutrients from the soil or air is deficient or lacking, the growth will be poor even when all other elements are abundant. (See also Law of minimum.)

Jute

Jute is a rough fiber that is made from the stems of an herbaceous plant, particularly of genus *Corchorus* (*C. olitorius* of India). Best fibers, 100 to 250 cm long, are obtained from *Corchorus*, which contain higher proportion of lignin and less cellulose than any other commercial vegetable fiber. The fibers are soft and lustrous but lose strength when wet. Jute is combustible.

Commercial applications of woven jute are evidenced in carpet making and packaging industries.

Jute is also seen to play an important role, in creating an alternative to plastic bags thus arresting further soil pollution and damage to the environment.

Jute cultivation encourages soil environment, since a major part of the plant is left behind in the soil after harvest. The residue decomposes and adds to the organic content for subsequent crops.

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K

KAAP

KAAP is the abbreviation of **Kellogg advanced ammonia process,** based on a precious metal-based ammonia synthesis catalyst.

Kainite

Kainite is a naturally occurring double salt of potassium and magnesium. It contains more than 12% potassium (as K_2O). A double sulphate of potassium (potassium sulphate occurring in nature as **langbeinite**) and magnesium (K_2SO_4, $2MgSO_4$), is made from kainite ($KCl, MgSO_4 \cdot 3H_2O$). The reaction is as follows:

$$KCl \cdot MgSO_4 + H_2SO_4 \longrightarrow KHSO_4 + MgSO_4 + HCl$$

Kairomones

Kairomones are volatile compounds released by plants and are used as insect attractants.

With the growing need for a more specific and less environment polluting pest control measure, specific insect attractants have become an important part of the pest control technology.

Chemical attractants can be used in conjunction with simple, inexpensive sticky traps for monitoring insect pest populations.

Two general types of attractants have been studied widely: (a) **sex pheromones**, and (b) plant kairomones. Kairomone attractants serve as major cues for the host plant selection by phytophagous insects. Kairomones are getting identified in increasing numbers as insect attractants, the most successful mixtures being eugenol with geraniol or phenyl ethyl propionate.

Kairomones are chemical messengers that bring good news to the receiver. For instance, floral scents are kairomones for the prospective honey bees. Many predators are guided by kairomones emitted by their food. For example, apple skins exude a chemical that attracts the codling moth larva. In some cases, kairomones prove helpful to vulnerable creatures. For example, certain marine mollusks can pick up the scent of their predators, the sea stars, and escape.

Kale

Kale is a green, edible vegetable of the mustard family. The plant attains a height of 60 to 75 cm. It is a source of vitamins A, B-complex and C.

Kalium

Kalium, a Latin name for potassium, is a silvery-white and soft metallic element, occurring naturally as potassium chloride in seawater and in minerals like sylvite, carnallite and **kainite**. These metal salts are also used as fertilizers.

Kalium is an essential element in living organisms and many industrially useful compounds. The potassium ion, the most abundant cation in plant tissues, plays a crucial role in protein synthesis. The passage of potassium and sodium ions across the nerve cell membrane in animals is responsible for changes of electrical potential, accompanying the transmission of impulses.

Chemically, kalium, like sodium, is highly reactive and is obtained by electrolysis. It forms an orange-colored super-oxide (K_2O) that contains an oxygen ion.

Kallar

Kallar is another name for **sodic** or **alkali soil**. *Kallar* soils have a pH above 9, an exchangeable sodium percentage higher than 15 and an electrical conductivity greater than 4 dS/m, thus making them hard to work on. Highly sodic soils tend to impede drainage in the subsoil layers because it makes the soil surface hard. In regions of sodic ground water, continuous use of underground water sources (tube-wells, etc.) also build up the exchangeable sodium element in the root zone. Such lands are found in large portions of North India.

The reclamation of these lands is done by the process of replacing this excessive exchangeable sodium (Na^+) from the root zone with more favorable calcium ions. **Gypsum** ($CaSO_4 \cdot 2H_2O$), a soluble salt, is added as a soil amendment to correct this soil condition. Since gypsum is poorly soluble in water, it is broadcast a week before transplanting paddy. An amount of 10 to 15 tons of gypsum per hectare is generally recommended for reclaiming the soil.

Kallar grass

Kallar grass (*Leptochloa fusca*) is a plant which thrives in salt-affected saline and waterlogged soils which exist in large parts of India and Pakistan, and parts of Australia and the USA. *Kallar* grass gets propagated very easily through seeds, root stumps or stem cuttings. It has the ability to transport oxygen through its stem to the root system helping it to survive in flooded soils.

Kallar grass is beneficial to farmers since it reclaims saline soils. It evaporates ground waters and reduces the salinity of such water, which is beneficial to the soil. Many wastelands are reported to have been reclaimed by the extensive cultivation of *kallar* grass (for periods of three to five years) in Pakistan, giving many farmers a good source of income from such improved lands.

Kandic horizon

Kandic horizon is a subsurface horizon with more than 4% clay content which is higher than what the overlying horizon contains.

Kandic horizon, which occurs in oxisols and ultisols, is dominated by low activity clays (1:1). It has a low cation exchange capacity. The clay fraction is composed of minerals primarily from the kaolinite group associated with variable amounts of iron and aluminum hydroxides.

The introduction of the kandic horizon in the system gives a diagnostic criterion for differentiating ultisols and alfisols from oxisols and inceptisols.

The presence of the kandic horizon indicates a high degree of weathering of mineral material.

Kanten

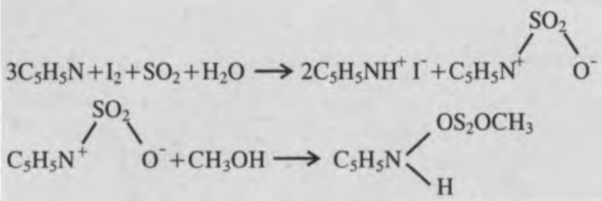
In Japan, **agar** is derived from *Gelidium* sp. which is a bright red seaweed. This agar is called *kanten*, which means cold sky in Japanese, because the agar was made in cold winter days. Agar is used as a solidifying agent in the culture medium for the multiplication of beneficial bacteria like *Azotobacter* and *Azospirillum*. These bacteria are useful in the production of biofertilizers.

Kaolinite

Kaolinite is a clay mineral belonging to the 1:1 class with no inter-layer space. It has an empirical formula $Al_2SiO_5(OH)_4$. It is most common in **laterite soils** and has the lowest cation exchange capacity (5 to 15 meq per 100 g) among the common soil minerals. It is used as a filler in the manufacture of paper, paints and rubbers and is used in the ceramic industry.

Karl Fischer method

For determining the quantity of water in a compound or substance, Karl Fischer proposed a method in 1935. He used a reagent prepared by sulphur dioxide reaction with iodine solution in a mixture of anhydrous methanol and anhydrous pyridine. Water reacts with the reagent in a two-stage process in which one molecule of iodine disappears for each molecule of water.



$$3C_5H_5N + I_2 + SO_2 + H_2O \longrightarrow 2C_5H_5NH^+I^- + C_5H_5N^+\overset{SO_2}{\diagup\;\diagdown}O^-$$

$$C_5H_5N^+\overset{SO_2}{\diagup\;\diagdown}O^- + CH_3OH \longrightarrow C_5H_5N\begin{matrix}\diagup OSO_2OCH_3\\ \diagdown H\end{matrix}$$

The end of the reaction is determined electrometrically. If a small electromotive force (e.m.f.) is applied across two platinum electrodes immersed in the reaction mixture, a current flows through the mixture as long as free iodine is present to remove the hydrogen and depolarize the cathode (Fig.K.1); when the last trace of iodine undergoes reaction, the current comes down to zero or very close to zero. The technique may also be combined with a direct titration of the sample with a **Karl Fischer reagent**, wherein the current suddenly increases at the first appearance of the unused iodine in the solution.

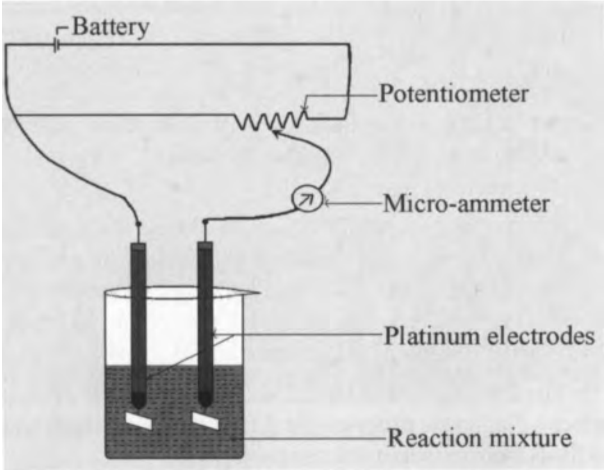


Fig.K.1: A diagrammatic representation of a Karl Fischer titrator.

The Karl Fischer method is useful for substances that do not react with any component of the reagent, or with hydrogen iodide formed during the reaction with water. The interfering compounds include oxidizing agents, reducing agents, and those forming water with weak acids and bases.

The Karl Fischer procedure is used for the determination of water present in hydrated salts or adsorbed on the surface of solids. The procedure is more rapid and direct than the one commonly used in drying processes. While there now exist many modern instruments for this determination, the present method is useful for the determination of water in both solid as well as liquid fertilizers.

Karl Fischer reagent

Karl Fischer reagent is a solution of iodine, sulphur dioxide and pyridine in methanol or methyl alcohol. The reagent is used for determination of water. (See also Karl Fischer method.)

Karstic flow

A strong flow of water with dissolved rocks in the limestone region is called karstic flow.

Katteklei

Acid sulphate soils, or **cat clays**, are found especially in coastal belts, estuarine and delta areas of humid tropics. These are known as *Katteklei* (cat's coat) in The Netherlands.

Kellogg advanced ammonia process of ammonia synthesis: See Ammonia production processes

Kellogg-Lopker process for phosphoric acid: See Phosphoric acid production processes

Kellogg's horizontal converter technology: See Ammonia production processes

Kelp

Kelp (*Ascophyllum nodosum*) is a type of seaweed found on the shores of the Atlantic ocean. It is a naturally occurring and quick-acting source of potassium. It contains around 5% potash, as well as N (upto 5%), P (upto 8%) and a smaller proportion of B, Ca, Fe, Mn and Mo. Kelp is dried and powdered and applied to the soil as required. It is considered to be a plant growth-promoting agent, anti-fungal agent, etc.

Keratin

Fibrous proteins are generally insoluble in water and consist of long, coiled strands or flat sheets which have strength and elasticity. Keratin and collagen come in this category. Keratin is present in hair and wool. It is characterized by the high contents of several amino acids, especially cystine, arginine and serine. Keratins are generally harder than the fibrous collagen. Keratins are insoluble in organic solvents, but absorb and hold water.

Kernel: See Cereals

Kernite

Kernite ($Na_2B_4O_7{\cdot}4H_2O$) is a borate mineral, like **rasorite** and **tincal** ($Na_2B_4O_7{\cdot}10H_2O$). These three are the main sources of borax. Kernite is found in Kern country, California.

Ketoses

Monosaccharides containing a ketone group (carbonyl) are called ketoses. **Carbohydrates** are produced in plants by photosynthesis and are classified into monosaccharides, **oligosaccharides** and **polysaccharides**. The term 'carbohydrates' now includes all polyhydroxy-aldehydes and ketones along with substances they yield on hydrolysis. Monosaccharides containing a ketone group are called ketoses and those containing aldehyde groups are called **aldoses**. The most important ketoses containing five carbon atoms are pentoses and those containing six carbon atoms are hexoses. One important hexose is fructose, a sugar found in honey and fruit, the structure of which is

$$CH_2OH\text{-}CO\text{-}CHOH\text{-}CHOH\text{-}CHOH\text{-}CH_2OH$$

Khaira

Khaira is a symptom of zinc deficiency found in wetland rice, the deficiency being indicated by areas of chocolate brown and burned appearance of the foliage. The deficiency is due to a high pH or the presence of calcium carbonate ($CaCO_3$) in flooded rice soil, and also due to acid soils.

The concentration of many nutrients, except zinc, increases in submerged soils. In acidic soils, zinc deficiency is attributed to the increased pH under reducing conditions and consequent precipitation of franklinite ($ZnFe_2O_4$) or sphalerite (ZnS).

Zinc solubility increases as the pH decreases in a submerged calcareous soil. However, the higher the soil pH and the poorer the aeration, the greater the zinc deficiency, particularly in calcareous soils.

The common symptoms of zinc deficiency include (a) occurrence of light green, yellow or white areas between the veins of the leaves, particularly on older and low-level leaves, (b) tissue death in discolored and chlorotic leaf areas, (c) shortening of the stem or stalk internodes, resulting in a bushy, rosetted appearance of the leaves, (d) small, narrow, thickened leaves, (e) early loss of foliage, and (f) malformation of the fruit, often with little or no yield.

Zinc deficiency in tobacco is also called ***khaira* disease**; the symptoms are dead spots all over the tobacco leaves.

***Khaira* disease**: See *Khaira*

Khanats

'*Khanats*' is another word for '***Ganats***' or '***Kharezes***' which are horizontal wells found in Iran and Afghanistan.

Kharezes: See *Khanats*

Kharif

'*Kharif*' is a term of Persian and Urdu origins and is derived from the Arabic word *Kharif*, which means autumn or the autumnal rain. It denotes one of two distinct cropping seasons in the Indian subcontinent. The two seasons are *Kharif* (June to October) and ***Rabi*** (October to April). (See also Cropping pattern.)

Kieserite

Kieserite is a greyish-white crystalline powder which contains about 16% magnesium and is used as a fertilizer. It is regarded as a concentrated form of epsom salt, having less water of crystallization. The monohydrate $MgSO_4{\cdot}H_2O$ (monoclinic) occurs in nature as kieserite which contains 27% magnesium (as MgO) and 22% sulphur. (See also Magnesium sulphate.)

Kingdom protista

Kingdom protista is one of the kingdoms described under Whittaker's Five Kingdom theory, for the classification of organisms.

Kjeldahl method

Kjeldahl method is a very convenient technique for the estimation of nitrogen in analytical chemistry. The method depends on the principle that most nitrogenous organic compounds, when heated with concentrated sulphuric acid in the presence of copper sulphate as a catalyst, decompose quantitatively to give ammonium sulphate. This ammonium sulphate, when further heated with excess of 40% sodium hydroxide (NaOH) solution, decomposes to liberate ammonia – which is bubbled through and absorbed in a known volume of a standard acid. Some of this acid is neutralized by the evolved ammonia, while the excess acid is back titrated against a standard alkali.

$$\text{Nitrogen}\,(\%) = \frac{1.4\,NV}{W}$$

where N is the normality of the acid, V is the volume of the acid used up by the ammonia and W is the weight of the substance taken for analysis.

Koppers-Totzek method for coal gasification for ammonia production: See Ammonia production processes

Koppers-Totzek method for partial oxidation process: See Ammonia production processes

Kotka superphosphate

Kotka superphosphate - so named because it was originally made in the city of Kotka, Finland - is a mixture of superphosphate and phosphate rock. It needs little curing and its free acid content is low. Its effectiveness is equal to that of equivalent amounts of fully acidulated superphosphate plus raw phosphate rock called **acidulated phosphate rock**, applied separately. It contains about 16% phosphorus (as P_2O_5) of which 6% is water-soluble. (See also Single superphosphate.)

Kozeny formula for filtration

In the context of **filtration**, the quantity of water (Q) that gets filtered in a unit time is known as the **filtration rate** and is given by the Kozeny formula. It is given as

$$Q = \frac{C}{\eta} \times \frac{P_o^3}{(1-P)^2} \times \frac{1}{S^2}$$

where S is the surface area of the particles, C is the coefficient taking into account the form, the cross-sectional area and the tortuosity of the capillaries; P is the total porosity, P_0 is the porosity accessible to moving water; and η is the viscosity of water.

Krebs cycle

Krebs cycle, also known as **tricarboxylic acid cycle (TCA cycle)** or **citric acid cycle**, denotes a series of enzymatic reactions occurring in living cells of aerobic organisms. The net result is the conversion of pyruvic acid (formed by the anaerobic metabolism of carbohydrates) into carbon dioxide and water. The metabolic intermediates are degraded through a combination of decarboxylation and dehydrogenation.

Krebs cycle (Fig.K.2) is thus a major terminal pathway of oxidation involved in the respiration in animal and plant cells.

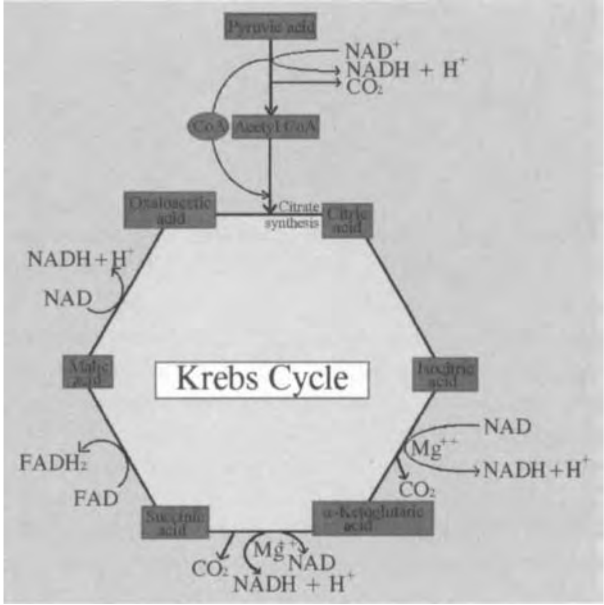


Fig.K.2: A schematic showing the broad pathway of the Krebs cycle.

Kuhlman Den process

Kuhlman Den process is one of the processes used in the manufacture of normal superphosphates.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

L

Label

The Association of American Plant Food Control Officials and the corresponding bodies of other countries define a label as the display on a container, or a statement accompanying a container giving information about the product within.

In the case of fertilizers, putting a label on the package or container identifies the fertilizer and promulgates its essential characteristics (Fig.L.1).

Phosphate solubilising Microorganisms

PHOSPHO - INOCULANT

Phospho - Inoculant for
Phosphate Solubilization in soil

DIRECTION FOR USE :

✱ The contents of packet are phosphate solubilising micro organisms. Lignite powder is used as carrier material.

USE IN CEREALS AND PULSES :

✱ Mix the inoculant uniformly with seeds gently with minimum ammount of water taking care to avoid damage of seed coat. Dry the inoculated seeds under shade over clean paper or gunny bag and sow immediately.

PLANTATION AND HORTICULTURAL CROPS :

✱ Mix 20 - 25 gm.Phospho-inoculant with 5 kg compost and apply in pits before planting or such mixture (Phospho - Inoculant + Compost) may also be placed in the soil around the trunk and pulverise the soil before the onset of mansoon.

✱ Phospho - Inoculant is not a chemical fertilizer and hence , Should not be mixed with any chemical fertilizer or fungicides, weedicides and insecticides.

USE THIS BIOFERTILIZER IN :

✱ All cereals , pulses , cash crops fruit crops , ornamentals etc.

STORE IN COOL PLACE , AWAY FROM DIRECT SUNLIGHT AND HEAT.

Weight : 250 gm. * Price : Rs. 10/-

Fig.L.1: A label identifies a product and provides information on its essential characteristics.

Transport authorities all over the world require a warning written on the container if hazardous or delicate material is sought to be transported by air, highway, rail or water.

Some classifications of labels are: Corrosive, Dangerous when wet, Explosive, Flammable gas, Flammable liquid, Flammable solid, Irritant, Non-flammable gas, Organic, Peroxide, Oxidizer, Poison, and Radioactive.

Adding a radioactive isotope, heavy isotope or fluorescent dye to a chemical compound to trace its course and behavior through a series of living organisms is known as labeling. This technique is also used in frictional wearing of moving parts in automotive engines.

Labelled compound

A compound containing a radioactive or stable isotope is referred to as a labeled compound. A radioactive labeled compound behaves chemically and physically in the same way as an otherwise identical stable compound; its presence can easily be detected using a **Geiger counter**. A labeled compound is used in tracing the behavior of a substance in both biochemical and engineering research.

A labeled fertilizer is used in research to determine the fate of an applied nutrient in the soil-plant system. For example, ^{32}P is used as a label for fertilizer phosphorus.

Labelling: See Label

Labile nutrients: See Labile pool

Labile pool

Some nutrients are easily solubilized and become available to plants during the growing season. The total amount of such a nutrient is called labile pool. **Labile nutrients** are those that undergo easy transformation to become available to plants.

Laboratory analysis of soil

Soil analysis or laboratory analysis of soil involves the extraction of nutrients from the soil and the plant, identifying the nutrients and determining their concentrations. Soil testing reveals the quantity of nutrients that plants can utilize from the soil, or the nutrient-supplying ability of the soil.

The procedure involved in laboratory analysis should be simple, rapid and accurate; the extracted values of the nutrients should correlate with those of the actual crop growth and crop yield, under various conditions.

Soil testing has certain goals, which are to (a) find out the amount of nutrients to be added to the soil, (b) estimate the acidity, salinity and elemental phytotoxicity that reduces the productivity of the soil, and (c) determine if the intended use of the soil may have a negative impact on the environment.

Many techniques are used to assess soil fertility. These include visual diagnosis, in-field evaluation, tissue analysis and remote sensing. Plant analysis includes both rapid in-field tissue testing and in-laboratory elemental analysis of the samples.

Lac-coated urea

Lac-coated urea (**LCU**) is the urea coated with shellac and is a modified fertilizer. It contains 33% urea-nitrogen. The final product carries 18% rosin ester of lac, 3.3% double boiled linseed oil, 3.6% paraffin wax, 2.9% soap and 0.2% bitumen. It is used when a slow release of nutrients is called for.

Lactose agar test

Lactose agar test distinguishes rhizobia from agrobacteria. Agrobacteria utilize lactose by the action of ketolactose enzyme, while rhizobia cannot utilize the sugar. Nodule bacteria are grown on lactose (10 g/l) agar plates for four to ten days and the plates are flushed with Benedict's solution. The formation of yellowish-red coloration due to cuprous oxide (Cu_2O) being formed, indicates the presence of *Agrobacterium*.

LAF Cabinet

LAF cabinet stands for **laminar air flow cabinet**.

Lagoon

Lagoon is a scientifically constructed pond, 1 to 2 m deep, in which sewage and other organic wastes are decomposed by the action of algae, sunlight and oxygen. Such a treatment restores water to a purity equal to that obtained with other types of treatment. The so-called oxidation ponds are often used following sludge treatment. The waste may be retained in the lagoon for as long as 30 days and is then chlorinated and passed through a trickle filter.

Lag period

The period between the initial inoculation of a culture medium with an organism and the resumption of normal growth is called the lag period.

LAI

LAI is short for **leaf area index**.

Lambert-Beer law

The Lambert-Beer law provides the basis for using spectroscopy in quantitative analysis. The absorbance of light (A) passing through a sample solution is given by

$$A = Ecl$$

where E is the molar absorptivity or molar extinction coefficient, c is the concentration of the solution and l is the length to which light travels through the solution. The colorimetric method, based on the Lambert-Beer law, is used for the determination of such elements as phosphorus, manganese and cobalt in the soil.

Laminar air flow cabinet

Laminar air flow cabinet or **LAF cabinet** (Fig.L.2) functions to maintain aseptic (sterile) conditions and a uniform flow of filtered air in the cabinet to avoid contamination. It is essential for microbiological, pathological and tissue culture studies and for biofertilizer production.

LAF cabinet is used for carrying out isolation, inoculation and microbiological work relating to aseptic transfer and growth of micro-organisms.

A **laminar flow** is a fluid flow in which a fluid or air moves in parallel layers without fluctuations or turbulence, and where the successive particles passing at any point have the same velocity.

Fig.L.2: A laminar air flow cabinet. 1. Body of the equipment, 2. UV lamp, 3. Glass sliding window, 4. Switch board, and 5. Metal base (working platform). Arrows show the direction of airflow.

A uniform velocity of the airflow through filters can control air-borne contamination. In some LAF cabinets, air-directing devices are incorporated by which the airflow can be converged or focussed on the obstructing objects. Pre-filters and high efficiency particulate filters, made of cellulose acetate plated aluminum foil, screen out particles larger than 0.3 µm.

Laminar erosion

The erosion or removal of the surface soil in a uniform manner under the influence of the surface run-off water or wind is called the **sheet erosion** or laminar erosion.

As one of the most frequent mass wasting processes, laminar erosion commonly occurs on slopes of hills with scanty vegetation cover. Overgrazing, intensive agricultural activities, deforestation and chemical degradation are some of the major reasons of all kinds of erosion, especially laminar erosion. Water erosion (especially laminar) accounts for more than 10% of the total soil degradation in Mexico, according to a study.

Laminar flow: See Laminar air flow cabinet

Laminated bags

A laminated bag is a bag with a lining of polythene sheets inside it which makes the bag very convenient for packing fertilizers or grains. The lining prevents insects (such as weevils) and moisture from entering the bags, and protects the product within. Lamination also facilitates bag fumigation.

Land capability classification

Land capability classification (**LCC**) is the classification of lands according to their ability to sustain crops that do not need any special site conditioning or treatment. LCC is done by United States Department of Agriculture (USDA). There are three broad levels, which are the capability class, the subclass and the unit. At the first level, there are eight classes: the first four classes are capable of producing adapted plants with good management; the next group of three classes produces specialized crops, with highly intensive management especially for soil and water conservation; the third group includes a land class which does not yield benefit on-site because of major limitations arising from erosion, wetness, limitation of rooting zone and climate.

LCC provides a meaningful assessment of soil for agricultural use.

Land drainage

Land drainage refers to the draining of excess water from wet soils with a view to improve soil aeration for better plant growth. There are various methods of draining excess water from land; for example, through open channels (open drains) or pipes located at some depth in the soil (closed drainage or underground drainage). Natural land drainage or internal drainage of the soil depends mainly on the permeability of the material (which is controlled by its texture), the position of the water table and the presence of impermeable substratum.

Land drainage stabilizes the soil structure, improves aeration and root development, allows the soil to warm up rapidly, promotes early crop growth, and lengthens the growing season for grass and arable crops. It also reduces weed growth and incidence of certain diseases of plants and animals.

Drainage systems are engineering structures which remove water in accordance with the relevant principles in soil physics and hydraulics.

Land equivalent ratio

Land equivalent ratio, **LER** for short, denotes the relative land area under a sole crop required to produce the same yield as obtained under a mixed or an intercropping system at the same management level. LER is calculated as the sum of the yield ratios of each component crop in an intercropping or mixed cropping system to its yield when grown as a sole crop. Thus,

$$\text{LER} = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}}$$

where Y_{ab} is the yield of species 'a' in association with species 'b', Y_{ba} is the yield of 'b' in association with 'a'; Y_{aa} and Y_{bb} are the yields of pure species 'a' and 'b', respectively.

Landform

The mass of a parent material has a distinct shape and characteristic particle sizes. Its minerals or organic masses are known as landforms.

Land man ratio

Land man ratio (**LMR**) is the ratio of the number of human beings to the land area. It indicates the population pressure at any given time and location. It is the pressure of people per net-cropped hectare of land. Low values of LMR are preferred to high values.

The population growing in areas under agriculture has resulted in a progressively increasing population pressure per net-cropped hectare in all countries. Surveys conducted in ten countries show that the population density is now between 3 and 12 persons per net-cropped hectare. In Japan, South Korea and Taiwan, the net-cropped area has decreased as the population increased, and the population density is now between 21 and 36 persons per net-cropped hectare. This has led to increasing concern about 'agricultural insecurity'.

Land pebble phosphate

A phosphate rock is of four kinds: land pebble phosphate, **hard rock phosphate**, **soft rock phosphate** and **river-pebble phosphate**, with the P_2O_5 content in them varying from 2 to 21%.

The term 'land pebble phosphate' originates from the phosphate found in Florida, USA. It occurs as pellets, pebbles and nodules close to the soil surface and is mined extensively.

Land races

Land races are plants that are original and local varieties of that species. They flourish in particular environments suited for their growth. Over the ages, land races have formed the basis of further evolution either through the natural process of selection or by genetic engineering. These varieties are commonly found to be robust and believed by some to be more nutritious. The economics of producing hybrids from these races, combined with the commitment of the local governments together decide the fate of most land races. Absence of a meaningful policy can sometimes result in the loss of unique genetic information that may have been useful in research.

A closer look at local varieties of say, grapes, reveals that *Vitis vinifera* and its sub-species, originating in the Middle East, generally have seedless berries. The varieties are tolerant to drought and salinity and are resistant to the grapevine fanleaf virus. Similarly, the race *Vitis amurensis* of Chinese origin had the property of tolerating cold temperature and is moderately resistant to fungal diseases. North American species that have unique properties include *Vitis aestivalis* var. *glauca* (drought resistant, foliar disease resistant and resistant to Pierce's disease, a bacterial attack, and lacking the strong fruit flavor), *Vitis monticola* (drought resistant) and *Vitis palmata* (very well suited to swampy, low oxygen conditions).

There are many land races, including those mentioned above, whose survival is under threat. A recent example of a threatened variety is the world's most favorite fruit and the fourth most important food crop, namely the banana whose genetic base is said to be disappearing. Wild species are being destroyed with increased urbanization in many places in India. To add to the challenge, the variety called Cavendish is being vastly threatened by black sigatoka fungus. New research to develop new resistant cultivars is seen as the only way to stem **genetic erosion**. Lands, forests, wetlands and the particular environment required by many such crop species have been destroyed by urbanization, industrial development and land being brought under cultivation. Financial constraints to develop and maintain germplasm and **seed banks**, absence of systematic documentation on research and that of a governmental policy are some of the factors that contribute to the loss of land races.

Langbeinite

Potassium sulphate occurs in nature as langbeinite which is a double sulphate of potassium and magnesium. Langbeinite is a source of potassium sulphate fertilizer.

Langelier's saturation index

Langelier's saturation index (SI) is an improvement over the **SAR (sodium adsorption ratio)** concept. **SI** was originally developed for predicting the carbonate deposition in boilers.

SI is defined as:

$$SI = 8.4 - pHc$$

$$pHc = (pK_2 - pK_{sp}) + pCa^{2+} + P_{(alk)}$$

where pK_2, pK_{sp} are the negative logarithms of the dissociation constant of H_2CO_3 and $CaCO_3$ solubility product, pCa^{2+} is the negative logarithm of Ca^{2+} concentration and $P_{(alk)}$ is the negative logarithm of the alkalinity concentration ($HCO_3^- + CO_3^{2-}$).

Langmuir equation: See Langmuir isotherm

Langmuir isotherm

From the kinetic theory of gases, Irving Langmuir developed the concept of monolayer adsorption of gases on surfaces. The concept, known as Langmuir isotherm, relates the amount of gas adsorbed on a plane solid surface to the pressure of gas in equilibrium with the surface.

The derivation of Langmuir isotherm assumes that the adsorption is restricted to a surface monolayer which is energetically uniform, and also assumes that there is no interaction between the adsorbed species. Here, the **langmuir equation** shows that the fraction (q) of the surface covered by the adsorbate at a gas pressure (p) is given by:

$$q = \frac{bp}{1 + bp}$$

where b is a constant, called the **adsorption coefficient**, which is the equilibrium constant for the adsorption process.

Langmuir visualized the adsorption process to consist two opposing tendencies (of gaseous molecules), one for the molecule to condense from the gaseous phase on the solid surface, and the other for the molecules to evaporate back into the gaseous phase.

The langmuir equation, while still in use, is of a limited value since surfaces are energetic and non-homogeneous, and interactions often occur between adsorbed species. Langmuir's isotherm is useful in other fields also. Langmuir's theory of monomolecular adsorption is valid only at comparatively low pressures and high temperatures.

In most soils, the sorption/desorption processes describe the phosphorus uptake and release (that control the phosphorus availability) better than the precipitation/dissolution reactions do. The processes relate to (a) high pH in calcareous soils, precipitation/dissolution, (b) a low pH in Fe/Al oxide soils, and (c) the adsorption/desorption. The soil phosphorus sorption is characterized by such parameters as are calculated from the Langmuir equation.

Lansfordite

Lansfordite is a naturally occurring pentahydrate of magnesium carbonate [$MgCO_3 \cdot 5H_2O$ (monoclinic)] used as a source of magnesium fertilizer.

Magnesium carbonate is a white compound and exists both in the anhydrous and hydrated forms.

LAR

LAR is short for **leaf area ratio**.

Large bag storage test

The tendency of a fertilizer to cake can be assessed in relative terms by (a) storage tests in large and small bags, and (b) accelerated storage.

The large bag storage test involves storage of the fertilizer in a standard sized bag for a period of 1 to 12 months, depending on the approximate period the fertilizer is likely to be stored. The material is evaluated at certain intervals (say, 1, 3, 6 and 12 months). The storage temperature may vary, depending on the actual storage conditions of the fertilizer. After storage, the test samples are evaluated for **bag set** by dropping the samples from a predetermined height and observing whether and how they break. The caking tendency of the fertilizer is determined by measuring the hardness and the percentage of lumps formed in the mass during storage.

Large granular urea

In contrast to prilled urea, which has particles of 1 to 2 mm size, large granular urea (**LGU**) has 6 to 8 mm sized granules and is found primarily suitable for rice. The large granules are also called **super-granules**. There is roughly a 30% saving in nitrogen by using LGU instead of prilled urea because of the higher efficiency of the LGU.

Urea super-granules were developed on the lines of the mud ball technique followed in China to increase the efficiency of fertilizer nitrogen. Studies showed that urea super-granules had a yield advantage over urea by about 11%. In light and sandy soils, urea super-granules have proved unsuitable owing to increased leaching. For best results, urea super-granules should be placed 4 to 5 cm below the soil surface.

Lateral meristem

Meristem is a portion of the plant tissue, found mainly at the growing tips of roots and shoots. Meristem is composed of actively dividing cells, forming new tissues of the plant. The lateral meristem or cambium is responsible for increasing the girth of the plant and causing its secondary growth.

The two most important cambia are **vascular cambium** and **cork cambium**. The tissues developing from these are considered to be a part of the plant's secondary growth.

Laterite soil

Soils from the tropical regions, formed by intensive weathering of underlying parent rock, and rich in iron oxide and aluminum are called laterite soils. The rock material, subjected to high rainfall and temperature is prone to oxidizing and leaching conditions. Such soils are thus devoid of sodium, potassium, calcium, magnesium and silica. Laterite is acidic in nature and poor in fertility. Iron oxide imparts the red brown color to the soil.

As a rule, most laterite material is hard and strong and is used in the construction industry (Fig.L.3), but there are few soft and brittle laterites.

Fig.L.3: Blocks of laterite soil are hard and are used for construction.

Laterites consist of kaolinite, goethite, hematite, etc. **Red soils** and laterite soils are mainly alfisols, ultisols or oxisols. Typical laterite is porous and clay-like. The aluminum-rich representative of laterite is bauxite.

Many parts of India, Sudan, Brazil, etc. have laterites. In India alone, 107 million hectares of land come under laterite soils.

Lava rock

Lava rock is a solid substance formed on cooling lava, the latter being a molten matter which flows from a volcano. Lava rock is used as a growing medium, especially for orchids like *Dendrobium*, since it retains water and never breaks down. The lava rock contains a large amount of air which helps the roots grow well in it. This medium helps pots from tipping over in the case of tall growing plants. Lava rock can accumulate salts easily, if irrigated water contains a large quantity of minerals, which could become harmful for salt-sensitive plants.

Law of Avogadro: See Chemical laws

Law of conservation of mass: See Chemical laws

Law of constant composition: See Law of definite proportions; Chemical laws

Law of constant proportions: See Law of definite proportions

Law of definite proportions

The law of definite proportions is a law of chemical combinations. It says that the proportion of elements in a compound is always the same, no matter how the compound is made. It is called the **law of constant compositions**, or the **law of constant proportions**. For example, copper carbonate always contains 5.3 parts of copper to 4 parts of oxygen to 1 part of carbon by mass (no matter how the compound is made).

Similarly, whatever its source, silver chloride (AgCl) contains Ag:Cl in the proportion of 100 g Ag : 32.86 g Cl, according to the law of constant proportions, giving it a definite composition. It is known that atoms of an element may consist of a number of isotopes having different masses. However, the law holds as long as any sample of the element contains the same relative proportion of the isotopes.

A serious departure from the law of definite proportions occurs in a large variety of solid compounds and non-stoichiometric compounds.

Law of diminishing returns

The law of diminishing returns states that increasing an input by the quantity of 1 unit (keeping the other inputs fixed) increases the output (in proportion to the increased input) till a stage is reached when the output begins to fall (Fig.L.4). The law of diminishing returns helps to describe the effect of increased fertilizer rates on crop growth or crop yield. According to the law, the yield increases at first, in proportion to the successive increment of the fertilizer. However, the increase in the yield begins to decline for the same input of the fertilizer. The law helps in arriving at an optimum fertilizer application rate. (See also Marginal returns from nutrients.)

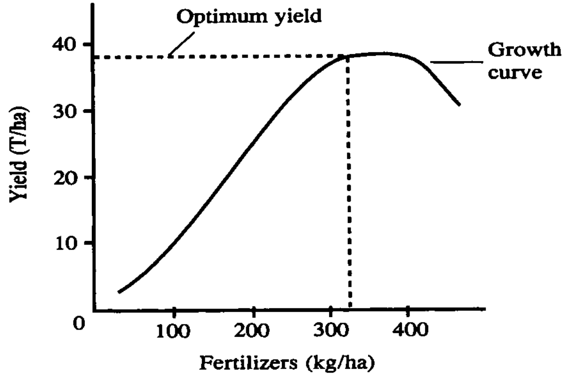


Fig.L.4: A graph of yield against fertilizers showing the law of diminishing returns.

Law of equivalent proportions: See Chemical combination, laws of

Law of mass action: See Chemical laws

Law of minimum

A balanced nutrition is an important aspect of sustainable agriculture. The law of minimum, given by **Justus von Liebig**, underscores the importance of plant nutrients. The law states that if an element deficient in the soil is supplied, the plant grows in proportion to the amount supplied up to the point of meeting the deficiency, and the supply of that element no longer limits its growth. The law also states that if one of the nutrients from the soil or air is deficient or lacking, the growth and development of the plant will be incomplete even when all other elements are in abundance.

This concept is often explained by the example of a wooden barrel made of staves of different heights (Fig.L.5). The capacity of the barrel to hold water is determined by the height of the shortest stave. In a similar manner, the plant growth is limited by the short supply of a particular growth factor to the plant, which acts as the minimum factor. This factor is often nitrogen. The inputs that do not correct the limiting factors are considered inefficient and a waste.

Plant nutrients, as also water, light, disease, temperature and crop genetic potential, are growth limiting factors. When one limiting factor is removed (for example, through fertilizer application or irrigation), the other nutrients or factors become limiting. Different factors could potentially control the rate of plant growth at different times. For example, unfavorable temperature in early spring, inadequate moisture in dry periods and improper nitrogen supply may limit the growth even if all other factors are favorable. Obviously, some factors always limit plant growth and ultimately, its genetic capability. By manipulating the soil-related factors over which farmers have some control, they can try to lengthen the limiting stave or staves to increase the crop yield and thereby, the profits.

The analogy of the barrel may explain some useful concepts: (i) If factors like the moisture or the day length limit the growth, there is no benefit in increasing plant nutrients above the level that the crop cannot use. (ii) When irrigation or nutrient addition removes the growth limitation, other factors become limiting. (iii) It is not a useful practice to raise the available level of one nutrient far above that of the others. Nutrients must be added to supply those needs of the crop which are not provided by the soil. This practice is often referred to as **balanced fertilization**. It does not mean that fertilizers must be added in a specific nutrient ratio, but that the nutrient supplying capacities are maintained in a relative balance to the crop needs.

The law of minimum has been very useful, as it identifies the limiting factors, and corrections thereto are an important part of farm management. The analogy of the barrel is, however, a simplification of reality. In fact, various factors do interact and the crop can make the best use of the factor that limits the growth and the yield when other factors are close to their optimum levels.

Law of multiple proportions: See Chemical combination, laws of; Chemical laws

Law of segregation : See Segregation in plant

Fig.L.5: Barrel staves of varying heights represent the growth-controlling factors and are an illustration of the 'Law of minimum'.

Laws of chemical combination: See Chemical combination, laws of

Layer silicates: See Clay minerals

LCA process

LCA is the abbreviation for **leading concept ammonia process of ammonia production**. (See also Ammonia production processes.)

LCC

LCC is short for **land capability classification**.

LC_{50} test for toxicity evaluation

Toxicity is evaluated on the basis of test dosages made on experimental animals under controlled conditions. The LC_{50} (lethal concentration 50%) test is one of the two most important tests, the other being the **LD_{50}** (lethal dose, 50%) test. The tests include exposure of the animal to (a) oral ingestion, (b) extended skin contact, and (c) inhalation of the material under test. LC_{50} is the quantity of a substance given by inhalation that is necessary to kill 50% of test animals exposed to it within a specified time.

LCU

LCU is short for **lac-coated urea**.

LD_{50} test for toxicity evaluation

The LD_{50} test is a toxicity evaluation test and gives the lethal effect of the toxic compound. LD_{50} is the quantity of a substance administered either orally or by skin contact necessary to kill 50% of exposed animals in laboratory tests within a specified period. A substance having LD_{50} is measured in mg/kg of body weight. (See also LC_{50} test for toxicity evaluation.)

LDPE

LDPE is short for **low density polyethylene**. LDPE sheets are used for lining jute bags in which fertilizers are stored. LDPE acts as a waterproofing material.

Lea

Lea is a type of modern plow.

Leached horizon

Percolating water takes away some clay and humus to a deeper section of the soil. The soil horizon thus bereft of valuable salts, humus and soil materials is the leached horizon. The layer from which soil materials and soluble salts are removed by downward moving water is called **leached layer** or **eluvial layer** (horizon).

Leached layer: See Leached horizon

Leaching

Leaching involves extraction of soluble constituents from a solid mixture by a downward movement with a percolating solvent. Leaching is closely related to solvent extraction, in which a soluble substance is dissolved from one liquid by another immiscible liquid. Both leaching and **solvent extraction** are often called **extraction**.

Plant nutrients are leached from the soil by excess water getting out of reach of the plant roots. The fertilizer in coarse-textured soils is lost under heavy rainfall or intense irrigation. The fertilizer ions, which are most easily prone to leaching, are those of nitrate, sulphate and chloride.

Leaching can occur either by percolation or by dispersion of particulate solids into the extracting liquid and a subsequent separation. In either case, the operation can be continuous or in batches.

Leaching occurs mainly during heavy rainfall or irrigation, resulting in a loss of the added fertilizers. Leaching of nitrate from the soil occurs due to heavy rainfall and/or irrigation in the first 3 weeks of the application of fertilizer. The rate of leaching is generally low if the soil clay content is high. However, a high leaching rate prevails in fallow and/or sandy soils, whereas in soils with a permanent plant cover (for example, grassland), it is low. Phosphates do not leach easily. The leaching of nitrates depletes the soil of nutrients such as Ca, Mg and K. This process gets accelerated by a preferential flow of water through the root channels, natural fissures and cracks in the soil. Liming generally reduces the leaching of potassium from the soil.

The extent of leaching of a herbicide depends on its solubility, the volume of water available, its distribution in the soil, and the adsorptive relationship of the herbicide with the soil. Herbicides should not move too deep as they could affect deep-rooted plants adversely (and become ineffective on the weeds). Water must be added to keep the soil salinity below a predetermined tolerance concentration.

The leaching of soluble salts from the root zone is essential in irrigated soils, as otherwise the salts get accumulated. The excess water required to leach out salts is known as the **leaching fraction (LF)** and is defined as the ratio between the amount of irrigation water applied and the fraction of applied water that passes through the root zone. It is given by

$$\mathrm{LF} = \frac{D_{dw}}{D_{iw}} = \frac{EC_{iw}}{EC_{dw}}$$

where D_{dw} is the depth of drainage water, D_{iw} is the depth of irrigation water, and EC_{iw} and EC_{dw} are the electrical conductivity of irrigation water and drainage water respectively.

Irrigating with salt water leads to accumulation of salt unless substantial quantity of water is added to wet the plant zone and maintain the salt balance. The additional water required for leaching, over the amount needed to wet the profile, is called the **leaching requirement (LR)**, and is defined as:

$$LR = \frac{EC_{iw}}{EC_{dw}}$$

where EC_{iw} is the electrical conductivity of irrigation water and EC_{dw} is the electrical conductivity of the soil saturation extract at which a 50% decrease in the yield is obtained in a uniformly saline soil. The equations for the leaching fraction and the leaching requirement are the same. Thus, the leaching fraction is the fraction of irrigation water passing through the lower root zone, while the leaching requirement is a calculated estimate of the amount of leaching required for keeping the soil salinity within the permissible limits.

The leaching requirement is a function of the (a) quality of irrigation water, (b) water consumptive use, (c) drainage capacity of the soil, (d) rainfall, (e) salt precipitation, (f) salt uptake by plants, (g) salinity of surface layers, and (h) method and frequency of irrigation.

To reduce the water requirement for leaching, the soil has to be under unsaturated conditions. Hence, any factor related to the soil or the method of application of irrigation water that affects the unsaturated flow in the soil decreases the water wastage. The relevant factors for this phenomenon are (a) growing crops during a cool season instead of a warm season, (b) growing salt-tolerant crops, (c) chiselling, sub-soiling or practising deep tillage to increase the permeability, (d) adding amendments, (e) using irrigation methods such as sprinklers, (f) wetting the soil prior to the onset of winter rains, and (g) leaching the area in stages.

With an increased use of salt water and the growing shortage of water, a larger quantity of water will be needed for leaching. As irrigation water becomes saltier, the LR fraction becomes larger. Increasing the water progressively reduces salt build-up.

Salt tolerant crops like wheat and sorghum can have a leaching requirement as low as 0.08 before the growth reduction starts occurring (with water containing 1350 ppm of salts). Lettuce, a salt sensitive plant, has a leaching requirement of 0.20, which is two and half times more than that for sorghum or wheat.

Leaching fraction: See Leaching

Leaching requirement: See Leaching

Lead chamber process for sulphuric acid production

Sulphuric acid is made by two processes: the lead chamber process and the **contact process**. Both processes involve burning of sulphur or sulphur ores, such as pyrites, to give sulphur dioxide which is converted to sulphur trioxide in the presence of a catalyst, followed by absorption of the sulphur trioxide in a concentrated acid. Nitric oxide produced during normal combustion of sulphur can be harmful in many processes. To reduce the formation of nitric oxide, the process of catalytic conversion of SO_2 to SO_3 is generally carried out in various steps. The SO_3 thus formed, is absorbed in a re-circulated stream of concentrated sulphuric acid.

The reaction in the lead chamber process is:

$$SO_3 + H_2O \xrightarrow{\text{In lead rooms}} H_2SO_4$$

Major disadvantages of the lead chamber process are the limitations in the throughput, quality and concentration of sulphuric acid which comes to about 78%. (See also Sulphuric acid production processes.)

Lead-free gasoline: See Gasoline

Leading concept ammonia process of ammonia production: See Ammonia production processes

Leaf

A leaf is a flat green structure that develops from the stem or a superficial group of tissues and the leaf buttress on the side of the stem apex of higher plants. Each leaf has a lateral bud in its axil. A typical leaf comprises a broad flat lamina (leaf blade) supported by a network of veins, a petiole or leaf stalk, and a leaf base which attaches the leaf to the stem (Fig.L.6).

Leaves contain chlorophyll and are the principal organs in which the important processes of photosynthesis and transpiration occur. The green color of leaves is due to chlorophyll sited in the chloroplasts. Leaves are arranged in a definite pattern (called **phyllotaxis**) and usually show a limited growth. Bryophyte leaves are simple appendages, not homologous to the leaves of vascular plants as they develop on the gametophyte generation.

Leaves show considerable variation in size, shape, texture, vein arrangement and in the type of attachment to the stem. They may be simple, in which case the lamina is a single unit (Fig.L.6.1); or they may be a compound unit divided into leaflets (Fig.L.6.2-4).

The types of leaves include **cotyledons** (seed leaves), **scale leaves** (which lack chlorophyll, develop on rhizomes or protect the inner leaves of a bud), **foliage leaves** (the main organs for photosynthesis, and transpiration), and **bracts** and **floral leaves** (like sepals, petals, stamens and carpels specialized for reproduction).

Leaves are often modified for special purposes. For example, the leaf bases of bulbs are swollen with food to survive winter. In some plants, leaves are reduced to spines for protection and as security against water shortages, and their photosynthetic function is carried out by another plant organ, like the cladode.

The leaf surface provides many characteristics for identification. The surface can be **glabrous** (smooth or free from hair), **glaucous** (covered with a whitish, waxy material), **scabrous** (rough or harsh to touch), **pubescent** (hairy), **puberulent** (very fine hair coverage), villons,

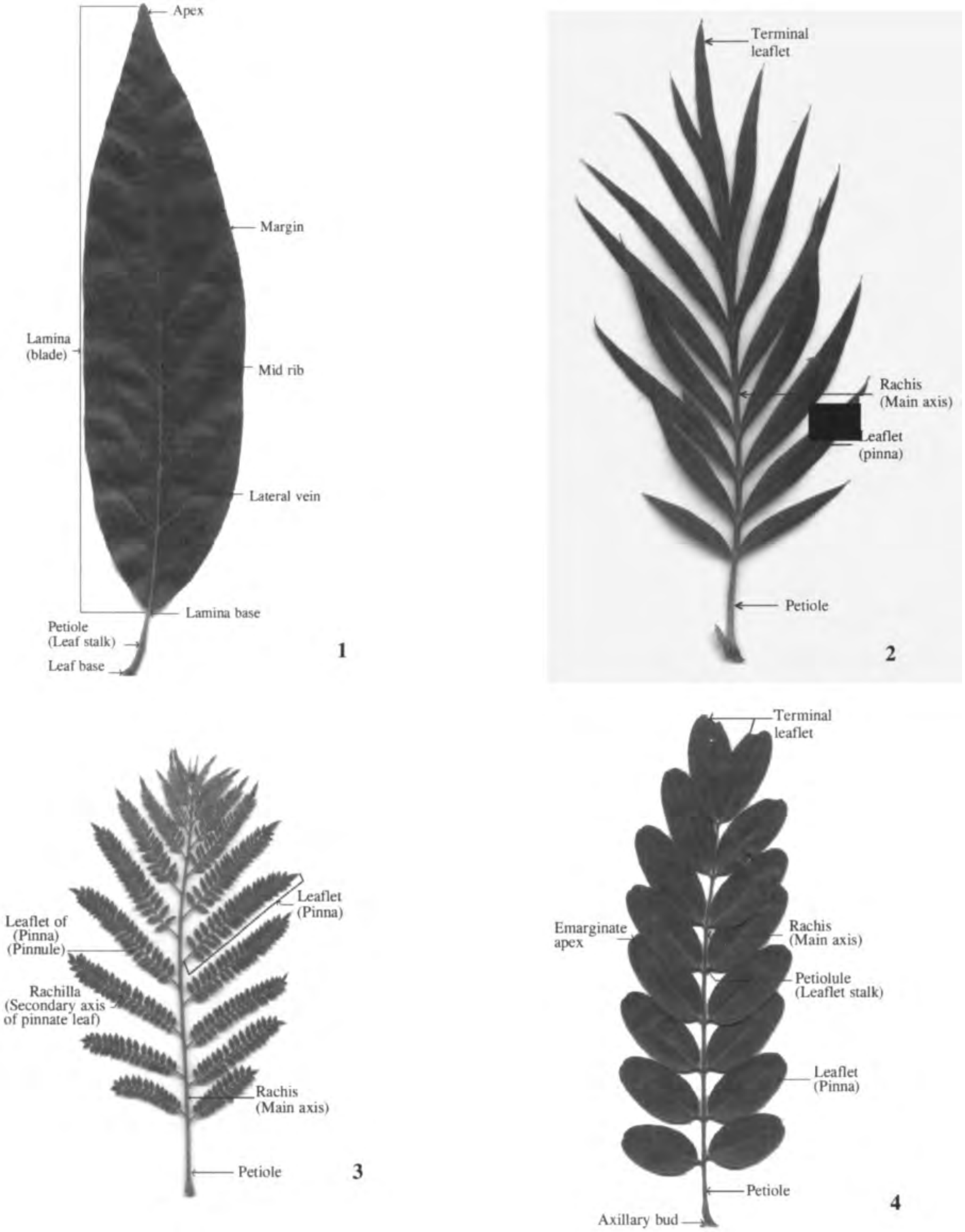


Fig.L.6: 1 is a simple leaf of Annona reticulata; 2, 3 and 4 are compound leaves of Grewalia robusta, Jacaranda mimosifolia, and Cassia fistula, respectively.

hirsute or hispid. The texture may be succulent (fleshy and juicy), hyaline (thin and transparent), chartaceous (papery and opaque), scarious (thin and dry) or coriaceous (tough and leathery).

Leaves may be **fugacious** (falling as soon as formed), deciduous (falling at the end of the growing season), **marcescent** (withering at the end of the growing season but not falling until spring) or **persistent** (remaining on the stem for more than one season).

In some plants, the leaves are adapted to catch insects, while in others they are modified to reduce water loss. Leaves produced immediately below the flowers are called **bracts**, and in some species (e.g., *Poinsettia*), they are highly colored.

Most leaves are covered by a waterproof covering or cuticle. Gaseous exchange takes place through small openings called **stomata**, through which vapor also passes. The blade of the leaf is strengthened by veins which contain the vascular tissue that is responsible for conducting water around the plant and substances essential for metabolism.

Leaf analysis: See Plant analysis

Leaf area index

Leaf area index (**LAI**) is the area of the leaf per unit area of the ground (Fig.L.7). LAI is, therefore, the total leaf area of a crop per unit of the soil area under it, and is equal to 1 when the leaf area is 1 sq. m. on a 1 sq. m. plot:

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Land area}}$$

The leaf area index can be 7 for modern rice varieties, 6 to 9 for wheat, 5 for maize and 3 for soybeans. It is influenced by factors relating to soil, plant and climate. LAI increases with advancement of age of the plant and the phosphorus level (it is increased at 80 days of growth for upland rice with phosphorus application of up to 44 kg/ha). Optimum values of LAI, which are 2 and 3, are obtained at 85 to 100 days after sowing for upland rice compared to 4 to 7 for lowland rice.

Fig.L.7: Plant canopy analyzer being used in groundnut field for estimating leaf area index.

The **crop growth rate** (CGR) is a product of LAI and the **net assimilation rate (NAR)**

$$\text{CGR} = \text{LAI} \times \text{NAR}$$

The net assimilation rate is the dry matter accumulation per unit area of the leaf and can be computed from

$$\text{NAR} = \frac{1}{A} \times \frac{dw}{dt}$$

where A is the leaf area and dw/dt is the change in the plant dry matter per unit time. NAR, which determines the efficiency of plant leaves in dry matter production, decreases with the crop growth because of the mutual shading of the leaves and the reduced photosynthetic efficiency of the older leaves.

The crop growth rate (CGR) is also the dry matter accumulation rate per unit area of the land and is expressed as grams per square meter (of the land area) per day. It is calculated as

$$\text{CGR} = \frac{W_2 - W_1}{\text{SA}\,(t_2 - t_1)}$$

where W_1 and W_2 are the crop dry weight at the beginning and end of the interval, t_1 and t_2 are the corresponding days, SA is the soil area occupied by the plants at each sampling.

The crop growth rate is normally low in the early growth stage and increases with time, reaching a maximum value at the time of flowering. The growth rates of some important crops are given in Table-L.1.

Table-L.1: Maximum growth rates of some crop plants.

Crop species	CGR (g/m^2/day)	Reference
Cereals		
Millet	54	Begg, 1965
Corn	51	Williams et al., 1965
Sorghum	51	Loomis and Williams, 1963
Sugar cane	42	Monteith, 1965
Rice	36	Tanaka, 1983
Barley	23	Cooper, 1970
Wheat	18	Cooper, 1970
Legumes		
Cowpea	28	Summerfield et al., 1983
Peanut	28	Williams et al., 1975
Soybean	23	Koller et al., 1970
Alfalfa	20	Nelson and Smith, 1968
Common bean	15	Laing et al. 1983
Roots and tubers		
Potato	37	Tanaka, 1983
Sugar beet	32	Watson, 1956

Source: Compiled by N.K. Fageria, for "Maximizing Crop Yields", 1992, Marcel Dekker, Inc., USA. With permission.

The **relative growth rate (RGR)** of a plant at an instant time (t) is defined as the increase of plant material per unit of the material present per unit of time.

$$\text{RGR} = \frac{1}{W} \times \frac{dw}{dt}$$

where W is the dry weight and dw/dt is the change in dry weight per unit time.

Leaf area ratio (LAR) of a plant at time (t) is defined as the ratio of the assimilatory material per unit of plant material present. This growth parameter is calculated as :

$$\text{LAR} = \frac{A}{W}$$

where A is the leaf area and W is the dry weight of leaf.

RGR, NAR and LAR are related.

$$\text{RGR} = \text{NAR} \times \text{LAR}$$
$$\frac{1}{W} \times \frac{dw}{dt} = \frac{1}{A} \times \frac{dw}{dt} \times \frac{A}{W}$$

Leaf area ratio: See Leaf area index

Leaf blast in rice

Leaf blast in rice is a widespread fungal disease caused by *Pyricularia grisea* (*Magnaparthe grisea* or *Pyricularia oryzae*). It is responsible for crop damage of up to 50% in affected areas. (See also Rice, major diseases of.)

Leaf blight disease of rice

Blight is a disease condition marked by sudden and severe formations of streaks, lesions and spotting on plant parts. It often attacks tissues, thus drying and killing them.

Blights are generally associated with fungal pathogens, but bacterial blights are also known.

Since blights can affect a particular part of the plant, the name of the blight is derived from the part that is affected, for example, leaf blight, stem blight, and blossom blight.

The bacterial leaf blight disease of rice is a major disease caused by the bacterium *Xanthomonas oryzae* pv. *oryzae*. This disease assumes almost epidemic proportions across the whole of Asia. In India, for instance, it once reduced yields by around 80% in the affected areas of large fields.

It is seen that any nutritionally stressed plant is more prone to fungal leaf diseases like leaf blight, blast, etc. While a fungicide may prevent further spread of the disease, the nutritional status of a crop is very critical in estimating the risk of fungal and viral diseases. It was observed in a study of the foxtail palm that potassium deficiency increased the risk of leaf spots or leaf blights. Similarly, calcium deficiency prevents the growth of strong cell walls, subjecting the crop to pathogenic attacks. (See also Rice, major diseases of.)

Leaf deficiency symptoms

Nutrient deficiency affects the roots, shoots, leaves, flowers and the fruits. Its symptoms are visible on the plant parts; those visible on the leaves are called the leaf deficiency symptoms or **foliar symptoms**. They appear as chlorosis, necrosis, cupping, pigmentation, folding and wrinkling. Fig.L.8 shows the relationship of nutrient deficiencies with the position of leaves on a plant. The deficiency symptoms of each nutrient element are also described. (See also Deficiency symptoms.)

Leaf nodules

A symbiotic nitrogen fixing association between plants and some bacterial species is sometimes seen as nodules on the leaves of the host plant. Such nodules are called leaf nodules.

This phenomenon is observed in some varieties of the psychotria plant (*Psychotria bacteriophila*) found in warm and tropical regions. The *Kiebsiella* bacterium passes through the stomata of the leaf primordia and enters the sub-stomatal chamber. This chamber enlarges to become a leaf nodule. Each nodule hosts a population of the Gram-negative, normal, degenerative bacteria in a specific zone of the nodule. Nitrogen fixing activity is observed among biological associations in leaf nodules.

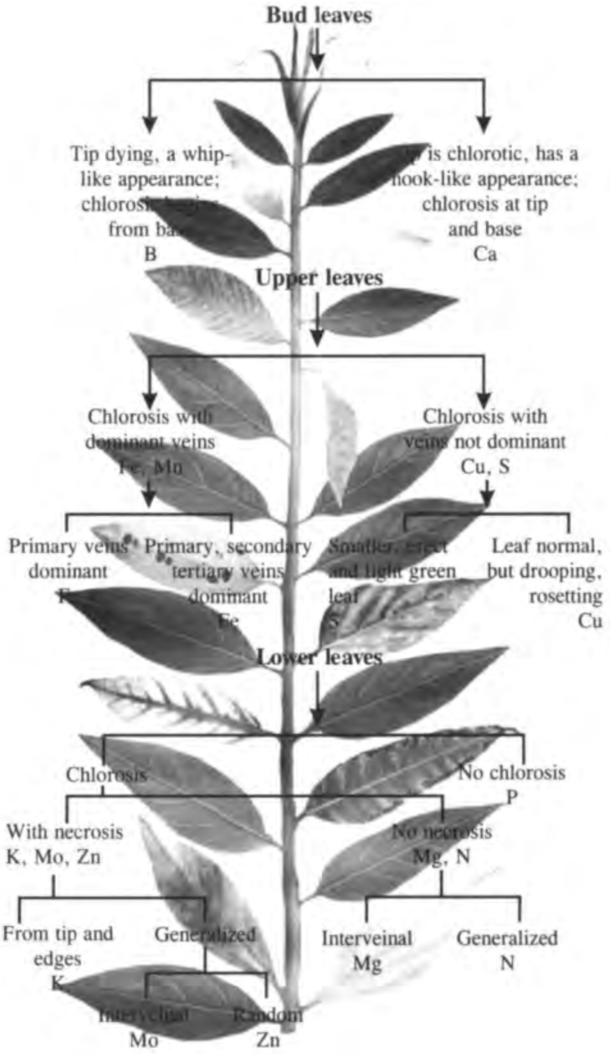


Fig.L.8: Reading nutrient deficiency based on leaf location and symptoms. (Courtesy: Institute of Micronutrient Technology, Pune, India).

Studies also seem to suggest heightened cytokinin activity in the leaf discs of infected *Psychotria punctata* leaves. Cytokinin is a plant growth hormone mainly responsible for promoting cell division and cell growth. Revelations such as cytokinin activity and nitrogen-fixing encourage researchers into harnessing the potential that may exist in such symbiotic associations.

Leaf scorch

Potassium deficiency affects healthy green areas of the leaves of many crops. In the later stages of potassium starvation in corn, for instance, the leaf edges become necrotic, the tissue disintegrates and the leaf acquires a ragged appearance. This condition is called leaf scorch.

Leaf succulents

Some plants grow and survive in unfavorable habitats such as dry soil and extremely dry or arid conditions. Such plants are called **xerophytes**. They are mostly succulents, and store water in their specialized, modified, spongy tissues. Based on the part in which these plants store water or moisture, they are categorized as leaf succulents, **stem succulents**, **root succulents** and **stem and root succulents**.

Leaf succulents have special structural and functional modifications like swollen leaves (Fig.L.9). The entire leaf is covered in a thin layer of assimilating tissue that absorbs water and carbon dioxide. Specialized leaves with hairy, rolled or reduced spines or thick cuticle lower the rate of transpiration. Sometimes, the leaf has a wax-like skin to prevent water loss. Leaf succulents have extremely short stems which are not very apparent. Examples of leaf succulents are crassulas, lithops, haworthias, aloes, etc.

Fig.L.9: Aloe vera, a leaf succulent.

Leaf tip burn, cauliflower

Calcium deficiency causes the disorder called the leaf tip burn in cauliflower.

Least significant difference

While comparing the means of several samples, there could be differences due to the fact that they are sample means and not true means and/or due to random fluctuations or natural variations. If the difference is significant, it is attributed to a true difference between the two methods or treatments. If it is small (i.e., insignificant), it is probably due to sampling. The least significant difference is a criterion for judging whether the difference is large or small. Any difference that exceeds the least significant difference is significant. This least significant difference is calculated by using the values in the **T-table**.

Leghemoglobin

Leghemoglobin is a substance which is present only in the root nodules of leguminous crops and gives pink color to the root nodules. It facilitates the diffusion of oxygen. The leghemoglobin pigment limits the oxygen supply to the bacteroid. The amount of leghemoglobin and the quantity of nodule bacteroids present together decide the amount of nitrogen fixed by legumes. Nitrogen fixation is an anaerobic process.

Structurally and functionally, leghemoglobin has much in common with animal myoglobin, including its property of binding oxygen.

Legume root nodulation

A nodule on a root is the result of a series of sequential events in the interaction between a specific *Rhizobium* strain and a specific leguminous root system. This process of nodule development is called legume root nodulation.

All legumes do not bear root nodules although cultivated grain and fodder legumes invariably possess nodules of varying sizes and shapes on their roots (Fig.L.10).

Fig.L.10: Nodulation on the roots of clusterbean.

Legumes

The plants of the family **Leguminosae**, which is a sub-family of Papilionoideae, are called legumes. The Leguminosae family is the second most important group of flowering plants, next only to Gramineae, and is grown as a source of food and fodder. These are dicots and form a symbiotic association with *Rhizobium* bacteria in the form of nodules. Under good nodulation, much of the plant's nitrogen needs can be met through biological nitrogen fixation. The term also includes any plant of the order Rosales that bears dry, dehiscent fruits.

Legumes are valued for their use in chemicals and aesthetics. They are also valued as timber, browse trees and shrubs, forage crops, cover crops, green manures, seeds, food and cooking fuel. Legumes, such as clover and alfalfa, serve as forage crop. As vegetables, peas, beans, etc., they offer a variety of protein-rich pods and seeds. Grain legumes, like soybean, offer excellent promise as an ingredient in the processed foods industry. Legumes are often grown as filler, catch or relay crops between cereal crops to enrich the soil with nitrogen, and to break the disease cycle.

The legume family contains about 650 genera and 18,000 species. In terms of sheer numbers of species and genera used by humans, legumes are by far the most utilized family. Grain legumes not only provide a variety to the human diet, they also supply dietary protein for many populations lacking in animal and fish protein. In addition, a grain legume like peanut, which fixes atmospheric nitrogen and thereby reduces the cost of nitrogen applications, is an excellent source of cooking oil, margarine and salad dressings (Fig.L.11).

Leguminosae

Leguminosae is the plant family of all legume plants.

Leguminous plants

Leguminous is a general name for plants of the pea family, the fruits of which are called **legumes** (pods). There are many economically important leguminous plants, including *Acacia*, bean, lentil, pea, *Leucaena* and soybean. The roots of leguminous plants produce nodules containing nitrogen fixing bacteria.

Lepidolite

Lepidolite, a variety of mica, is a fluorosilicate of potassium, lithium and aluminum found in pegmatites. Generally, rubidium occurs as an impurity. (See also Micas.)

LER

LER is short for **land equivalent ratio**.

Lessivage

The downward movement (**eluviation**) of clay particles from A horizon without any chemical change is called lessivage. Lessivage does not take place in calcareous soils or neutral soils because they retain a high percentage of exchangeable bivalent calcium (Ca^{2+}) ions and remain flocculated.

Lethal minimum effective dose

The minimum dose of a fungicide formulation required to provide an effective control of a pathogen is called a lethal minimum effective dose. This is a new concept adopted for the prevention of unnecessary overuse of fungicides.

Leucaena

Leucaena is a tropical plant which belongs to the family Leguminosae. It is grown widely in Asia, South America, Australia and parts of Africa for its shade and forage.

Leucaena is used as a means for forestation. It gets propagated through seeds or stems and grows very rapidly to a full grown tree. It is tolerant to a wide variety of soils.

This plant is cultivated for its value as a nitrogen supplier. Specific strains of rhizobia fix nitrogen on the root nodules and prove useful to the soil. The plant is also used as a source of green manure. Since it propagates fast, it can be grown on hilly slopes and other relatively poor soils, where it helps reduce soil erosion.

Leucaena can give yields up to 20 tons of dry matter per hectare. It is fed to cattle to increase their weight, especially in their young age. Some people are known to eat flowers and leaves of this plant.

Lewis acid

Named after an American chemist Gilbert N Lewis, Lewis acid is a compound or ionic species which can

Fig.L.11: Groundnut is one of the legumes grown largely for its edible oil (arachis oil).

accept an electron pair from a donor compound. While Lewis acids are electron pair acceptors, **Lewis bases** are electron pair donors and act as **ligands**.

$$\underset{\text{Lewis acid}}{BF_3} + \underset{\text{Lewis base}}{NH_3} \longrightarrow F_3B : NH_3$$

Lewis acids show acid effects on indicator colors and when dissolved in proper solvents.

Lewis base: See Lewis acid

Ley farming

The process involving the rotation of available crops (requiring annual cultivation) with artificial pastures (occupying the field for two or more years) is called ley farming.

Historically, ley farming was developed as an alternative to keeping a cereal crop farm fallow after harvest (for example, wheat-pasture rotation in some vast dry lands of Australia and the USA). When cereal crops were rotated with a legume crop, the legumes seemed to increase the nitrogen content of the soil. The legume crop was observed to break the pest cycle common in **volunteer wheat**. A wheat-legume farm was thus observed to reward the wheat crop. Soil erosion also reduced when ley farming thus replaced a wheat-pasture system. Wheat yields in southern Australia increased 48% and grain protein concentration increased by 2% with the introduction of ley farming.

LF

LF is short for **leaching fraction**.

LGU

LGU is short for **large granular urea**.

Lichen

Lichen is a simple slow growing plant. Characteristically, it forms a low crust-like, leaf-like, branching growth typically on rocks, walls and trees (Fig.L.12). They are composite plants comprising a fungus that has photosynthetic algal cells. Lichens get their supply of water and nutrients from the atmosphere and they may be sensitive indicators of atmospheric pollution.

Lichen is an ecologically obligate, stable mutualism between an exhabitant fungal partner and an inhabitant population of unicellular or filamentous algal or cyanobacterial cells. Lichen plays an important role in soil formation. They impart their grey, yellow or green color to the surface they cover.

The fungal partner of lichens is usually an ascomycete (sometimes a basidiomycete), the algal partner being a green (chlorophyta) or a blue-green (cyanophyta) alga. About 19% of all fungi and 42% of all ascomycota are lichenized. The number of photosynthetic partners involved in lichen formation is relatively small; out of 40 genera involved, 25 are algae and 15 are **cyanobacteria**.

Fig.L.12: Lichenized tree trunks in a forest.

The overall appearance of lichens is described as crustose (they make a thin and flat crust on the substratum), foliose (having a lobed, flat, leaf-like shape as shown in Fig.L.13) or fruticose (upright, branched forms, resembling shrubs). Lichens grow slowly from a few millimeters to several meters each year. They reproduce mostly by the development of apothecia or perithecia, forming new lichens on germination of the ascospores only in the presence of the algal partner in whose absence the fungus dies.

Nearly 700 chemicals, which are unique to lichens, help lichens to survive and ward off attacks by bacteria, other fungi and grazing herbivores.

Lichens belong to soil-crust communities and help stabilize soils, especially in desert areas. Cyanolichens

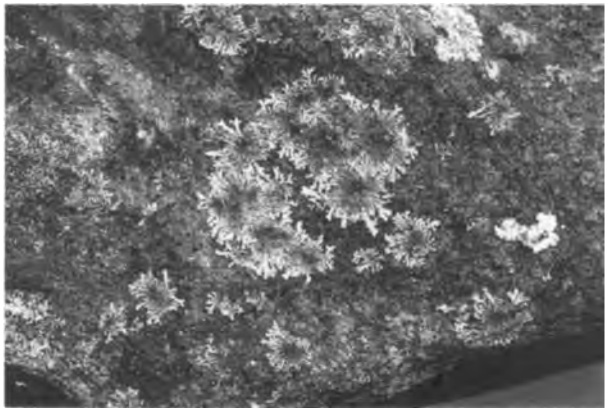


Fig.L.13: Xanthoparmelia keralensis Hale, a foliose lichen.

contribute to fixing nitrogen to the ecosystem in which they grow. Lichens are used for identifying the age of the surface (on which they grow) by a technique, called **lichenometry**.

Lichens are pollution indicators because of their differential sensitivity to sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone, as well as their ability to absorb and accumulate heavy metals and radionuclides.

Substances like pigments, toxins, antibiotics, etc. are obtained from lichens, which are especially useful as a source of dyes (for example, *Roccella*, providing litmus), medicines and perfumes. Some lichens, like Iceland moss and reindeer moss, are used as food in arctic regions.

Lichenometry: See Lichens

Liebig's law of minimum: See Law of minimum

Life cycle

Life cycle is a stage or successive stages in the growth and development of an organism that occur between the appearance and reappearance of the same organism. The life span of a plant from germination of the seed, to growth, maturation, reproduction, **senescence** and death is known as its life cycle.

Life saving irrigation

Life saving irrigation is an expression used for the irrigation provided for a dry land or rain-fed crop to save it from long spells of non-availability of moisture (moisture stress). The source of irrigation may be well water or rainwater stored in a tank near the crop site.

Ligand

A ligand, also called a **complexing agent**, is an ion or a molecule having a lone pair of electrons that can be attached to a metal atom by coordinate covalent bonding. A **Lewis base**, a compound or an ionic species which can donate an electron pair to an acceptor compound, acts as a ligand. For example, in hexaquacopper (II) ion $[Cu(H_2O)_6]^{2+}$, six water molecules coordinate to the central metal ion through lone pair of electrons on oxygen. In tetrachloroplatinate (II) ion $[PtCl_4]^{2-}$, four chloride ions are coordinated to a central Pt^{2+} ion through the lone pair of electrons of a chloride ion. The lone pair of electrons is donated to the free *d*- orbital of the metal.

Ligands donate a pair of electrons to a metal atom or ion-forming coordination complex, as for example, EDTA (ethylenediaminetetraacetic acid) does. These coordination compounds are used as fertilizers, especially as sources of micronutrients. The examples given above are of **monodentate ligands** in which there is only one point of attachment to the metal. There are also **polydentate ligands** which have two or more coordination points. For example, ethylenediamine and bipyridyl are bidentate ligands. Ethylenediaminetetraacetic acid (**EDTA**) is a **hexadentate ligand**.

Ligands can be neutral or charged molecules or atoms. Benzene and ethylene, which are neutral molecules can also act as ligands by donating the pi (π) electrons to the metal, as in the case of silver-benzene complex $[Ag(C_6H_6)]^+$.

Some of the commonly used ligands in fertilizers are **EDTA**, **EDDHA**, **DTPA** and HEDTA.

Light dependent reaction of photosynthesis

A light dependent reaction is one of the two principal reactions involved in photosynthesis, the other being the **Calvin cycle process**, also called **light independent reaction** or dark reaction. In the light dependent reaction, the sunlight is absorbed by photosynthetic green pigments or chlorophyll, and the energy is used to bring about photolysis. In this process, electrons move along the chains of electron carriers which cause a decrease in energy levels, with each move of electrons. This results in the making of adenosine triphosphate (ATP), and electrons reduce nicotinamide adenine dinucleotide phosphate (NADP). Water is split (**Hill reaction**) into hydrogen and oxygen, and the released oxygen is lost as a waste product.

Light independent reaction of photosynthesis

Light independent reaction is one of the key reactions in photosynthesis. The reaction was determined by Malvin Calvin, Benson and Bassham of the USA. Calvin discovered the sequence of compounds through which fixed carbon passed and the various stages involved therein. Calvin, investigated photosynthesis and discovered the cycle of reactions (the **Calvin cycle**) which constitutes the dark reaction.

The dark reaction does not require light, takes place in the stroma of chloroplasts, and uses the energy (ATP) and the reducing power (reduced NADP) produced during the light dependent reaction. Both the **light-dependent** and the light-independent reactions are controlled by enzymes.

Light microscope

Light microscope is a microscope in which visible light is used to illuminate the specimen (often referred to as a bright-field microscope).

Light soil

Light soil, colloquially called **Boy's land**, is easy to cultivate because its clay content is lesser than that of heavy soil.

Lignified tissue

A lignified tissue is dead xylem. Xylem has tube-like cells which carry water and ions from the roots to the leaves.

Lignified tissues form a mass of woody material like leaf veins, stems or roots in the plants, and act like a water conducting system.

Lignin

Lignin is a complex organic polymer. It is deposited within the cellulose of the plant cell walls during secondary thickening and is an important constituent of the soil organic matter (40%). It combines with holocellulose materials to help bind the cells together and direct the water flow. Its biodegradation is slow and the holocellulose content increases as the humus ages. Its main bio-degraders are the higher fungi whose maximum activity is in an aerated, slightly acid medium.

Lignin constitutes 25 to 35% of wood and is brown in color. It further darkens with age making lignin unsuitable in the manufacture of quality writing paper. Lignin is used in the manufacture of dimethyl sulphoxide, a compound that has been promoted as an effective pain-reliever and used in the treatment of ailments like arthritis, burns, toothaches, headaches and muscle strains.

Lignite

In the process of coal formation, there are various intermediate stages. These stages are referred to as the **ranks of coal**. Lignite or **brown coal** is one such rank.

Lignite is soft, brown and high in moisture content (35 to 40%). It weathers quickly, ignites spontaneously and has a low calorific value.

Coals are analyzed in two ways. The **ultimate analysis** determines the total percentage of elements present in coal. The **proximate analysis** gives an empirical estimate of the amounts of moisture, ash, volatile matter and fixed carbon in coal.

Lime

Lime is a white caustic alkaline substance. It consists of calcium oxide which is obtained by heating limestone, and has a high neutralizing value.

Lime chlorosis

There are many factors that prevent the formation of chlorophyll. Some of them are insufficient light, magnesium and iron. The formation of chlorophyll is also hindered by the excess of calcium carbonate in the soil. Such a condition is called lime chlorosis or lime induced chlorosis.

Lime determination, Drouinean method for: See Drouinean method for active lime determination

Lime nitrate

Lime nitrate is another name for calcium nitrate. (See also Calcium nitrate.)

Lime pan

A horizon enriched in calcium carbonate is known as a lime pan.

Lime requirement

Lime is required to neutralize soil acidity. The lime requirement is defined as moles of Ca^{2+} charge (limestone) per kilogram of the soil needed to decrease the soil acidity to an acceptable level for agricultural use, and is expressed as mole per kg. Its value is somewhere between the salt-replaceable acidity value and the **cation exchange capacity** (CEC) of the soil, measured with a buffered barium chloride ($BaCl_2$) solution.

The lime requirement is determined by the soil, its clay content and organic matter, and the scope it has of leaching with fresh water. This requirement is also determined by proton inputs from acidifying fertilizers and acid deposition. The soil acidity and the lime level have a fairly good correlation in temperate humid regions, so that the pH of the soil can be used as an index of the differing lime needs for various crops.

The measurement of lime requirement is done by various methods. Some of the methods are (a) field application of calcium carbonate ($CaCO_3$) (which takes many years to achieve a steady state), (b) incubation of soil samples with $CaCO_3$ (which takes months to complete), (c) soil titration with calcium hydroxide, $Ca(OH)_2$, (which takes many days), and (d) effect quick soil equilibrations with buffer solutions optimized for a given group in the given agricultural soils. The final choice of the method depends on the number of soil samples to be analyzed and the required accuracy.

The **Schomaker-Mclean-Pratt (SMP) buffer** consists of p-nitrophenol-triethanolamine-potassium chromate-calcium acetate and calcium chloride buffer, adjusted to pH 7.5 for which sodium hydroxide has been soil scientists' most preferred choice.

In tropical and sub-tropical humid low lands (oxisols and ultisols), the percentage of exchangeable aluminum is also used to determine the lime requirement.

Lime saltpeter

Lime saltpeter is also called calcium nitrate. (See Calcium nitrate.)

Limestone

Limestone is a hard sedimentary rock, consisting mainly of calcium carbonate or magnesium carbonate (dolomite). Limestone is the largest source of the element carbon at or near the Earth's surface. Limestone is most commonly used for liming and is also used as the reference material to evaluate the effectiveness of all other liming materials.

Limestone deposits are mined by the open pit method. Generally, 8 to 10 mesh material is considered desirable for soil application. The finer the limestone, the faster it reacts in neutralizing soil acidity.

Limestone has two origins, namely, autochthonous and allochthonous. **Autochthonous limestone** has been formed in place by biogenic precipitation from seawater while **allochthonous** limestone has been transported from the site of its original precipitation by the action of water current.

Some kinds of limestone (such as chalk) are soft but some others are hard that are used in the construction industry, as building material or in making cement.

When limestone is heated to around 1000°C, the calcium carbonate will dissociate and form carbon dioxide and lime. This lime is used in agriculture and in the manufacture of glass. Phosphate-rich limestones found in ocean waters form the raw material for many fertilizers.

Liming

The process of neutralizing soil acidity to the required level is called liming. Calcium carbonate, the most commonly used liming material, is a naturally occurring white solid, sparingly soluble in water.

Liming index

The liming index or the **acidity index** represents the base saturation which means the extent to which the material is saturated with exchangeable cations (other than hydrogen) as the percentage of the cation-exchange capacity.

Liming materials

Materials generally used for liming the soil are oxides, hydroxides, carbonates and silicates of calcium and/or magnesium. The accompanying anion must lower the hydrogen ion (H^+) activity and hence the trivalent aluminum (Al^{3+}) in the soil solution.

$$CaCO_3 + H_2O \longrightarrow Ca^{2+} + HCO_3^- + OH^-$$

Neutral salts, like gypsum, cannot neutralize hydrogen ion (H^+).

$$CaSO_4 + 2H_2O + 2H^+ \longrightarrow Ca^{2+} + 2H^+ + SO_4^{2-} + 2H_2O$$

A liming reaction starts with neutralization of hydrogen ion (H^+) in the solution by hydroxyl or bicarbonate added through the liming material. The continued removal of H^+ from the soil solution ultimately results in the precipitation of trivalent aluminum and iron as hydroxides and their replacement on the cation exchange complex by calcium and magnesium ions (Ca^{2+} and/or Mg^{2+}).

Liming materials used for correcting the acidity of soils are also called **agricultural lime**. The choice of the liming material is dictated by its cost, relative purity, ease of handling and efficiency to neutralize soil acidity.

Calcium oxide, known as **lime**, is a white powder with a neutralizing value, expressed as the calcium carbonate equivalent (CCE) of 179% (that of calcium carbonate being 100%). For quick results either calcium oxide (CaO) or calcium hydroxide [Ca $(OH)_2$] is used.

Calcium oxide is also known as **unslaked lime**, **burned lime** or **quicklime**. It is obtained by roasting calcium carbonate in a furnace. Often it cannot be completely mixed with soil because it absorbs water which causes it to cake.

Calcium hydroxide, also known as **slaked lime**, **hydrated lime** or **builders' lime**, is a white powder with a neutralizing value (CCE) of 136%. It is made by hydrating calcium oxide. Being highly hygroscopic, CaO gets converted to calcium hydroxide [Ca $(OH)_2$] before it can completely mix with soil.

Calcium carbonate and magnesium carbonate are common liming materials. Calcium carbonate or calcite or limestone is mined by the open pit method. Calcium-magnesium carbonate or dolomite has a neutralizing value of 70 to 109%. The degree of impurities reduces the neutralizing values of limestone and other liming materials. Marls which are soft and unconsolidated deposits of calcium carbonate often mixed with earth, have a neutralizing value of 70 to 90% depending on the clay content.

Blast furnace slag ($CaSiO_3$) is a by-product in the manufacture of pig iron. It has a neutralizing value of 75 to 90% and contains an appreciable amount of magnesium. **Basic slag** is a by-product of the open-hearth method of making steel from pig iron. In addition to its phosphorus content, the basic slag has a neutralizing value of about 60 to 70%. It is used because of its phosphorus content rather than as a liming material, particularly in saline-alkali soils. **Electric furnace slags**, which are produced by the reduction of rock phosphate in an electric furnace while preparing phosphorus, and in the manufacture of pig iron and steel, contain 0.9 to 2.3% phosphorus (P_2O_5), with a neutralizing value (CCE) ranging from 65 to 80%.

Linde ammonia concept of ammonia production:

See Ammonia production processes

Linear response

Linear response or **direct response** is indicated by an equation between two variables which give a straight line graph. It has the following general form:

$$y = m x + c$$

where m is the slope of the line, c is the intercept of the line on the y-axis, y is a dependent variable and x is an independent variable.

For example, a calibration in atomic absorption spectroscopy for the estimation of a plant nutrient can be obtained from the measured values of absorbance (y axis), which are determined by using a known concentration of the metal standards (x axis).

To obtain the regression line 'y on x', the slope of the line (m) and the intercept (c) are given by the equation:

$$m = \frac{n \Sigma x_i y_i - \Sigma x_i \Sigma y_i}{n \Sigma x_i^2 - (\Sigma x_i)^2}$$

$$c = \bar{y} - a \bar{x}$$

where $\bar{x}$ is the mean of all values of x_i, $\bar{y}$ is the mean of all values of y_i and a is the constant.

Electrical conductivity (EC) of the soil water extract has a linear response (Fig.L.14) with ions (like sodium, potassium, etc.) present in the soil. With an increase in the salt concentration of the soil, the osmotic pressure of the soil increases.

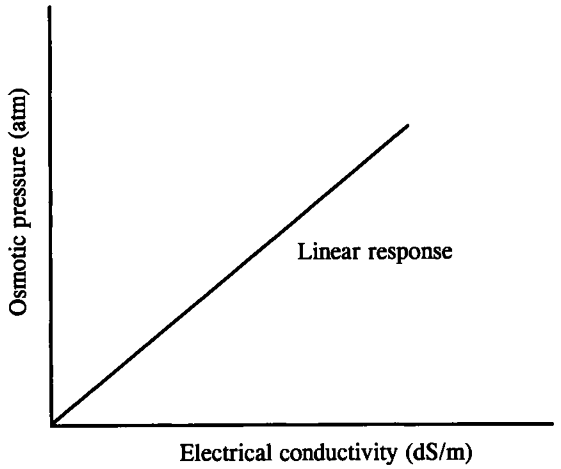


Fig.L.14: Linear response of EC of soil water extract against osmotic pressure.

Lipids

Lipids, diverse group of organic compounds in living organisms, are insoluble in water but soluble in organic solvents such as chloroform, benzene, etc. Lipids are present in all living cells, but their proportion varies from tissue to tissue.

Lipids are broadly classified as **complex lipids** and **simple lipids**, the former being the esters of long chain fatty acids (like glycerides, glycolipids, **phospholipids** and waxes), and the latter being devoid of fatty acids and inclusive of steroids and terpenes.

Lipids have a wide variety of functions in living organisms. Fats and oils are convenient means of storing food energy in plants and animals. Triglycerides accumulate in certain areas, such as adipose tissues in human beings and in plant seeds, where they represent a form of energy storage. Phospholipids and sterols (such as cholesterol) are major components of cell or plasma membranes. Waxes provide vital water proofing for body surfaces. Terpenes include vitamins A, E and K and phytol; the latter is a component of chlorophyll and occurs in essential oils such as menthol and camphor. Steroids include adrenal hormones, sex hormones and bile acids.

Lipids can combine with proteins to form **lipoproteins** (like cell membranes in bacterial cell walls), and may associate with polysaccharides to form **lipopolysaccharides**.

Lipophitic

Lipophitic substances are non-polar substances having affinity with oils and are soluble in oils or other non-polar solvents.

Lipopolysaccharides: See Lipids

Lipoproteins: See Lipids

Liquid

Liquid is an amorphous (non-crystalline) form of matter intermediate between gases and solids in which the molecules are much more highly concentrated than in solids. Liquids take the shape of their containers but have fixed volume at a particular temperature and are incompressible.

Liquid molecules are free to move within the limits set by intermolecular attractive forces. At the air/liquid interface the vibration of the molecules causes some of them to be ejected from the liquid at a rate depending on the surface tension. The tendency of molecules to escape from a liquid surface is called **fugacity** and is largely responsible for evaporation. When the air space is restricted, the escaping molecules eventually saturate the air and thus the number of molecules leaving the liquid is equal to those returning to it as a result of molecular attraction. In these circumstances, the liquid/air system is said to be in equilibrium.

Liquids vary greatly in viscosity, boiling point, vapor pressure and surface tension. Mercury has a specific gravity of 13.6 and the highest surface tension of all liquids. Glass has the highest viscosity. Polar liquids are those where molecules have opposite electrical charges on their terminal atoms or groups, which impart a force called **dipolemoment**. Water is a polar liquid with high dielectric constant. Pure hydrocarbon liquids are generally non-polar.

Liquid coating agents

One of the techniques of preventing caking in fertilizers is to coat them with a substance that is a liquid or very finely divided inert powder. The liquid coating agents, which are sprayed onto the surface of fertilizer particles, are organic surfactants or non-surfactants. They usually function as a crystal modifier to inhibit or weaken the crystal growth and/or as hydrophobic barriers for absorbing moisture.

Liquid fertilizers

Commercial fertilizers are available both as solid and liquid. Liquid fertilizers or **fluid fertilizers** are of two types. In one, the components are in a clear solution form while in the other, the solids are held in suspension by adding a special kind of clay which stabilizes the suspension, and delays its settling.

The main ingredients of liquid fertilizers are anhydrous ammonia, aqua ammonia, non-pressure nitrogen solutions (like that of urea-ammonium nitrate, for nitrogen supply) and ammonium polyphosphate, which is an important source of phosphorus. (10-34-0 is the common grade). Potassium chloride is used to supply potassium. Much of the sulphur used in liquid fertilizers is added as ammonium thiosulphate solution.

Liquid fertilizers (Fig.L.15) are cheap and simple to make, store, transport and handle (by pumping). They can be applied by the farmer far more easily than solids, as these are easily sprayable at a specific place in the field with an applicator. Liquid fertilizers can be exactly and uniformly metered out in a liquid form even at low rates of nitrogen (15 to 30 kg/ha). They can be applied along

Fig.L.15: Liquid micronutrient fertilizers (Courtesy: Institute for Micronutrient Technology, Pune, India).

with irrigation water in drip feeds (a method known as **fertigation**) and as foliar sprays. The production of liquid fertilizers costs lesser than solid fertilizer.

Liquid fertilizers can be easily mixed with a variety of micronutrients and agricultural pesticides. The dissolution of micronutrients in a clear fertilizer is promoted by gelatinizing agents or by complexing them with polyphosphates. The pulverized addition, for instance, of copper sulphate, sodium molybdate, sodium borate, zinc oxide or manganese oxide to water can give a suspension for spraying.

Non-pressurized liquid fertilizers are generally stored in concrete or mild steel tanks. An inhibitor that resists corrosion is required in the case of a non-pressurized urea-ammonium nitrate solution. The tanks can be lined with a film of polyvinyl chloride. For pressurized liquid fertilizers, double-walled vessels with 'a leak warning system' are recommended.

A liquid fertilizer plant is classified according to the type of operation - whether hot mix or cold mix. A hot mix plant uses phosphoric acid and ammonia, the term "hot" because of the heat of reaction generated in the process. A cold mix plant mixes ammonium phosphate solution with other ingredients and no heat of reaction evolves. The cold mix plant is simple and inexpensive as the process involves a blending and a mixing operation. The hot mix plant combines the neutralization and mixing processes, and calls for additional cooling to avoid ammonia loss from the mix which can reach temperatures as high as 100°C.

The demerits of liquid fertilizers are that they are often corrosive, have a lower nutrient content because of their diluted form. They are sensitive to impurities, to precipitation and crystallization especially caused by magnesium and fluorine at lower temperatures or in cold weather. They are expected to take a prominent place in the world of fertilizers, especially as more and more agricultural services and meteorological data become available.

Liquid inoculant

Liquid inoculant is a liquid culture diluted for use and stored at 4°C. As *Rhizobium*, *Azotobacter*, etc. have poor survival rate on the seed, the liquid inoculant can be added to the seed before planting or directly applied in the seed row.

Liquid limit

If clay is moistened till it flows by itself and then allowed to dry progressively, it will move from the liquid stage to a plastic stage. The plastic stage will allow the clay to be moulded to retain its shape. This means that it passes from the liquid limit to the **plasticity limit**. The difference between the two limits is the plasticity index of clay, which is very important in evaluating the soil for agriculture.

Liquid manure

Liquid manure contains urine and dung liquor draining from farm stables and sheds. It contains valuable nitrogen and potash.

Liquid nitrogen fertilizers

Liquid nitrogen fertilizers are nitrogen fertilizers in liquid form which are usually less concentrated than those in the form of granules, powder or crystals. A solution of urea and ammonium nitrate, also called **UAN solution** or **URAN** solution, contains 25 to 30% nitrogen and is often used for top dressing, particularly on grassland and winter cereals. Aqua ammonia and pressurized anhydrous ammonia are among the other liquid nitrogenous fertilizers.

The use of nitrogen solutions has been constantly on the rise. This is because they can be (a) handled and spread more uniformly and accurately than solid nitrogen fertilizers, (b) simultaneously applied along with pesticides, (c) applied through various types of irrigation systems, (d) safely transported in pipelines, etc., (e) produced and stored economically, (f) used in formulations with fluid P, K and S fertilizers, and (g) used more safely than solid fertilizers.

LISA

LISA is short for **low input sustainable agriculture**.

Lister

Lister is a modified form of plow bottom which, in effect, is a right and a left moldboard joined at the shin so as to throw the soil both to the right and to the left. This produces a furrow or trough, in which the seeds are sown. Such furrows are known as lists.

Lithosequence

A complex unit of soils, the succession of which is constantly found in a defined order without any apparent generic link between them, is called a **soil sequence**. The sequences are named based on the predominant pedogenic factor causing the differentiation. The differentiation caused by the original material is called the lithosequence.

Lithosols

Lithosols (according to FAO-UNESCO system of soil classification) refers to a thin soil comprising mainly freshly and imperfectly weathered rock fragments. It is an azonal group of soils having an incomplete solum or poorly expressed soil morphology.

Lithosols are also defined as soils with very weak differentiation of generic horizons and whose solid and continuous parent material is found at less than 30 cm depth.

Little leaf

Little leaf refers to **zinc deficiency** in cotton.

LMR

LMR is short for **land man ratio**.

Loams

Loams are fertile soils made up of organic matter mixed with clay, sand and silt almost in equal proportions. It is a class of mineral soils containing 7 to 27% clay, 28 to 50% silt and less than 52% sand. The ratio of the constituents in the loams determines the types of plants they can support.

The **textural triangle** (as shown in the **soil texture**) is used to determine the soil textural nomenclature after the percentages of sand, clay and silt are known from laboratory analyses. In classifying and mapping the soil, the names of the fragments precede the textural name of the soil. For example, if a sandy loam contains over 20% gravel, the textural name becomes 'gravelly sandy loam'; if it contains more than 50% gravel of the soil weight, it is known as 'very gravelly sandy loam'. (See also Silt loam; Soil texture.)

Loamy sand classes

Loamy sand classes are soil textural classes, depending on the sand content of the soil. The feel of the loamy sand class of soil which does not stick to the fingers is said to be very gritty.

Loamy soil

Loamy soil is a medium-textured soil containing approximately 25% clay, 35% silt and 40% sand.

Localized placement

Localized placement is a method of applying a fertilizer. It is resorted to when the fertilizer is employed in small quantities. The fertilizer is placed along with, or close to the seeds or the plants.

Localized placement is executed through any of the following ways: (i) Contact placement. (ii) Drill placement. (iii) Band placement. (iv) Row placement. (v) Pellet placement.

Localized placement is generally useful for phosphorus and potassium, as these are relatively immobile and most crops need them early in the season and during the reproductive growth stage.

Contact placement refers to the combined application of seed and small quantities of fertilizer. This method is useful for applying phosphatic and potassic fertilizers to wheat, barley, sorghum, pearl millet, cotton and grasses. However, young plants can get damaged owing to excessive concentration of the fertilizer. For rain-fed areas, drilling of nitrogenous fertilizers is better than broadcasting or foliar spraying. Combining the drilling application of the fertilizer and the seeds is not advisable for pulses and legumes.

In **band placement**, the fertilizer is placed in bands. There are two types of band placements, namely, the **hill placement** of fertilizers and the **row placement** of fertilizers. In hill placement, fertilizers are placed close to plants which are arranged on both sides of the bands, keeping a distance of about 1 meter between them. The hill placement method is suitable for nitrogenous and phosphatic fertilizers. This method is adopted in the case of orange, banana, papaya, apple, pear, coconut, cashew and other fruit trees, and also commonly employed by vegetable growers. The row placement, in which the fertilizer is placed on one or both sides of the crop rows, is suitable for sugar cane, potato, maize, tobacco, cotton, cereals and vegetables. A higher rate of application is possible with row placement than with hill placement.

In **pellet placement**, the nitrogenous fertilizer in the form of pellets is applied between the two rows of paddy crops. The fertilizer is mixed with the soil in the ratio of 1:10 and applied as small pellets.

In the **side dressing** method, fertilizers are spread between the rows or around the plants. Localized placement is more important with phosphorus and potassium than with nitrogenous fertilizers.

Lodging

Lodging is the bending and breaking of stalks from their normal upright position. The single most important obstacle to increasing the yield of many cereal crops is their susceptibility to lodging. The morphology of most cereals is such that the grain-bearing organs are found at the top of the stem, which place a strain on the stalk to support the weight of the grain, especially in high winds or wind driven rains. The degree of stem lodging (that is, the angle at which stems deviate from being perpendicular) can vary from slight slanting to lying flat on the ground.

Lodging can occur at any stage of the plant development. If it occurs at the seedling or the vegetative stage, the plants may regain their upright position – a negative geotropic response – resulting in goose-necking or a curvature of the lower stems.

Lodging, which results in the loss of yield if it occurs while the crop is actively producing photosynthates for vegetative or reproductive development, disrupts the highly organized plant leaf canopy, culminating in greater mutual shading, and reduced air movement and carbon dioxide supply.

Lodging occurring at maturity, results in a 10% greater reduction in the average yield than that occurring 15 to 20 days after heading.

Some indirect yield losses also occur as a result of the lodged grain at harvest time (Fig.L.16). This happens because the lodged grains provide a resting place for birds and a habitat for rodents. Lodging also leads to restricted air movement which results in premature seed sprouting and decay on coming in contact with the soil. This leads to the grains getting wet, and a poor quality grain yield. The wet grain that cannot be stored without supplemental drying has a lower value due to its poor quality.

Fig.L.16: Lodging in rainfed sorghum at harvesting.

If lodging occurs when plants are metabolically active, apical dominance may be destroyed and late tillering may occur, especially if the disrupted leaf canopy allows sunlight to strike the basal nodes. The losses from lodging in terms of quality and yield of grains are often extensive.

Lodging is sometimes described as an 'abundance disease', meaning that it may occur under highly productive environmental conditions, thereby restricting the exploitation of the otherwise yield-promoting factors.

Three types of lodging can be identified: (i) Bending of stems at the base. (ii) Breakage of stems at any point along their length. (iii) Root lodging.

Lodging may be caused by (a) physical forces exerted by wind, rain or hail, (b) insects damaging and weakening the roots and stems, (c) diseases, (d) fertility imbalance such as inadequate potassium relative to nitrogen, (e) high yields in association with plant population, (f) herbicide damage, and genetic weakness.

Finally, lodging creates a very real barrier to the production of high grain yield and represents a severe limitation to increasing the yield potential. Breeding and management practices must be combined to help reduce the lodging problem.

Loess

Loess, transported and deposited by wind, is the soil material finer than sands and covering land areas. A loess can cover land surface from a few meters to several hundred meters. Loess is characterized by a neutral pH, and well-balanced clay and organic matter.

Loess soils are a type of aeolian soils. Loess soils are unconsolidated, unstratified, calcareous and rich in plant nutrients. They are productive and have unusual properties, in that they (a) are open and porous, (b) have vertical cuts making them fairly stable, and (c) can prevent problems like the formation of sinkholes, cavities and subsurface channel cutting, when used for earthen dams.

Its main components are quartz, feldspar, calcite and clay mineral.

There are large areas covered by loess soils in the USA, China, Germany and Argentina.

Long dung

The decomposed mixture of dung and urine of farm animals along with litter and leftover materials from roughage or fodder is called **farmyard manure** or long dung.

Long grain rice

Long grain rice is a rice classification based on the grain length. Broadly, there are long grain rice, **medium grain rice** and **short grain rice**. Long grain rice is called so since it is much longer than its width. This popular rice becomes fluffy and dry with separate grains. Some varieties have a rich aroma. Many varieties of long grain rice have been cultivated in India for centuries. In the USA, long grain rice varieties account for three-fourths of the domestic rice crop.

Longitudinal dunes: See Dune

Loose pour bulk density

There are two types of bulk density, namely the loose pour and the tapped. The loose pour bulk density is the mass per unit volume of a substance after it is tipped freely into a container under clearly specified conditions. It gives the minimum density (meaning, the greatest volume) expected. The loose pour bulk density values are useful in designing equipment and containers of the correct size.

Loose smut: See Wheat – common diseases

Lo Trau

Lo Trau is a Vietnamese word (*Lo* meaning stove and

Trau meaning rice hull) which means a rice-hull fired stove. A *Lo Trau* is used for cooking.

Rice hull, a natural by-product of rice harvest, is used as an alternative fuel generating 3240 kcal/kg rice hull in a *Lo Trau*.

Lo Trau is a wide-mouthed pan fitted on three support brackets. This main body has an inner body which has two drums. Fine soil is filled in between the two drums to provide the required insulation (Fig.L.17).

Fig.L.17: A picture of a typical Lo Trau stove. Courtesy: "A Guide to Savant's Integrated Rice Agrotechnology", 2001. Narayan K. Savant, Continental Prakashan, Pune, India.

Rice hull can be filled evenly between the inner body and the main outer body with enough space (about 2 cm) between the lower rim of the inner body and wall of the main outer body, to allow the hull to descend easily. The hull may be ignited with the help of a piece of burning paper. Care should be taken to ensure a steady flow of hull in the combustion chamber and on the ash holder along with proper ventilation. A medium-sized *Lo Trau* requires about 1.5 kg of dry rice hull for one hour of cooking.

According to an estimate, a medium hull-fired stove used to feed five to six persons of a family can save about 2 tons of firewood every year. Thus, use of such stoves on a wide scale can slow down the rate of degradation of forests. Such a method of cooking helps generate **rice hull ash** which is very beneficial for incorporation into a seedbed before sowing the rice seed.

Low density polyethylene: See LDPE

Low humic gley

The soil order inceptisols was earlier known as low humic gley in the USA.

Low input sustainable agriculture

Any system of farming which attempts to maximize outputs by keeping the cost low is called low input sustainable agriculture or **LISA**. Organic inputs are abundantly used under LISA and hence the two systems LISA and **organic farming** are similar.

But LISA differs slightly from organic farming. Although the two farming systems depend predominantly on natural and biologically available inputs, LISA does so to keep the costs of production low, whereas the organic farming system does so because it does not believe in using synthetic inputs.

Hence, LISA will use easily available environmentally friendly material like compost, animal manure, bio-fertilizers, rock phosphates, green manure, etc. Crop rotation is routinely practiced, with legumes as one of the crops for regular nitrogen supplies. Farmers advocating this low input farming generally mix certain crops in their farms to break pest cycles and certain weeds. LISA does not exclude synthetic fertilizers. However, they are used in moderation and only where necessary because the focus is to keep energy cost low. The rationale is that expensive mechanized tillage, major irrigation systems and aerial spraying of pesticides and fertilizers increase costs substantially, but may not guarantee commensurate returns. LISA followers believe that although yields may be moderate, a low cost structure can still ensure greater profits.

LISA attempts to synthesize the best management practices carried out in organic farming and select practices of modern agriculture.

Lowland rice

Lowland is a low-lying land in a region or district as distinct from hill areas and mountains. Rice grown under almost continuously flooded conditions is known as lowland rice, since rice is essentially a hydrophyte.

Low soil

A soil with $pH > 4$ is called low soil. Low soil affects root growth. Soil with $pH > 5$ suppresses bacterial life and favors fungal life.

LR

LR is short for **leaching requirement**.

Lupini rhizobia

Lupini rhizobia are one of the slow growing strains of rhizobia. (See also Rhizobia.)

Lurgi method for coal gasification: See Ammonia production processes

Luvisols

Luvisols is one of the 106 soil units according to the FAO-UNESCO legend. These are moderately developed soils from temperate regions. Luvisols have an argillic horizon with a base saturation of at least 50% in the lower part of the B horizon at less than 125 cm depth. The cation exchange capacity of these soils [as determined by 1M ammonium acetate (NH_4OAc), pH 7] is equal to or more than 24 moles per kg of clay throughout. There is no E horizon with abrupt transition to a poorly permeable horizon or signs of redistribution of clay or penetration of tongues, which are diagnostic of **planosols**, nitisols and podzoluvisols, respectively.

These soils have an accumulation of clays in its subsurface levels. Luvisols cover about 650 to 700 million hectares of total world land area which include the Mediterranean region. They are also found in varying proportions in North America, South Africa and Australia. Luvisols may be haplic, chromic, calcic, vertic, albic, stagnic or gleyic.

Luxury consumption

The absorption of potassium (or any other nutrient) in excess of that required for optimum growth, results in accumulation of the nutrient without a corresponding increase in the plant growth. Such an uptake is known as luxury consumption. It is a waste from the farmers' point of view.

L value

The quantity of isotopically exchangeable phosphorus, utilized by a growing plant over the span of a growing season, is called the L value. The E value is the laboratory equivalent of the L value, measured over a shorter but specified period of equilibration.

Lyophilic colloids

Lyophilic colloids go into colloidal suspension in a liquid. The colloid is stabilized by the formation of an adsorbed layer of molecules of the dispersing medium about the suspended particles. If the liquid is water, it is called hydrophilic. Glue, gelatin and milk fat are examples of lyophilic colloids. (See also Hydrophilic colloids.)

Lyophilization

Lyophilization or **freeze-drying** is a technique of end product recovery and a means of preserving cultures of various micro-organisms. In this technique, water is removed under vacuum while the tissue remains in the frozen state at ultra low temperatures.

A preparation of micro-organisms produced by freeze-drying is known as a **lyophilized culture**. *Rhizobium, Azotobacter, Azospirillum*, etc. can be maintained as lyophilized cultures for long periods.

Lyophilized culture: See Lyophilization

Lyophobic colloids

Colloids are either lyophilic or lyophobic. Lyophobic colloids exhibit little affinity between the dispersed phase and the solvent, whereas lyophilic colloids are strongly associated with the solvent. They are called **hydrophilic colloids** when water is the dispersion medium, and **hydrophobic colloids** when their dispersion requires application of mechanical or electrical forces to give a suspension.

Colloidal gold or colloidal arsenic sulphide are examples of lyophobic colloid.

Lyotropic series

Cations are held on the exchange sites with different adsorption strengths. The ease with which these elemental ions can be replaced or exchanged varies in the order $Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+}$. This series is known as lyotropic series.

Lysimeter

Lysimeter is a simple instrument for measuring water movement, gains or losses through the undisturbed block of soil. A lysimeter is used for estimating evapotranspiration. It consists of an oil drum 58 cm in diameter, placed into a collection chamber. The drum is filled with soil over a layer of gravel to facilitate drainage, and grass is grown in it. The soil is kept at field capacity by supplementing the rainfall with daily irrigation from above.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

M

Machinery costs

Generally, machinery costs comprise two components: (i) **Fixed costs**, which include depreciation, interest costs, investment, taxes, shelter and insurance. The fixed costs accrue whether the machine is used or not. These are the costs of ownership. Each fixed cost is estimated based on a financial or calendar year. (ii) **Variable costs** include the money spent on repairs, maintenance, fuel and labor. Variable costs are incurred only when the machinery is used.

The knowledge of the use of annual machine-hours is necessary to obtain the total annual cost.

Obviously, the following are some of the factors that can help to keep the costs to the minimum and they are (a) full utilization of the machine-width and the machine-time, (b) reduction in the original investment, and (c) increasing the service life of the machine.

Macro and micro elements, interaction of

Macro and micro nutrient elements, applied in a balanced proportion, are necessary for maintaining soil fertility and crop productivity.

The absorption of nutrients by the crop from the soil mass depends on the actual level of nutrients in the available form, their translocation from the roots to the leaf organ, and the metabolic changes taking place in the active tissue. The process of nutrient absorption is affected by the type of interaction that takes place between two or more nutrient elements, both in soil and the plant tissue, (e.g., among macro elements, micro elements or between macro and micro elements).

In the interaction between any two essential elements, one element may have an effect on the crop absorption of the other element. The response of the crop may be good, fair or even negative. For example, when zinc and phosphate are added to soil separately, the combined effect on the crop is quite different from that when the two elements are added together. The magnitude and the nature of the effect depend on the proportion of the mix of the two elements applied to the soil.

Interactions of some micronutrients with elements in the soil or in the crop can be summarized as follows: (i) Boron interacts with nitrogen, phosphorus, potash, sulphur, calcium, magnesium, zinc, iron, manganese, copper and molybdenum. (ii) Copper interacts with nitrogen, phosphorus, sulphur, zinc and molybdenum. (iii) Iron interacts with phosphate, potash, sulphur, manganese, zinc and nitrogen. (iv) Manganese interacts with phosphate, iron, zinc and potash. (v) Molybdenum interacts with phosphate, sulphur, zinc, iron and copper. (vi) Zinc interacts with phosphate, potash, calcium, magnesium, molybdenum, sulphur, boron and iron.

Factors influencing the above mentioned interactions are (a) lime status of soil, (b) organic carbon level in soil, and (c) fertilizer dose, pH and chemical nature. The intensity, efficiency and nature of microbial activity in the soil, and the soil moisture status also influence the interaction between two elements. The interaction, whether positive or negative, influences the growth rate of the crop and ultimately the crop productivity in the said soil. Scientific agriculture has to consider the positive and negative effects of the interactions on both the soil and the crop, and accordingly modify management practices.

The application of (a) Mn, Zn and Cu has an adverse effect on the absorption of Fe, (b) Ni, Zn and Cu produce adverse effect on the absorption of Mn, and (c) Zn and Cu has an adverse effect on each other all the time.

In all the three cases, what is considered the effect, is exhibited only when two specific elements interact. In soil, however, all essential elements are present in their available form, to which are added a few elements through fertilizers. This leads to a complex interaction between the available and added elements. When bulky organic manures are applied along with essential nutrients, the effect of the interaction between different elements gets modified due to chelation; its impact on nutrient uptake and the crop yield vary considerably, depending upon the management practices adopted. Today, micronutrients are sold in multiple combinations either in simple or chelated form. Further, major nutrients like N, P and K are also sold in the form of mixtures, compounds or complex forms. In this situation, the interaction between macro and micro elements is bound to be quite different, and it may be very complex in certain situations. The change in the crop yield level caused by the application of different nutrient elements is to be understood on the basis of the above situation.

All management practices involving irrigation, fertigation, soil and the crop species influence the nature of interaction, and ultimately affect the crop yield and the crop quality.

Macromolecule

Macromolecule is a molecule, usually organic, composed of an aggregation of hundreds or thousands of atoms. Such giant molecules are, in general, of two types: (a) individual compounds that cannot be subdivided without losing their chemical identity. Proteins, which have molecular weights running into millions, is an example of this class, and (b) combinations of repeating chemical units, called **monomers**, linked together into a chain or network structures, called polymers. Each monomer has the same chemical constitution as the polymer, for example, ethylene (C_2H_4), and polyethylene (C_2H_4). Synthetic elastomers are typical of this kind of macromolecules; cellulose is the most common example found in nature. Most macromolecules are in a colloidal size range.

Macronutrients

Macronutrients or **major nutrients**, namely, nitrogen, phosphorus, potassium, calcium, magnesium and sulphur are required by plants in relatively large amounts as compared to micronutrients. Macronutrients are further classified into **primary nutrients** and **secondary nutrients**. Primary nutrients include N, P and K which are most commonly applied to almost each crop, except where organic farming is practiced. On average, most plants contain N, P and K in the ratio of 2:0.44: 0.83 (or N: P_2O_5: K_2O= 2: 1: 1).

Macropores

Pores are the openings in the soil; large pores with an average diameter of around 5 mm are called macropores. They are often created by faunal and root activity, and they drain at field capacity.

Magnesia

Magnesia is a term used for magnesium oxide (MgO). **Magnesite**, **caustic-calcium magnesite**, **dead-burned magnesite** and **synthetic magnesite** are also loosely used as synonyms for magnesia.

Magnesite

Magnesite is a white, colorless or grey mineral containing 40 to 45% MgO, and is mostly magnesium carbonate in the trigonal system. It is used in the manufacture of magnesium sulphate and directly as an amendment for acid soils.

Magnesite is formed as a replacement mineral of magnesium-rich rocks when carbon dioxide is available. Magnesite and the terms **caustic-calcined magnesite**, **dead-burned magnesite** and **synthetic magnesite** are loosely used as synonyms for **magnesia**.

Magnesite is mined both as an ore for magnesium and as a magnesium source. It occurs in Austria, Greece, Norway, India, Australia, South Africa and the USA. It is resistant to molten metal and basic slags, and is used in open hearth furnaces, electric steel furnaces, copper and nickel converters, refining industries and other metallurgical industries. It is used directly on soils for neutralizing soil acidity, or in the preparation of magnesium sulphate which is used as a secondary nutrient.

Magnesium

Magnesium (Mg) is an essential element for plant and animal growth. It belongs to Group 2, and has an atomic weight of 24.32 and atomic number of 13. Its position in the Periodic Table is shown in Fig.M.1.

Magnesium is the eighth most abundant element in the earth's crust. It is made by electrolysis of fused magnesium chloride taken from sea water. Magnesium is a light, silvery-white, hard, reactive metal. It plays a crucial role in the life of both plants and animals. Magnesium and its compounds are also used in light metal alloys, incendiary devices, flash bulbs, flares, fertilizers and in medicine.

Fig.M.1: Position of magnesium in the Periodic Table.

Magnesium is a constituent of chlorophyll, protochlorophyll, pectin and phyllis. While its role in plant metabolism is not very clear, it seems to perform many functions in plants. For example, as the only metallic constituent of chlorophyll, Mg gives green color to leaves and has the structure of hemoglobin. It plays a role in photosynthesis, forming hexose sugar from water and carbon dioxide in the presence of sunlight. Magnesium regulates the uptake of other materials by the plant, and acts as a carrier of phosphorus to the seeds in the plant. Mg promotes the formation of oils and fats. It plays a role in the translocation of starch. Almost the whole of magnesium dissolves in the cell sap of the plant and becomes readily mobile in the plant. Many important colloidal chemical functions are ascribed to this fraction of magnesium.

Magnesium also participates in the production of proteins, fats, vitamins and some catalytic reactions in the enzyme system. It is mobile in plants and serves as a structural component in the ribosome, playing an important role in protein synthesis.

The above ground portion of most mature grain crops and grasses contain about 0.1 to 0.4% of magnesium, whereas that of cotton, soybean and alfalfa plants contain 0.3 to 0.6%. Plants absorb magnesium as a divalent cation (Mg^{2+}). Its absorption depends on many factors, such as the amount of solution Mg^{2+}, the soil pH and type, the percentage of Mg saturation on the cation exchange complex (CEC), and quantities of other exchangeable ions. Many soils absorb magnesium in a non-exchangeable form ($MgCO_3$). Nitrate ions promote its absorption, whereas the ions of ammonium, potassium and calcium ions restrict it.

Plant species and varieties differ in their magnesium requirement. For instance, corn, potato, oil palm, cotton, citrus, tobacco, sugar beet and pastures respond to a high magnesium content. Seasonal and environmental conditions interact with plant varieties for magnesium uptake and cause **magnesium deficiency**.

The non-availability of magnesium in soils having less than one mole of the exchangeable magnesium per kg of soil, or the presence of magnesium in amounts less than 4% of the CEC, are indications of magnesium deficiency. Magnesium deficiencies occur in soils with high ratios of exchangeable Ca/Mg which should not exceed 10:1 or 15:1, depending on specific conditions. A high level of exchangeable potassium may interfere with the uptake of Mg by crops. The recommended ratios of K to Mg are less than 5:1 for field crops, 3:1 for vegetables and sugar beets, and 2:1 for fruits and green house crops.

The symptoms of magnesium deficiency, which do not occur too frequently, first appear on older leaves and then spread to younger ones. The green chlorophyll disappears, leaving behind spots between the leaf veins. The leaf margin then turns yellow (interveinal chlorosis in older leaves), while the leaf veins remain green, as shown in Fig.M.2. The leaves exhibit a stripy or spotty appearance. However, unlike the deficiencies of K and Cu, the Mg deficiency symptoms of necrosis seldom occur, except for chlorotic discoloration. A large number of leaves may fall as a result of magnesium deficiency, especially in fruit and berry crops. Magnesium deficiency causes significant injuries, particularly in fruit crops, which may extend to the roots, and create phosphorus deficiency in oil plants, such as palm and linseed.

Fig.M.2: Magnesium deficiency makes the leaf chlorotic. Veins remain green and the leaf detaches easily.

Magnesium deficiency in cotton and grapes appears as purplish red leaves with green veins. As the leaves become older, they turn brown. The lower leaves are affected first in corn, as whitish stripes appear along the veins and a purplish color is seen on the underside. In tobacco, it is known as **sand down** and appears as loss of green color at the tips of the lower leaves. As the deficiency worsens, the upper leaves become bleached and turn white in color. The deficiency in animals shows up as low blood-serum magnesium and muscle spasm, finally leading to death.

Soil analysis is widely used to detect the Mg deficiency and to estimate the Mg requirement of the plant. The most effective material for correcting magnesium deficiency and soil acidity is **dolomitic limestone** or **dolomite**. Magnesium uptake is greater from fine dolomite than from the coarse variety, while it is less than that from magnesium sulphate. An addition of 16.8 to 33.6 kg/ha of dolomite significantly increases the dry weight of corn. Similarly, the clover yield is higher with soluble magnesium than with dolomite. For soil with a pH more than 6.0, water-soluble magnesium sulphate is preferred to dolomite as a source of magnesium.

Other materials containing magnesium are magnesia, magnesium nitrate, magnesium silicate, serpentine, magnesium chloride solution, synthetic chelates and natural organic complexing substances. Magnesium sulphate ($MgSO_4$), magnesium chloride ($MgCl_2$), magnesium nitrate [$Mg(NO_3)_2$] and synthetic and natural chelates are well suited for clear-liquid foliar applications.

The double sulphate of potassium and magnesium is the most widely used magnesium additive for suspensions. Magnesium ammonium phosphate has non-burning and non-leaching characteristics. These are especially valuable when the fertilizer comes in contact with seeds or roots.

Depending on factors like the magnesium content, the rate of weathering, uptake by plants etc., magnesium ions (Mg^{2+}) can be leached from soils.

Forage crops, particularly forage grass with magnesium concentration less than 2 g/kg, are dangerous for the cattle which on consumption of such grass, may get a disease called hypomagnesemia or **grass tetany**, in which the blood magnesium level decreases abnormally. A high application rate of potas3sium (K) or ammonium (NH_4^+) fertilizers depresses the magnesium (Mg^{2+}) level in plants. The factors responsible for grass tetany include a high concentration of potassium (>30 g/kg), the $K/Ca^{++}+Mg^{++}$ equivalent ratio >2.2, and the nitrogen concentration >40 g/kg in the plant. Grass tetany often occurs in spring. The level of magnesium in the soil may be increased by adding dolomite if liming is advisable, or by adding magnesium fertilizers, such as $MgSO_4$ and MgO.

Magnesium borate

Magnesium borate or boracite is a boron compound, used for overcoming boron deficiency. All boron materials used in the production of fertilizers are stable chemicals and create no storage problem.

Magnesium carbonate

Magnesium carbonate is a white compound occurring in anhydrous and hydrated forms. It is used as a fertilizer and also for making magnesium oxide.

The anhydrous material is found naturally in mineral magnesite. There is also a trihydrate, $MgCO_3 \cdot 3H_2O$ (rhombic) that occurs naturally as nesquehonite, and a pentahydrate, $MgCO_3 \cdot 5H_2O$ (monoclinic) that occurs as lansfordite.

Magnesium carbonate also occurs in a mixed salt dolomite ($CaCO_3 \cdot MgCO_3$) and as basic magnesium carbonate in two minerals, namely, artinite [$MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O$] and **hydromagnesite** [$3MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O$]. Heating magnesium oxide in a stream of carbon dioxide leads to the formation of the anhydrous salt.

$$MgO + CO_2(g) \longrightarrow MgCO_3(s)$$

Above 350°C, the reverse reaction predominates and the carbonate decomposes to give back MgO.

Magnesium carbonate pentahydrate

Magnesium carbonate pentahydrate, $MgCO_3 \cdot 5H_2O$ (monoclinic) occurs as lansfordite and is used as a fertilizer as well as an intermediate for the preparation of other magnesium salts.

Magnesium chelate: See Chelate

Magnesium deficiency: See Magnesium

Magnesium-iron mica: See Biotite

Magnesium sulphate

Magnesium sulphate is a white compound existing both in anhydrous (rhombic) and hydrated crystalline forms. The monohydrate $MgSO_4 \cdot H_2O$ (monoclinic) occurs in nature as **kieserite**. It is a greyish-white crystalline powder which contains about 16% magnesium and is used as a fertilizer. It is regarded as a concentrated form of epsom salt, having less water of crystallization. The commonest hydrate is heptahydrate $MgSO_4 \cdot 7H_2O$ (also called rhombic or **epsom salt**) which occurs naturally as the **mineral epsomite**. It is a white powder with a bitter, saline taste. The salt in the monoclinic form loses its structural water at 150°C, while the rhombic form loses water at 200°C.

Magnesium sulphate is used in sizing and fireproofing cotton and silk, in tanning leather, in the manufacture of fertilizers, in explosives and matches, in medicines as a laxative, and as a veterinary medicine for the treatment of inflammations and infected wounds.

Maintenance application

Fertilizers applied to soil to maintain its fertility and nutrient levels are known as maintenance applications. Such applications are also made to fertile soils to minimize the loss of nutrients by plant uptake.

Maintenance costs

Total maintenance costs include the cost of material, labor, supervision and scheduling. Material cost broadly accounts for 50% of the total maintenance cost, labor about 40%, and supervision and scheduling, about 10%. This is true for a general category of traditional industry. Generally, annual maintenance costs can be estimated at a minimum of approximately 4% of the fixed investment cost; for corrosive processes or those with extensive instrumentation, this can be 7 to 10%.

Major irrigation systems

Irrigation systems, in which water is drawn from large, natural or man-made reservoirs like dams and distributed to areas away from the dam site, by a network of canals, are known as major irrigation systems.

Major nutrients

A mineral element, considered essential to the growth and development of plants is called a **plant nutrient**. Seventeen elements are essential to plant growth, out of which N, P, K, Ca, Mg and S are considered major nutrients or **macronutrients**. Major nutrients are categorized into primary (N, P, K) and secondary nutrients (Ca, Mg, S).

Management of soil potassium

Soil potassium can be effectively managed by (a) maximizing the efficiency of the added potassium, (b) minimizing the excess absorption of potassium by plants, and (c) maximizing the use of natural potassium sources.

Small, split applications instead of heavy applications of potassium fertilizers prevent excessive potassium uptake by plants. The maintenance of soil pH at 6 to 6.5 with lime reduces potassium losses by leaching. The addition of crop residues and manure amounts to increasing the potassium content in the soil.

Management of soil phosphorus

The availability of **soil phosphorus**, both in organic and inorganic forms, is low in many sandy, low-humus soils. Both the forms undergo transformation. The available phosphorus is influenced by the soil pH. Although the application of 11.2 kg/ha of fertilizer phosphorus is found to be quite effective in the soil with pH range of 6 to 7, the optimum availability of phosphorus in mineral soils occurs at pH 6.5. However, twice the amount of fertilizer phosphorus is seen to be required at a soil pH of 5. Sesquioxide clays, iron oxides and aluminum oxides in the soil often have large capacities for adsorption of the added soluble phosphate.

Phosphorus deficiencies are corrected by the addition of phosphate fertilizers. On rain-fed crops, the fertilizer is placed in a band of about 5 cm to one or both sides of the seed, and 5 cm below the seed. In this way there is a minimum contact between the fertilizer and the seed, and yet the fertilizer is available to the first formed young roots.

Phosphorus in excess may not be retained in the soil, but if it does, it causes **zinc deficiency** in corn, beans and flax.

The task of efficient management of soil phosphorus requires the understanding of three major strategies. These are the (a) efficient utilization of native soil phosphorus, (b) efficient utilization of fertilizer phosphorus, and (c) direct use of rock phosphate. The strategies for efficient utilization of native soil phosphorus include the use of phosphorus-efficient crops and their cultivars. Plant species with deeper and wider root systems can feed better on native soil phosphorus.

The use of **vasicular arbuscular mycorrhizae (VAM)** for increasing the root extraction of phosphorus is common. *Bacillus megatherium* var. *phosphobacterium*, called **biofertilizer phosphobacterium**, is used for increasing the availability of native soil phosphorus, the best results occurring on neutral to alkaline soils with a high organic matter content.

Management practices in corn cultivation: See Corn cultivation - management practices

Management practices in wheat cultivation: See Wheat - recommended cultivation practices

Manganese

Manganese (Mn) is a transition element with atomic number 25 and atomic weight 54.93. It belongs to Group 7 of the Periodic Table (Fig.M.3) and is an essential plant nutrient which plays an important role in plant biochemical processes. It is absorbed by plants in the form of manganese ions (Mn^{2+}) or as an organic complex. In green plants, manganese influences the light-dependent water splitting reaction (**Hill reaction**) and oxygen evolution during photosynthesis. Manganese provides oxygen to poorly ventilated interior soil pores, where iron in the form of ferrous ion (Fe^{2+}) and complex organic molecules would otherwise remain non-oxidized.

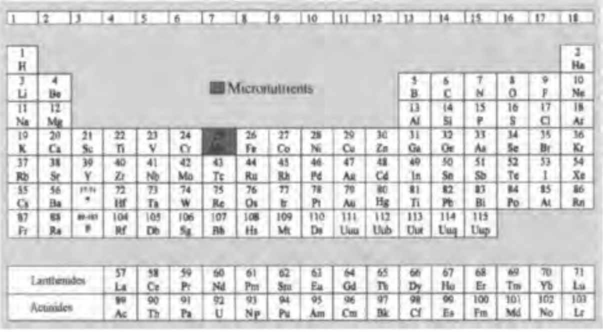


Fig.M.3: Position of manganese in the Periodic Table.

Manganese is associated with several enzyme systems and electron transport. It exists as manganese ion (Mn^{2+}) in plant cells in many complex forms. It can form metalloproteins and is tightly bound in chloroplast with its average concentration of 100 ppm in the plant cell.

Manganese serves as a co-factor or a prosthetic group of enzymes involved in reactions concerned with oxidation-reduction, carboxylation, decarboxylation, photophosphorylation and hydrolysis. It affects respiration, amino acid synthesis, lignin biosynthesis and hormone levels in plants. It regulates the metabolism of carbohydrates, proteins, nucleic acids, secondary metabolites, ascorbic acid and citric acid cycles. With other metals, it works in the activation of enzymes such as arginase, cysteine desulphydrase, deoxyribonuclease and yeast phosphatase. Manganese is a specific activator of the enzyme, namely, prolidase and glutamyl transferase.

Manganese is the tenth most abundant element (average 650 ppm) in the earth's upper crust. It occurs in primary rocks and in various water-soluble, exchangeable, easily reducible complexes or in organically bound ferromagnesian materials. It also occurs as amorphous sesquioxides and crystalline minerals. Soil generally constitutes 1 to 1.5% of manganese which varies with climatic conditions, plant materials, moisture conditions, the soil type, crop species and crop varieties. High intensity farming exhausts soil manganese.

Soil manganese exists in three-valence state formed by the decomposition of ferromagnesian rocks. Its content varies from a trace quantity to several thousand kg/ha. In most soils, the total manganese usually ranges from 200 to 2000 ppm; except in some Indian soils, where it ranges from 37 to 11500 ppm. The availability of manganese to plants is influenced by a number of factors such as the soil pH, the oxidizing conditions, the organic matter, the lime content and the soil moisture. In oxidized soils, most manganese precipitates as insoluble pyrolusite (MnO_2). As organic matter decomposes and the soil becomes acidic, manganese solubility increases owing to reduction of manganese (IV) ions. Soils with high manganese content and the concomitant soil acidity may result in high toxicity of manganese in plants (i.e., higher toxicity levels of manganese compared to those of zinc, iron or copper at the same soil pH levels). The level of oxidation of manganese is low in poorly drained soils, which leads to the accumulation of organic matter that transforms manganese to its reduced form. Coarse soils are more manganese-deficient than the fine textured ones.

Deficient, normal and excess levels of manganese occur when its content is less than 25 ppm, 50 to 200 ppm and over 400 ppm, respectively. Compared to grasses, legumes contain lesser amounts of manganese and are very sensitive to **manganese deficiency**. Grains drain very small quantities of manganese from the soil. Hence, the need for additional manganese does not commonly arise. Manganese deficiencies are quite common in sandy soils, organic soils and calcareous soils with high pH. The deficiency of Mn is named differently as '**marsh spot**' of peas, '**grey speck of oats**', '**speckled yellows**' of sugar beets and '**crinkly leaf**' or '**curly top**' of cotton, leafy green crops, etc. Like in the case of iron, manganese deficiency occurs in young leaves which wither or produce interveinal chlorosis with prominent dark green spots along the major veins. In the case of iron deficiency, veins also become light yellow or yellow, which is the only visible difference between an iron deficiency and a manganese deficiency. In manganese deficiency, the veins remain green with a fine reticulate pattern, with or without necrosis, as shown in Fig.M.4 and M.5. The formation of complexes with organic matter in the soil, especially at lower pH values, is one of the reasons for manganese deficiency.

Fig.M.4: Manganese deficiency is evident by symptoms such as chlorosis, dark green spots, and a checkered appearance on leaves.

Fig.M.5: Manganese deficiency in citrus.

Manganese deficiency compares with the normal signs of magnesium (Mg) deficiency, except that Mg deficiency is first seen on older leaves.

An increase in the soil pH enhances both the chemical and the microbial oxidation of manganese. To correct manganese deficiency in soils, the pH should be kept at around 6.4 by adding sulphur or manganese sulphate at the rate of 37 to 75 kg/ha along with other fertilizers. For growing crops, 2 to 5 kg of manganese sulphate in 450 liters of water is sprayed per 0.4 ha. Chelated manganese compounds are also applied. The addition of manganese fertilizer to the soil or to the foliage alleviates manganese deficiency. Making soils more acidic helps in correcting the deficiency. Manganese deficiency depends on plant species, and its symptoms are visible on top leaves 20 to 50 days after sowing. The recommended optimum manganese content in plants is between 1 and 5 ppm for most crops.

Manganese-supplying materials are manganese sulphate, manganous oxide, manganese dioxide, manganese ammonium phosphate, glass frits, manganese chelates and fine dust (a by-product in the manufacture of ferro-manganese metal). These materials may be added to the soil in the range of 0.5 kg Mn/ha in foliar sprays to 20 to 25 kg Mn/ha for soil applications. Around 224 kg/ha chelate containing 5% manganese meets the requirement of 11 kg/ha of manganese. This can be directly applied to the soil. However, this method is quite expensive.

Manganous oxide (with 65% Mn) can also be sprayed on foliage with no risk of burning when the spray solution has a pH of about 7.0. Manganese dioxide (with 48% manganese) is suitable for use as fertilizer. These two grades of oxides are sparingly soluble in water, but are soluble in weak acids. Manganous oxide is much more effective than manganese dioxide, even though the Mn content is comparable in the two. Frits contain 7% manganese along with other nutrients, whereas chelates contain 6 to 9% manganese.

Large doses of manganese (100 to 600 ppm) are harmful to plants and can cause a reduction of about 10% in the dry matter yield. Generally, **manganese toxicity** manifests itself by brown spots on older leaves surrounded by chlorotic areas. The other visual indications are crinkled leaf spots in cotton, stem streak and necrosis in potato, and internal bark necrosis in apple trees.

Excess manganese can cause deficiencies of Fe, Mg and Ca. Excess Mn can be seen in degraded, highly acidic soils under reduced conditions such as in acid sulphate soils. While strongly acidic soils raise the Mn toxicity level, lime controls it. Plants may be affected by excessive soluble manganese which is usually present in very acidic soils. However, in cases of soil pH being 7.5 and above, manganese availability is very low.

Manganese chelates

Manganese chelates are complexes of manganese ions with organic ligands or chelating agents like acetyl acetone, EDTA, HEDTA, EDDHA, etc.

Manganese chelates are not stable and not effective for soil application. At high concentrations of manganese chelates, calcium replaces some of the manganese from the chelates and the freed manganese is usually converted into its unavailable forms. Meanwhile, if there is more calcium or iron available, it accentuates the deficiency of manganese.

Manganese chelates are used as foliar sprays (1 to 2 kg/ha) to correct the deficiency; for example, manganese - EDTA chelates (with 5 to 12% manganese).

Manganese deficiency: See Manganese

Manganese frits

Frits are melted glass particles containing measured quantities of micronutrients, like copper, iron, boron, zinc, manganese and molybdenum. When granulated powdered glass is impregnated with manganese, the frits become manganese frits. These are applied when the nutrient is required to be released slowly.

Manganese toxicity: See Manganese

Man-made wilting

The phenomenon of leaves drooping is called **wilting**. This is caused mainly by the loss of water through evaporation. Sometimes, wilting becomes convenient. For example, in haymaking and silage making, plants are often crimped or lacerated to increase wilting in order to reduce moisture. This is artificial or man-made wilting.

Mannheim process for potassium sulphate production: See Potassium sulphate production processes

Man's land

Man's land or **heavy land** has a high clay content, which makes it harder to cultivate than the **light soils**.

Manure

Manure is organic matter, either of vegetative or animal origin. It is spread or incorporated in soil for enhancing the nutrient value of the soil for the benefit of the plants (Fig. M.6).

Organic manure acts as a soil conditioner, increases water holding capacity of soil, maintains soil structure, provides nutrient fertility to the soil, and helps prevent soil erosion (through vegetative manure like litter, straw, green clippings).

Animal manure is the oldest known fertilizer. It is a good way of disposing large quantities of animal waste created in farms. Commonly used animal manures are horse manure, sheep manure, cattle manure, pig manure, poultry manure and fish manure. Manures of different animals are often suitably mixed for use in specific crop and soil conditions. For example, pig dung is considered suitable for dry and hot conditions, whereas a mixture of cow dung and poultry dung is considered an ideal manure for rapeseed, lupines, peas and flowering plants.

Cow manure is the most basic manure, generally accounting for the largest proportion in a manure mixture. Cattle manure has 0.55% K and is required in quantities of 110 kg per 100 sq m.

Horse manure is coarse, light and dry. It is only half as dense as other manures and is regarded as a fast acting substance to stimulate growth. It is generally added to cow manure or in combination with other manures. Horse manure contains 0.65% N, 0.25% P and 0.5% K. If incorporated exclusively, around 91 kg are required to be added to 100 sq m area.

Sheep manure is considered most effective among the non-poultry manures, since it promotes quick growth of crops. It can be dried, bagged and sold. It contains 1% N, 0.75% P and 0.40% K. Ideally, 90 kg of this manure is required to be spread over a 100 sq m of land.

Cattle manure is cool, wet and restrained and decomposes more easily than horse manure. It also has less nitrogen loss compared to that from horse manure.

Pig manure is wet, runny, cold and slow acting. But compared to horse manure, the nitrogen loss is less, and rotting is faster. The nutrient value is 0.5% of N, 0.3 % of P and 0.45% of K. But larger quantities of around 100 kg are required to be spread or applied per 100 sq m of land.

Poultry manure is acrid and considered the most effective manure. The dry matter content is twice as much in cattle and pig manure. The phosphorus content is between 1 and 2% which is considered quite high.

The constitution of each manure and its nutrient value depend on factors such as fodder, the age of the animal, the collection and storage system and processing methods utilized, the animals chosen, the species of each animal, etc.

Manures can be used on the field either in its fresh form or after processing. Some types of manures can be made are warm manure, cold manure, farmyard manure, deep litter, slurry manure and compost. The basis of each type is to use different components of manure, to minimize the nutrient loss and change the kind of decomposition process, as necessary.

Warm manure is a manure system that combines aerobic and anaerobic decomposition in the manure heap. **Cold manure** system is based on anaerobic decomposition. **Slurry manure** is a mixture of all the components of manure, like excreta, urine, wasted feed and water, straw, etc. In the **deep litter system** of manure making, litter is allowed to collect on a straw mat on which animals walk. This manure becomes compacted. **Farmyard manure** (FYM) is a type of manure made from feces and other solid waste, like straw, bedding, plant waste, etc. Generally, this manure mix is stored in heaps to which fresh inputs are added.

Important parameters in manuring are the time of application, machinery used and the method of manure application.

Nutrient efficiency of manure depends on the time of application and the surroundings. Adding manure just prior to seeding is a common practice. Since manure nutrients are released gradually, the application of manure at this time provides a nutrient supply during the growing season of the crop. Spring application is considered ideal. In summers, a manure application helps pasture and hay. The application of manure is not advised during or even just prior to rains, or even in autumn because of the risk of soluble nutrients being leached out. A winter application in very cold zones is not ideal, since nutrients cannot soak into a frozen soil.

In so far as tools for applying manure are concerned, deep plowing equipments can prove detrimental; light

Fig.M.6: Undecomposed farm waste (left) and completely decomposed manure.

cultivators and one-pass tillage equipment are recommended. This is because both micro-organisms and oxygen are abundant in the upper layers of the soil. The combined action of these two ingredients can effectively process manure for the benefit of crop and soil. Solid manure needs to be crushed before being distributed. Liquid manure may be spread through high pressure nozzles.

Manure distribution is best done by the incorporation of manure straight into the soil. This method is preferred over the broadcast method for a number of reasons. If manures are spread on the surface, they increase the risk of disease to grazing animals, and also the loss of nitrogen. Surface application also promotes surface rooting of plants which is not beneficial for the crop. Incorporation of manure, done in the upper layers of the soil helps to restore soil moisture. Adequate manure and soil moisture encourage the activity of fungi and bacteria. Manure also keeps the soil aerated.

Manure can be processed into **compost**. Among the various innovations in compost making is biodynamic compost preparation. Rudolf Steiner is considered among the first to have initiated the thinking on enriching plants and soils with properties that are inherently prevalent in some natural plant materials (like flowers, barks, etc). Some examples of such recommended plant parts are Yarrow flowers (*Achillea millefolium*), wild camomile, stinging nettle, oak bark (*Quercus robur*), dandelion, and valerian. These materials are believed to improve the relationship between N and P in the soil, reinforce the soil's relation with Ca, impart good health to the soil, restore a good soil structure, prevent plant diseases, encourage a right relationship between Si and K, etc.

Manure application

The **manure** can be fresh or processed. It may be applied by spreading or by incorporation, the latter being commonly preferred. There are many ways propounded by farmers the world over. The ideal natural way to spread manure is to allow animals to graze freely in the pastures, so that they defecate across the field. This method also allows birds to break up and spread the manure since they come looking for food in the heaps. Manure distribution by natural means is suitable for cattle, horses and pigs. This method, although not possible in every farm, requires least labor.

Incorporation of manure in the soil is preferred over surface spreading. Incorporation prevents the spread of possible infection and is hygienically better. Deep litter and hardened dung may be mixed and crushed in a machine for better incorporation. Suitable tools, cultivators, one-pass tillage equipments and injection techniques must be used to incorporate manure.

Incorporation of manure in upper layers of the soil helps increase bacteria and fungal activity since these organisms do not commonly live in the deep layers. Manure incorporation helps restore soil moisture which combines with microbial activity to provide plants with the required nutrition. Soil is observed to remain aerated, as a result of shallow incorporation.

Manure, carryover effect of

The carryover effect of manure is the same as the **residual effect of manure**. It is the ability of a manure or fertilizer to continue to provide nutrition to a crop. The effect may be witnessed for over a season after the application is made.

Unutilized nutrients from the previous season become available to plants in the current season. The long term residual benefits are encountered more for K and P than for N. (See also Carryover effect of fertilizer.)

Manure management practices

A typical farm with livestock generates excreta, urine, litter, wastewater, bedding, etc. These lead to the formation of substantial amounts of manure. Only 3 to 4 horses are sufficient to provide manure to an acre of farmland.

Although manure is an important input to the soil, it is considered to be an environmental hazard, if not handled properly.

Animal waste carries many pathogens which, if not properly managed, can ruin the surrounding land as well as ground water when it percolates through the soil along with rain water. Fresh manure broadcast on a farm also becomes ineffective owing to nitrogen losses. Thus, for manure management, which is the responsibility of the farm owners the world over, one major guideline generally, relates to monitoring of the manure disposal means.

The following are a few management practices for manure disposal.

(i) Use only as much manure as is necessary. Although large amounts of manure are needed to provide necessary nutrients to plants, its excess should be avoided, especially in a situation when for instance, a horse produces around 25 liters of excreta, urine and wasted feed every day. Spilt applications may be resorted to as a practice. The risk of run-off of manure is high if the crops are irrigated after manure is applied.

(ii) There should be a temporary storage container on each farm to ensure that manure does not flow away or spread infection. The storage facility must be away from wells, tanks, domestic water supply or any other water source. Excess disposal systems should be in place in accordance with local regulations.

(iii) Processing of manure into **warm**, **cold**, **slurry** or **FYM** manures is another way of managing manure.

(iv) Composting is a very effective means of managing fresh manure. It reduces the volume and weight of fresh manure by 40 to 60%. It also reduces the odor and kills weed seeds. Composting ensures a long shelf life of the manure and hence makes it a marketable produce that would be bought by nurseries, pasture owners, landscapers, etc.

MAP

MAP is short for **monoammonium phosphate**.

Marathon-Howard process for chemical recovery

A treatment of waste sulphite liquor from sulphite pulp manufacture to recover chemicals and reduce stream pollution is known as Marathon-Howard process.

Waste sulphite is treated with lime which precipitates out as (a) calcium sulphite for use in preparing fresh cooking acid for the sulphite pulp process, and (b) a basic calcium salt of lignin sulphonic acid which can be pressed and used as a fuel or raw material for vanillin, lignin, plastics and other chemicals. The remaining liquor, with its biological oxygen demand reduced to 80%, is the effluent.

Marble

Marble, which in a chip form is often used as a source of carbon dioxide in laboratory experiments, is one of the major sources of calcium carbonate. It is used for neutralizing acidic soils. It is formed when limestone is metamorphosed so that the rock is re-crystallized and hardened.

Pure marble, is snow-white in color, and is used for making sculptures. The color is affected by impurities. (See also Calcium carbonate.)

Marcescent leaves

Marcescent leaves are those which wither at the end of the growing season but do not fall until spring. Marcescence is the plant property of retaining a dead organ that normally would be shed. Oak, beech and hornbeam are examples of trees that demonstrate marcesence. At the time the leaves die (which may be due to disease or frost), the abscission layer is not yet developed, and hence the organ remains on the plant and the base of the petiole is alive throughout winter. The development of the abscission layer generally gets completed in spring after which the dead leaves fall.

Marginal quality water

Based on the total salt content of water and its ionic composition, irrigation water is classified as marginal quality water, **good quality water, saline water** or **sodic water**. The water with electrical conductivity between 2 and 4 dS/m, SAR less than 10 and residual carbonate content of less than 2.5 meq/l is classified as marginal quality water.

Marginal rate of return

The efficiency of a fertilizer application is determined by the crop response and the price ratio between the crop output and the fertilizer input. The Food and Agricultural Organisation (FAO) defines this ratio using 3 parameters, one of which is the marginal rate of return (**MRR**), the other two being the **value to cost ratio** (**VCR**) and the fertilizer-crop price ratio. MRR is the profit made over the break-even yields for the given production costs.

Marginal returns from nutrients

Marginal returns from nutrients are the economic returns from the last unit of the nutrient added. These are the returns from one unit change in the quantity of the nutrient (resource) used per unit area.

The **law of diminishing returns** states that increasing the quantity of input by one unit, while keeping the other inputs constant, initially increases the output in proportion to the increased input, then stabilizes or stagnates the output, and subsequently diminishes it. For example, if a fertilizer applied to a crop growing on a fixed land area is increased, the yield increases at first. Later, the increased amount of the fertilizer increases the yield at a diminishing rate. In the end, any further addition of the fertilizer actually reduces the yield. The yield reduction may happen, for instance, due to toxicity brought about by the excess of fertilizer inputs.

In another example, increasing the plant population on a fixed land area increases the yield, but the marginal returns decrease as the plants begin to compete vigorously for light, water and nutrients. Eventually, overcrowding decreases the yield.

Fig.M.7 gives three stages (I, II, and III) of returns. Stage I shows a case of small quantities of one resource bringing higher marginal returns, till the average product equals marginal product. Stage II shows how the additional unit of the variable resource produces no significant increase in the total output. Stage III demonstrates how a further addition of resources produces less than the maximum output, thus making the application inefficient.

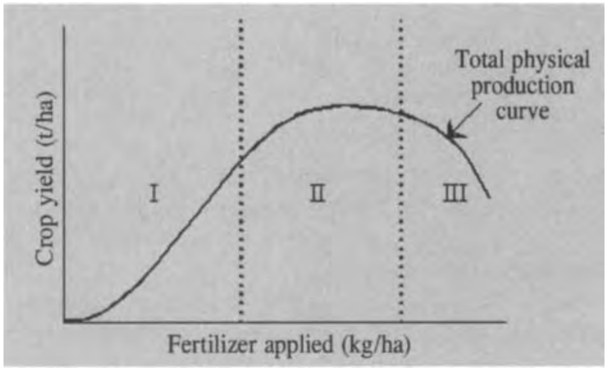


Fig.M.7: A graph demonstrating the law of diminishing returns.

Maritime dunes

Maritime dunes are formed on shores, and are generally asymmetrical because of the prevailing winds. The slope facing the wind direction is gentle. A maritime dune is unstable. It can move several meters and rise to a height of 150 m in a year.

Marl

Marl is one of the major sources of calcium carbonate. Marls are soft, unconsolidated deposits of calcium carbonate, often mixed with earth, and have a neutralizing value (calcium carbonate equivalent - CCE) in the range of 70 to 90%, depending on the clay content.

Marsh gas

Methane, especially generated by decaying matter in marshes, is called marsh gas or **swamp gas**. It is the end product of the anaerobic decay of plants. It is produced in sewage marshes and in coal mines.

Marsh spot of peas

Marsh spot of peas is a disease seen in peas. It is caused by manganese deficiency. A foliar spray of $MnSO_4$ is generally sufficient to supply the required quantities of Mn to peas. Incorporating $MnSO_4$ into mineral soil at the rate of 30 kg/ha is a common practice.

Mass flow

Mass flow is the movement of nutrient ions in the soil, aided by water from rainfall or an irrigation system. Mass flow is the passive movement of the fluid along with the solutes in response to gravity, osmotic potential and the temperature gradient.

Nutrients move to the vicinity of the roots by mass flow, **diffusion** and/or **root interception**, thus aiding their absorption by plants. The amount of nutrients reaching the roots by this process depends on their concentration in the soil solution and the rate of water transport to and into the roots. Soil property, climatic conditions, nutrient solubility and plant species affect the nutrient supply by mass flow. The level of a given nutrient in the soil solution depends on the balance between the rate of supply to the roots by mass flow and the rate of absorption into the root. Mass flow supplies to the plants abundant ions of calcium and magnesium, as well as mobile nutrients, such as the sulphates or the nitrates.

The contribution of mass flow of nutrients to the roots is calculated by the product of the soil solution concentration and the volume of water that has transpired through the leaves. Transpiration is not a constant or continuous process; it varies with climate, plant species, plant age, soil conditions, water location in soil and transpiration time. At night, mass flow is greatly restricted. Moreover, young plants need a higher nutrient concentration, and mass flow can meet a small fraction of the demand.

Mass wasting

Mass wasting is another name for **gravity erosion**. It occurs when large masses of soil are moved by gravity and thus wasted. The movement can be instantaneous, as in a landslide, or slow and persistent over many decades, as in the case of **soil creep**.

Master horizons

Soil consists of several horizontal layers having their own characteristic color and texture. These layers are called horizons and are identified by letter and number codes. The **horizons**, identified with capital letters **O**, **A**, **E**, **B**, **C** and **R** are master horizons.

Maximum bulk density

Maximum bulk density is defined as mass per unit volume of the material tipped into a container and then compacted under clearly specified conditions. It is also known as the tapped bulk density. Generally, the maximum bulk density or **tapped bulk density** is 6 to 12% higher than the **loose pour bulk density**.

Maximum nutrient content

The total amount of nutrient taken up by a growing crop reflects the maximum nutrient content of that crop. The nutrient content varies during different stages of growth. For example, cereals have a fast nutrient uptake in the early growth stages when 60 to 80% of the total need gets fulfilled.

Maximum nutrient efficiency

When nutrient concentration is near its highest level, the plants use up the nutrient to produce maximum yield. At this point, excessive nutrient levels in the plant do not exist. Thus, the maximum nutrient efficiency is obtained at that level.

Maximum water-holding capacity

Water-holding capacity indicates the ability of the soil to retain water. Clayey soils have small pores and small-sized particles and hold the maximum amount of water. Therefore, clayey soils are said to have the maximum water-holding capacity. But clay soil holds water so tightly that the water does not necessarily become available to plants. The largest amount of water available to plants is held by the silt loams or other high-silt soils. They have larger particles compared to clayey soils, and hence a smaller total surface area, but their small pores too hold large amounts of water. The maximum water-holding capacity (**MWHC**) indicates the average moisture content of the sample soil of one centimeter height, which at its lower surface, is in equilibrium with the water table.

Maxitz-Standard Den process for superphosphate manufacture

For the manufacture of normal superphosphates, continuous processes are preferred over batch processes. Maxitz-Standard Den process is one such continuous process. (See also Normal superphosphate.)

Mean

A mean value or an average value is obtained by dividing the sum of a set of replicate measurements by the number of individual results in the set. For example, if we have to find the mean of four values, say, 10.1, 9.9, 10.0, and 10.2, the mean, $\bar{X}$ is calculated as:

$$\text{Mean} = \bar{X} = \frac{10.1+9.9+10.0+10.2}{4} = \frac{40.2}{4} = 10.05$$

The mean or the average is defined as the figure obtained by dividing the total value of variates by the number of variates. This can be expressed by a general formula as under:

$$\bar{X} = (X_1 + X_2 + X_3 \ldots\ldots\ldots X_n) / n$$
$$= (\Sigma X_i)/n$$

where $\bar{X}$ is the mean, X_i is the value of i variates and n is the number of variates.

The calculated mean, however, has the following drawbacks: (i) Since 'mean' is calculated from all values in a series, some abnormal variates can affect the average considerably. (ii) 'Mean' gives a value that may not exist in the given data. (iii) 'Mean' sometimes gives almost an absurd value. (iv) Mean may sometimes lead to wrong conclusions.

Meander furrows

Clay soils undergo large volume changes when wet. When clay particles are wet, there is inadequate aeration, and water infiltration becomes slow.

One of the methods of irrigating clay soils is by cutting passageways across the furrow direction to connect several channels so that water flows back and forth like a snake's trail. This method is known as the meander furrows method, or **dead-end serpentine scheme** or **block serpentine scheme**.

Mean life

Mean life is defined as the reciprocal of decay constant. Decay refers to the chemical breakdown of an organic material into its elements. The decay of the total number (N_0) of nuclides to give N nuclides after time t is given by

$$N = N_0 e^{-\lambda t}$$

where λ is the decay constant, or disintegration constant, and t is the time.

Mean square error

If samples of observations are taken from different treatments (or methods), the **analysis of variance (AOV)** technique requires a measure of "natural" or random variation as opposed to variation due to an assignable cause. This measure is called mean square error. It is obtained by averaging the squared standard deviations of observations in individual samples.

Measure of reliability

The measure of reliability is reflected by the difference in the observed value from the expected value. This is dependent both on the method of analysis and the precision with which an experiment is conducted.

Measuring adsorption

Adsorption is measured experimentally in soils from the (a) reaction between the soil and a solution of known composition at a fixed temperature, pressure and specified time, and (b) chemical analysis of the leached soil, the soil solution or both, to determine its composition.

In the first operation, the reaction takes place either by a **batch process** that involves mixing of soil particles uniformly in solution or by a **flow-through process** wherein a solution is in uniform motion relative to the column of soil particles. It is important to ensure that the reaction time is just enough to facilitate a detectable accumulation of the adsorbate, to avoid unwanted side-reactions such as those concerning redox, precipitation or dissolution. In the batch process, chemical analysis is carried out after the soil is separated as far as possible from the reacted solution by centrifuge or gravitational force. In the flow-through process, the effluent solution is analyzed to determine the changes caused by adsorption.

Mechanical devices for agricultural operation

Mechanical devices are used as agricultural tools for crop cultivation to improve and modernize farming operations. These may be hand operated tools, animal drawn implements, engine powered equipments and other technological devices such as electric motors, pumps, solar driers, irrigation and drainage equipment, tractors, etc. as shown in Fig.M.8.

The objectives of using mechanical devices, and in particular, powered implements are to (a) reduce drudgery in farm work, (b) increase farm output – both,

Fig.M.8: The tractor is one of the most popular mechanical devices used for many operations in agriculture.

the actual production and productivity (i.e., output per human-hour), (c) improve timeliness of field operations, (d) reduce the loss and wastage of agricultural produce, (e) reclaim degraded lands and develop new land for agriculture, and thus, (f) improve the well-being of farm families.

Mechanical efficiency

Mechanical efficiency depends on how well a machine converts energy from one form to another. For example, an engine converts chemical energy or heat energy into mechanical power and causes torque and rotation of the engine crankshaft. All energy in the fuel is not converted into torque and shaft rotation, but a substantial portion gets converted into heat and escapes through the radiator and the exhaust. Therefore, engines are not 100% efficient. A typical petrol engine is about 35% efficient; a diesel engine is slightly better. An electric motor has higher efficiency in converting electrical energy into shaft rotation, etc with an efficiency of around 95%.

Medic rhizobia

Medic rhizobia, the strain of fast-growing, acid producing ***Rhizobium*** species, form nodules on the roots of pea group of legumes for atmospheric nitrogen fixation.

Mediterranean climate

The kind of climate prevalent in the **xeric moisture regime** (dry) is known as the mediterranean climate.

Medium grain rice

Medium grain rice is a category in the classification of rice based on the length of the grain, the others being **long grain** and **short grain**. When cooked, it becomes tender and softer than long grain rice. This variety is popular in Asia and Latin America.

Mehlich No. 1 extractant

Mehlich No.1, extractant is a mixture of 0.05N hydrochloric acid (HCl) and 0.0125N sulphuric acid (H_2SO_4). It is used for extracting P, Ca, Na and Mg, especially from sandy soil.

Generally, the acidic extractant is used on acid soils, and the alkaline extractant on calcareous soils. Mehlich No. 1 extractant is suitable for highly weathered acidic soils with a low cation exchange capacity.

The critical value of phosphorus in soil is 25 mg/kg or more, and is defined as the **soil test concentration**. This level of P is considered optimum for plant growth, beyond which any addition of the nutrient is unlikely to increase the yield.

Mehlich No. 1 is a good extractant of calcium phosphate, and a limited one for aluminum phosphate. When rock phosphate is applied to soils, this extractant dissolves un-reacted rock phosphate to such an extent that the phosphorus supply exceeds the phosphorus requirement of the fertilizer.

The extraction procedure involves the use of a 5 g sample added to 25 ml of the reagent, shaken for 5 minutes, followed by filtering and titrating for extraction of phosphorus.

Mehlich No. 2 extractant

Mehlich No. 2 extractant is a mixture of 0.2N acetic acid (CH_3COOH) in 0.015N ammonium fluoride (NH_4F) and 0.2N ammonium chloride (NH_4Cl) in 0.012N hydrochloric acid (HCl). It is used to extract P, K, Ca and Mg from soils. NH_4^+, Na^+, H^+ or a combination of the cations displaces these ions from the exchange sites.

Mehlich No. 3 extractant

Mehlich No. 3 extractant is a multi-nutrient (including phosphorus) extractant suitable for a wide range of soils. It is well correlated with **Bray P1 test method**. The critical value of phosphorus is 50 mg per kg.

Mehlich No. 3 extractant is a mixture of 0.2M acetic acid (CH_3COOH), 0.25M ammonium nitrate (NH_4NO_3), 0.015M ammonium fluoride (NH_4F), 0.013M nitric acid (HNO_3) and 0.001M EDTA, having a pH of 2.5. The calibrations using this extractant for phosphorus sufficiency are shown in Table-M.1.

Table-M.1: Calibrations for Mehlich No.3 tests for P sufficiency level.

P sufficiency level	Mehlich #3 (ppm)	Recommendation of fertilizer P in kg/ha
Very low	<7	25
Low	8-14	15
Medium	15-28	8
High	>28	0

Acidic soil tests may also extract some non-exchangeable potassium from micaceous clays because hydrogen ions (H^+) can penetrate the interlayer and displace the potassium ions. An acidic extractant may also overestimate exchangeable calcium and magnesium in calcareous soils, owing to the dissolution of calcium and magnesium-bearing minerals.

The phosphorus extraction process involves shaking of 5 g of the dried sample with 50 ml extraction reagent for 5 minutes. The solution is filtered immediately and the filtrate is titrated for phosphorus.

Mehlich test

The Mehlich test gives an estimate of soil phosphorus. It uses extractant 0.015M NH_4F, 0.2M acetic acid, 0.025M NH_4NO_3 and 0.13M nitric acid.

Melt granulation

Granulation is the result of the agglomeration of particles. Granules are produced from various feedstocks - solids, slurries and melts. The granulation process which uses melt as feedstock is called melt granulation. This involves spraying of a salt melt in the top of the granulation tower.

Membrane hydrolysis

Dialysis membrane equilibrium, set up in the presence of a colloid and a low molecular mass electrolyte, is called a **Donnan equilibrium**. A special case of the Donnan equilibrium is membrane hydrolysis. Both the Donnan equilibrium and the membrane hydrolysis lead to the formation of a membrane potential at the dialysis membrane.

Merchant grade acid: See Wet process phosphoric acid

Mercury ohm

Ohm is the derived SI unit of electrical resistance. The international ohm, also called mercury ohm, is defined in terms of the resistance of a column of mercury.

Meristem

Meristem is a region of plant tissue, found chiefly at the growing tips of roots and shoots and in the cambium, composed of actively dividing cells forming new tissues.

Three types of meristem occur in plants, namely, apical, lateral (cambium) and intercalary meristems. (Fig.M.9).

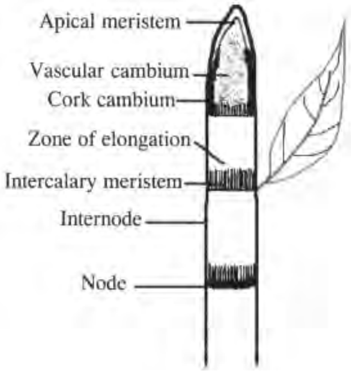


Fig.M.9: Plant meristematic tissues in a diagram of shoot.

An **apical meristem** is the region at the tip of each shoot and root of a plant in which the cell division occurs continuously to produce new tissues. The new tissues produced are collectively known as **primary tissues of the plant**. **Cambium**, or the lateral meristem, is responsible for increasing the girth of the plant; in other words, it causes secondary growth. The two most important lateral meristems are **vascular cambium** and **cork cambium**. The tissues developing from these are considered as part of the plant's secondary growth.

Intercalary meristem is the region of meristem tissues at the base of internodes in monocot stems, particularly in grasses. If the tip of the stem containing apical meristem is removed, the uppermost, undisturbed intercalary meristem becomes apical meristem and starts intercalary growth.

Merphos

Merphos is used as a defoliant in cotton and as a harvesting aid.

Merseburg process for producing ammonium sulphate

Ammonium-carbonate-gypsum process for producing ammonium sulphate is also known as the Merseburg process. (See also Ammonium sulphate production processes.)

Mesic

Mesic is a soil temperature regime where the average soil temperature is in the range of 8 to 15°C.

Mesoelements

Calcium (Ca), magnesium (Mg) and sulphur (S) are called mesoelements. They are also called **major nutrients** or **secondary nutrients**. These are often applied along with the primary nutrients, namely, N, P and K, but in smaller quantities.

Mesrophyte

A plant living in a terrestrial environment, with adequate supply of water and mineral salts is called a mesrophyte. For example, wheat, cotton (Fig.M.10), pulse crops and all flowering plants are mesrophytes. Such plants wilt easily when exposed to drought conditions.

Fig.M.10: Plants like cotton and wheat are mesrophytes.

Messenger RNA: See Ribonucleic acid

Metabolism

Metabolism refers to all the chemical processes that occur within a living organism, resulting in energy production.

The chemical transformations occurring in an organism from the time a nutrient substance enters it, till it leaves the organism is called metabolism.

Metabolism can be divided into two types anabolism and catabolism. Anabolism can be described as reactions that build up more complex substances from the smaller ones, whereas catabolism involves reactions that break down complex substances into simpler ones. Anabolism requires energy while catabolic reactions liberate energy.

Metabolic reactions are catalyzed by enzymes in a finely controlled manner. All energy required to maintain life is derived from sunlight by photosynthesis and most organisms use the products of photosynthesis either directly or indirectly. The energy is stored in most living organisms in a specific chemical compound, called adenosine triphosphate (**ATP**). ATP can transfer its energy to other molecules by a loss of phosphate, which it can regain from catabolic reactions.

Metabolite

Metabolite is a substance formed in the process of metabolism or it is a substance necessary for metabolism. It is an intermediate substance produced and used in the processes of a living cell or organism. Metabolites affect replacement and growth in living tissues and are also a source of energy in the body. Examples of metabolite are nucleic acids, enzymes, glucose, cholesterol, etc.

Metaborate

Metaborate is the salt of metaboric acid. It is one of the two known types of borate, the other being **orthoborate**. Both are used as fertilizers.

Metal ammonium phosphates

Metal ammonium phosphates (with a general formula $MNH_4 PO_4 \cdot xH_2O$ where M is the divalent metal ion like that of Ca, Mg, Mn, Fe, Zn or Cu) represent a separate class of phosphates. These are slow-release sources of nitrogen or micronutrients. The nitrogen content of metal ammonium phosphate ranges from 6.9 to 8.3%.

Metaphosphates

Metaphosphates are salts of metaphosphoric acid (HPO_3). Calcium metaphosphate, [$Ca(PO_3)_2$] is an important metaphosphate. For its manufacture, elemental phosphorus is burned and the resultant phosphorus pentoxide (P_2O_5) vapor is reacted with phosphate rock. The molten product, cooled in a steel drum, gives vitreous flakes which are crushed to a 10-mesh size (about 1.6 mm).

Pure calcium metaphosphate should contain 71.7% phosphorus (as P_2O_5); however, in practice, the phosphorus content is 65% because of the impurities in rock phosphate. It is applied to soil as a source of phosphorus.

Calcium metaphosphate, which is water insoluble, hydrolyzes slowly. More than 98% of phosphorus (as P_2O_5) is soluble in neutral ammonium citrate. The main disadvantages of calcium metaphosphate are its (a) dependence on elemental phosphorus, and (b) its slow rate of hydrolysis, making it unsuitable for short duration crops.

Metaphosphoric acid salts

Metaphosphates are salts of metaphosphoric acid. Calcium metaphosphate is one of the important salts of this series.

Meteorology: See Agricultural meteorology

Methemoglobinemia

Methemoglobinemia is a disease which afflicts both humans and animals. It is caused by excess quantities of nitrates and nitrites in water and food. If excess nitrates enter the digestive system, the microbes reduce the nitrate ions to nitrite ions which cause methemoglobinemia. The nitrites transform oxyhemoglobin (the oxygen carrier in blood) into an inactive form of methemoglobin which cannot carry oxygen in blood. This transformation is reversible. When the conversion of nitrates into nitrites is more than 10%, symptoms such as grey or blue skin appear. When the conversion exceeds 40%, the condition can be fatal. The nitrites get into the bloodstream and cause suffocation or blue color in babies. It is also referred to as **nitrate poisoning**. Infants suffering from this condition are referred to as blue babies because of the appearance of greyish-blue skin; and the syndrome is known as the blue baby syndrome.

By UN standards, the acceptable nitrate content in water is 50 mg/l. The other diseases associated with nitrates are goitre, serious birth defects, heart diseases and infections. Methemoglobinemia can also occur in animals fed on nitrate-rich herbage. The strongly reducing conditions in the rumen of cattle and sheep convert ingested nitrate to nitrite. Thus, ruminants are more susceptible to nitrate poisoning than monogastric animals. Some vegetables like spinach and carrots can tolerate high nitrate content.

Excessive application of manure or fertilizer can result in potentially hazardous nitrate content in feed. The excess nitrate enters the soil water through the sub-soil levels and finally reaches rivers causing a serious threat to the environmental balance.

Methane

Methane (CH_4) is a colorless gas produced from a highly reduced paddy field. This odorless gas is also produced by decomposing organic matter in sewage and marshes. It is the chief constituent of natural gas. It occurs in coal gas and water gas and is produced in petroleum refining.

There is now enough evidence to suggest that rice cultivation results in increased methane emission to the atmosphere.

The reasons for interest in methane are that it is an important energy source, which has a global warming potential of about 24.5% (carbon dioxide being 100%), and is responsible for approximately 25% of the anticipated warming.

Atmospheric methane originates mainly from biogenic sources, such as rice paddies and natural wetlands. Rice paddies account for 15 to 20% of the world's total anthropogenic methane emission. In addition to the role of rice plant in methane emission, it also plays a significant role in methane oxidation because oxygen transported below the ground by plants, leaks out of the rhizosphere into the sediments, stimulating the methane oxidizing activity. Most of the methane emitted from rice fields is expected to be from the Asian region as it has 90% of the total world rice harvested area.

Several investigations have demonstrated that methane flux in rice fields is dependent on the variety of rice [dryland, irrigated or deep ponded water], water level, fertilizer application and crop phenology. Strategies to mitigate methane emission from paddy soils of the world have been identified, which include (a) a form and dose of nitrogen and other chemical fertilizers, (b) the mode of fertilizer application, (c) water management, and (d) cultivation practices. Recent studies have indicated that methane emission decreased by about 50% after the application of an ammonium based fertilizer, due to oxidation of methane. The various options to mitigate methane emission are (a) direct seeding of paddy crop, (b) intermittent irrigation, (c) soil amendment with sulphate containing fertilizers, and (d) compost addition in place of fresh organic matter.

Methanogen

The bacteria belonging to the sub-kingdom archebacteria and responsible for the production of methane gas are called methanogens. They respirate anaerobically and tolerate high temperatures and salty environment. They live in swamps and marshes, where oxygen is absent or insufficient.

Methanogens help in decomposition of organic waste by reducing carbon and oxidizing hydrogen, thus producing methane.

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

Since methane is essential for the production of biogas, methanogens are a critical part of the process.

Method of determining acidity or basicity

A method of determining acidity or basicity was developed by **Pierre**. It is based on the assumption that the acid-forming effect of a fertilizer is caused by all the chlorine and sulphur, one-half of the nitrogen and one-third of the phosphorus. However, Andrews modified this assumption to state that it was the entire amount of nitrogen which contributed to soil acidity. There is also another assumption that the presence of calcium, magnesium, potassium and sodium in the fertilizer raises the basicity or pH of the soil.

Mica muscovite

Muscovite is a mineral of the mica group. It has the structural composition of [$KAl_3Si_3O_{10}(OH)_2$]. Mica muscovite is dioctahedral.

Micas

Micas are layer silicates which are rich in potassium. Silicates may be regarded as metal derivatives of silicic acid and are obtained by fusing metal oxides or metal carbonates with sand.

Silicates are insoluble in water, except for silicates of alkali metals. They exist in different forms based on the sharing of one or more faces of silicate (SiO_4) tetrahedral. These are: (a) orthosilicates, (b) pyrosilicates, (c) chain silicates, (d) cyclic or ring silicates, (e) sheet silicates, and (f) three-dimensional silicates. When three oxygen atoms of silicate (SiO_4) tetrahedron are shared with the adjacent tetrahedral, the result is an infinite two-dimensional sheet of composition (Si_2O_5). The metal ions present hold the layers together by weak electrostatic forces. As a result, minerals cleave easily. Micas belong to this class. They are commonly found as small flakes or lamellar plates without a crystal outline.

The most common micas are **muscovite** [$KAl_3Si_3O_{10}(OH)_2$], **paragonite** [$NaAl_2(AlSi_3)O_{10}(OH)_2$], **biotite** [$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$], **phlogopite** [$KMg_2Al_2Si_3O_{10}(OH)_2$] and **lepidolite**. Muscovite and biotite contain about 10% potassium.

Muscovite and biotite sometimes occur in thick blocks, tabular prisms with a hexagonal outline that can be up to several feet across. The prominent basal cleavage is a consequence of the layered crystal structure. Thin cleavage sheets of mica, particularly muscovite and phlogopite, are elastic, flexible and tough. They range from being translucent to transparent, and have a low electrical and thermal conductivity as well as a high dielectric strength. These are, therefore, used as electrical insulators.

Mica sheets can be produced from silicate (SiO_4) tetrahedral - by having a single tetrahedron, share each of its three basal oxygen atoms with a different adjacent SiO_4 tetrahedron. They have Mohs' hardness of 2 to 3 and specific gravities of 2.8 to 3.2.

Commercial mica is of two types: sheet and scrap or flake. **Sheet muscovite** is used as a dielectric in capacitors and as vacuum tubes in electronic equipment. A lower quality muscovite is used as an insulator in home electrical appliances. **Scrap** or **flake mica** is ground for use in coatings on roofing materials as waterproof fabrics; this mica is also used in paint, wallpaper, joint cement, plastics, cosmetics, well-drilling products and a variety of agricultural products.

Mica transforms to the expanding form of 2:1 clay minerals, such as vermiculite and smectite, when hydrated. The exchangeable cations replace the primary interlayer cation.

Micelle

Micelle is an electrically charged colloidal particle, usually organic in nature, composed of large molecules like in soaps and surfactants. Micelles are aggregates of fatty acid anions (soap) having their hydrophobic tails in the interior and their polar heads pointing outward, to interact with polar water molecules. A soap solution is not a true solution. It does not contain individual fatty acid anions dispersed in the water but rather a group of ions (micelles). Thus a soap water mixture is really a suspension of micelles in water, and since the relatively large micelles scatter light, soap water looks cloudy.

Soap dissolves grease by taking the grease molecules into the interior of the micelle, where they can be carried away by the water. Soap can be viewed as an emulsifying agent, since it acts to suspend the normally incompatible grease in the water. Because of this ability, soap is also called a **wetting agent** or surfactant. A major disadvantage is that soap anions form precipitates with cations in hard water, mainly Ca^{2+} and Mg^{2+}.

Phospholipids form a significant portion of the cell membrane and exist in the form of a phospholipid bilayer in an aqueous solution with their tails in the interior and their polar heads interfacing with the polar water molecules. The latter have proteins distributed within. This is very similar to the structure of fatty acid anions.

Microbial immobilization

In immobilization, an element is converted from an inorganic to organic form in microbial mass or plant tissues. In microbial immobilization, soluble nutrients are converted to their non-available forms by the action of micro-organisms.

Microclimate

The climatic conditions near plants and/or the air column (from the ground level) up to a height of 2 m get modified as a result of local parameters, and such a situation is known as the microclimate of that area.

Microcrystalline cellulose: See Anti-caking agent

Microfauna

Animal life distributed over a particular region, habitat or geological period is known as **fauna**. Microscopic animals living in a microhabitat are known as microfauna. These are often too small to be distinguished without a microscope. Microfauna includes protozoa like flagellates, ciliates and amoebae, and nematodes.

Microflora

The entire spectrum of plant life of a particular region, habitat or geological period is called **flora**. Plants that are visible only through a microscope, such as fungi, are known as microflora.

Micro-irrigation

Micro-irrigation is a method of delivering water to the soil, using a low-pressure distribution system, aided by special flow-control outlets. Examples of micro-irrigation are **drip**, **sub-surface**, **bubbler**, **sprinkler** or **trickle irrigation**. All these forms of micro-irrigation have similar criteria of design and management and they deliver water to individual plants or rows of plants (Fig.M.11).

Fig.M.11: Drip irrigation is a form of micro-irrigation. Drip irrigation channels along with emitters are seen in the picture.

The water outlets, which are made at short distances along narrow tubing, ensure that the soil near the plant is wetted; this is unlike **surface irrigation** or sprinkler irrigation which wets a much larger area. The outlets are emitters, orifices, bubblers, sprayers or micro sprinklers, with flows ranging from 2 to 100 liters per hour. A large tree may need six to eight emitters whereas a grapevine may require only one or two.

The micro-irrigation system has many beneficial features, and leads to improved crop quality and yield. It is especially useful for widely spaced plants like cotton, tomato and melons (where water is supplied to the roots without wetting the whole soil surface). The system is also useful for many arid regions for watering high-value crops such as fruit and nut trees, sugar cane, pineapple, strawberry, grape and other vine crops, vegetables and flowers.

Micro-irrigation systems offer the following advantages : (i) Deep percolation losses, field edge losses and evaporation losses are minimized. (ii) Soil evaporation is low (because only a portion of the surface area gets wet). (iii) Weeds are more easily controlled in the non-irrigated portions of the soil. (iv) Bacteria, fungi, pests and diseases are restricted, as the above ground plant parts remain completely dry. (v) The soil water level being high, and yet the plant leaves not being in contact with the water, saline water is likely to be used, causing less stress and damage to the plant. (vi) A high temporal soil water level is maintained and consequently transpiration demand is met. (vii) Water is applied at a low pressure which reduces the chances of run-off. (viii) Prescribed quantities (even small quantities) of pesticides and fertilizers can be injected and be effective. (ix) Drip system can be adapted to steep hills. (x) Less labor is required since the system can be automated .

However, micro-irrigation poses the following constraints in its application: (i) The costs of setting-up the system are high, and the system components, especially the emitters, get clogged easily owing to the lodging of biological and chemical matter. Salinity may pose a separate set of problems, hindering the ideal implementation of the system. (ii) Since only a part of the soil-root volume is wetted, the plant roots may be restricted to the soil volume near each emitter. (iii) Dry soil area between the emitter lateral lines may result in dust formation from tillage operations, and subsequently lead to wind erosion. (iv) Skilled labor is required to operate and maintain the system (although the number of laborers would be small). (v) Rodents may damage the tubing or other rubber/plastic components. (vi) Although micro-irrigation system is successfully used in the case of cotton, sorghum and sweet corn, it does not seem to be too well adapted to field crops in some countries.

Bubbler irrigation is a modification of drip irrigation. A low water pressure and standing open tubes, with all the tube openings at one level, are the features of bubbler irrigation. It is used on slightly sloping lands. All openings of the standing tubes are in one level. The water flow rate depends upon the tube diameter, the water pressure and the elevation of each tube.

Micro sprayers are one of the devices used in micro-irrigation. Their advantages are that they (a) have large nozzle orifices, thus minimizing the problem of the emitters getting clogged, and making the filtration of irrigation water redundant, (b) are operated at pressures of the order of 2 atmospheres, which is much lower than in drip systems, and (c) can be scaled down for use in small farms. The minor disadvantages of micro sprayers are as follows: (i) As wetting of leaves is involved, brackish water cannot be used for this kind of irrigation. (ii) Since the area wetted is larger than in the drip system, evaporation losses and water requirements are high.

Micrometeorology: See Agricultural meteorology

Micronutrient deficiency, quantification of: See Micronutrients

Micronutrient fertilizer production processes

For supplying micronutrients to plants, several methods are in practice. Considering the minute quantity required by plants, micronutrients are either mixed with other primary fertilizers or added to the soil as **frits** or **chelates**.

Chelates are produced by complexing the micronutrient metal with a **chelating agent**. Here the metal combines with the organic molecule and a ring is formed. The chelating agent functions as a carrier of the metal ion and helps the metal ion to remain in mobile form. Chelation prevents the chemical reaction of micronutrient elements in the soil. The commonly used chelating agents are EDTA, EDDHA, DTPA, HEEDTA and CDTA.

The chelates can be either used as foliar spray or added to the soil. Iron chelates are soluble and mostly used as soil application, copper chelates are stable and used for soil application. Zinc chelates are more effective as soil treatment. Manganese chelates have low solubility and so they are more effective as foliar sprays.

Chelates are compatible with dry fertilizers. Chelates can not be mixed with liquid fertilizers if they contain ammonia and free phosphatic acid.

For making frits, the glass components feldspar, soda ash, silica, cryolite, sodium nitrate and borax are thoroughly mixed and fused in a smelting furnace at 900 to 100°C. The molten material is quenched in water, dried and milled. The micronutrient metal is added to the glass before it is fused. Usually the frits contain more than one micronutrient metal. The solubility of the metallic salts in the frits depends on the particle size and change in the composition of the matrix. The water-insoluble fritted material slowly releases the micronutrients contained in it. Frits are generally applied to the soil after mixing them with the fertilizer.

When a micronutrient is mixed with other fertilizers, chemical reactions are likely to occur.

Soluble salts of copper, manganese, iron and zinc are likely to become insoluble when incorporated in ammonium phosphate or ammoniated mixed fertilizers. The reactions may lead to the formation of several metal ammonium phosphates, such as $Zn(NH_4)PO_4$. In general, water solubility decreases with an increase in the pH of the fertilizer. Thus, loss of solubility delays the nutrient availability. Sodium borate, when incorporated in ammoniated fertilizers containing calcium, gets converted into insoluble calcium borate.

Many water-insoluble micronutrients (oxides, carbonates and silicates) become partially soluble when mixed with superphosphates. Some insoluble oxides become soluble when added to ammonium polyphosphates. Zinc oxide and cuprous oxide become soluble when added to ammonium nitrate solutions. The solubility can be increased by adding ammonia to make the pH of the solution 7 or 8, the increase being due to the formation of amine complexes with metal nitrates. The addition of copper in ammonium nitrate increases the sensitivity.

Coating of micronutrients on granular fertilizers reduces the reactivity, but affects its water solubility. Chelated micronutrients incorporated in fertilizers lead to less reaction of the type that causes loss of water solubility. However, high temperatures and use of ammonia and acids in the granulation process can cause decomposition of the chelate and hence loss of the micronutrient availability. Frits, when incorporated in neutral fertilizers, remain as they are but when incorporated in triple superphosphate, increase their solubility.

The following are production methods of micronutrient fertilizer blends.

(i) Dry mixing: The simplest method of producing micronutrients in primary nutrients is by dry mixing. This works well for non-granular materials. Segregation is not a problem when all materials are less than 1 mm in size. However, fine materials tend to cake. For instance, zinc sulphate, when added to primary nutrients, cake the fertilizer. There are hundreds of formulations in use made with non-granular materials. In the Philippines, zinc sulphate heptahydrate is supplied to farmers for mixing with fertilizers. This is used for a basal application for rice to supply 1 kg of zinc per hectare.

(ii) Bulk blending: Bulk mixing is a dry mixing where all nutrients are granular in size ranging from 1.0 to 3.3 mm. One problem is segregation. Unless all materials are of uniform size, segregation occurs in piles, in bins, in spreader trucks or during mechanical spreading. The materials for blending are continuously fed from separate hoppers by weigh belts to a connecting belt where they form layers. Since the bagging hopper is continuously filled and emptied, there is little chance of segregation.

Another problem with blends is the sparse distribution of the micronutrient carriers. For example, only one granule in thirty may be a micronutrient carrier. Also, the higher the concentration of the micronutrient material, the fewer the granules required to provide a given application rate. Intentional dilution of the micronutrient with either an inert material or a primary nutrient material is often resorted to. For example, micronutrients are granulated with clay or vermiculite to produce granules containing 1 to 5% of a micronutrient element or similar percentages of two or more micronutrients.

(iii) Incorporation of micronutrients in granular fertilizers: This is not technically difficult. However, to produce small lots of special grades in large granulation plants is uneconomical. In Europe, there is a demand for boron for root crops and fodder turnips. Boron is incorporated in a superphosphate based PK mixture in amounts of 0.2 to 0.5% boron. Production of ground and granulated PK fertilizers containing trace elements is reported in France. NPK fertilizers containing copper are made in Denmark. Colemanite is added as a source of boron in superphosphate and ammonium sulphate. Several companies market fertilizers containing small percentages of two or more micronutrients. In general, no important technical problem would be expected in incorporating small quantities of micronutrients in fertilizers.

When large percentages of micronutrients are required to be incorporated in fertilizers, some problems may occur. Anhydrous sodium tetraborate is granulated with concentrated superphosphate using steam. A small amount of ammonia is added to reduce the free acidity of superphosphate. However, when pentahydrate of sodium borate is used in place of the anhydrous one, large balls are formed in the dryer, and the granules are soft and weak. This is attributed to the release of water of hydration in the dryer.

Pilot plant studies of granulated ammonium nitrate incorporated with zinc oxide, borax or both in a pan granulator have shown the formation of $3Zn(OH)_2 \cdot NH_4NO_3$, which is water insoluble. Tests have shown that physical properties of the products are as good as those of straight ammonium nitrate and the sensitivity of ammonium nitrate to detonation is not increased by borax or zinc oxide. One company now markets a product containing 30% nitrogen and 10% zinc.

It was found that zinc oxide incorporated in ammonium polyphosphate at 1 to 3% zinc did not react with ammonium polyphosphate in the absence of water. In similar tests with diammonium phosphate-zinc oxide granules, most of the diammonium phosphate dissolved and diffused into the soil while the zinc remained at the granule site as $Zn(NH_4)PO_4$. Substantial percentages of iron, manganese and copper were incorporated in the granular ammonium polyphosphate.

(iv) Coating of micronutrients on granular fertilizers: When small quantities of micronutrients are to be added to granular fertilizers, they should be added as a coating on the fertilizer granules. The coating can be added to any kind of granular fertilizer compound, fertilizers, bulk blends or straight fertilizers. The operation is simple and equipment is inexpensive. Each granule is coated with a micronutrient as opposed to bulk blends containing granular micronutrients in which only one granule in thirty may be a micronutrient carrier.

One drawback of the coating technique is that the addition of a micronutrient lowers the primary nutrient grade. The dilution by a micronutrient can be compensated for by adding less filler. Another method for grade adjustment is by using two materials of different concentrations, such as ammonium sulphate and urea, in varying proportions.

Some micronutrients adhere to granular fertilizers without a binder. For example, finely powdered zinc oxide when applied as a coating to granular ammonium nitrate in a rotary drum, up to 8% of the zinc applied as zinc oxide remains with upto 93% adherence. However, this adherence decreases with time. The spray of steam in the coating drum increases the adherence. More complete adherence is obtained with a lower percentage of zinc oxide.

Most micronutrients need a binder for good adherence to the surface of the granular fertilizer. The binder may be oil, wax, water or fertilizer solution. Batch method is used for uniform coating. In general, the best results are obtained when the micronutrient is finely ground (< 100 mesh). A 1:2 mixture of numbers 2 and 6 fuel oil and of microcrystalline wax and number 2 fuel oil give the best long-term adherence. The amount of the binder ranges from 0.5 to 5.0% of the mixture. In some cases, the addition of 2% clay improves adherence when water is used as a binder. Ammonium polyphosphate is a good binder for zinc, manganese and iron oxides. The oxides react with the solution to give a hard, smooth coating using 3% of the ammonium polyphosphate. Good adherence is observed even after 2 weeks.

More than 97% adherence is obtained by using a solution of 64% ammonium nitrate as a binder for micronutrients on bulk blends. Coating with oil and clay is a common practice for both bulk blends and chemically granulated mixtures. But waxy material for coating proves to be better.

Micronutrients

The elements that help plant growth are called plant nutrients. There are seventeen essential nutrients, some of which are required in large quantities (**macro nutrients**) and some in as small a quantity as about 50 ppm, which are called micronutrient or **minor nutrients**. These are chlorine, iron, boron, manganese, zinc, copper, molybdenum and nickel.

The solubility and availability of micronutrient ions are affected by the presence of complexing and chelating agents secreted from roots and produced during microbial degradation of residues.

Micronutrients and the forms in which they are commonly taken up by plants are given in Table-M.2.

Table-M.2: Soluble forms of micronutrients for plant absorption.

Micronutrient	Nutrient absorption as
Boron	Dissociated/undissociated H_4BO_3
Chlorine	Chloride (Cl^-) anion
Copper	Cupric (Cu^{2+}) cation
Iron	Predominantly as ferrous (Fe^{2+}) cation
Manganese	Manganese (Mn^{2+}) cation
Molybdenum	Molybdate $(MoO_4)^{2-}$ anion
Zinc	Zinc (Zn^{2+}) cation
Nickel	Nickel (Ni^{2+}) cation

Each micronutrient plays a specific role in the growth and development of the plant. Most micronutrients, especially the transition metals (Zn, Fe, Mn, Cu, Mo and Ni) are constituents of many metalloenzymes. They function in key metabolic events such as chlorophyll synthesis, photosynthesis, respiration, protein synthesis, nitrogen fixation, assimilation of nitrates and sulphates, etc. Micronutrients are, therefore, responsible for key processes in plants including those aimed at efficient utilization of even major nutrients.

Each micronutrient has specific functions in a plant system. Important specific roles of micronutrients are given in Table-M.3.

Micronutrients are, to an extent, present in soils. Several soil factors influence their availability to plant absorption, thus determining their deficiency. However, both the deficiency and the requirement are dynamic factors. They vary with the type and properties of the soil, characteristics of the plant, the cultivation and management practices, the level of crop productivity, the supply of fertilizers, etc.

Continuous removal of nutrients from soil reserves, the ever increasing intensity of crop cultivation with the use of high yielding varieties, and adoption of intensive fertilizer applications (major nutrients) cause deficiency of one or more micronutrients in soils and/or plants.

Deficiency of micronutrients in plants is associated initially with hidden deficiency and subsequently visible deficiency. The deficiency that has not expressed itself in the form of any signs or symptoms is called hidden deficiency. In the initial stages of such a deficiency, the plant adjusts itself to the situation. Diagnosing this deficiency is extremely difficult even by leaf analysis, unless the situation is critical. However, any positive crop response to the application of micronutrients is indicative of the existence of hidden deficiency. In fact, hidden deficiency in various crops is far more widespread than it is recognized.

Table-M.3: Important functions of micronutrients in a plant system.

Micronutrient	Functions
Boron	Development of root and shoot growing points, cell division and extension, cell wall development, pollen germination and growth, fruit development, carbohydrate metabolism and protein synthesis.
Chlorine	Evolution of oxygen during photosynthesis, raising/maintaining cell osmotic pressure and tissue hydration.
Copper	Involvement in protein and carbohydrate metabolism, symbiotic nitrogen fixation, lignin formation, catalytic activation of several enzymes.
Iron	Activation of several enzymes, chlorophyll synthesis, respiration, carbohydrate production, nitrate and sulphate reduction and in nitrogen assimilation.
Manganese	Direct role in photosynthesis, splitting of water and in activation of several enzymes.
Molybdenum	Functions in enzymes like nitrate reductase (protein synthesis) and nitrogenase (nitrogen fixation by legumes).
Zinc	Role in several enzyme systems, protein synthesis, auxin synthesis, and starch formation.

Visible deficiency occurs when the plant system is unable to cope up with the hidden deficiency internally. The plant then loses its nutrient balance and expresses a deficiency situation by characteristic visible symptoms. By this time, the problem of micronutrient deficiency is already aggravated. The application of micronutrients at this stage would remedy the situation, but plants may not give yields to their potential. Hence, to obtain high yields, micronutrients have to be applied prior to the occurrence of hidden deficiency and not after that of visible deficiency symptoms.

Quantification of micronutrient deficiency: A micronutrient deficiency is often quantified based on the analysis of the soil/plant samples. The critical limits established for the soil and plants under experimental conditions are used to express the extent of deficiency in the field conditions. Despite limitations, this method is universally followed.

Most research on micronutrients has been mainly focused on a single nutrient basis (e.g., zinc deficiency or iron deficiency). Fertilizers made of a single micronutrient are used to correct specific deficiencies. Deficiency of more than one micronutrient in the same soil/crop can also exist. The intensity of deficiency varies from mild to severe. The problem of multimicronutrient deficiency could be more than what is currently recognized and is bound to increase further as more areas and crops come under investigation. Multimicronutrient fertilizers are being largely used on crops grown under intensive cultivation systems, plantation crops, cash crops, vegetables, fruits, ornamentals, etc.

Micronutrients are applied in many ways, including foliar application, seed treatment, root dipping of transplanted seedlings and application with pesticides. However, the most popular method is to apply micronutrients with primary nutrients that the farmer regularly uses. This helps him save the time he would have otherwise spent for micronutrient application. Also, by this method, the micronutrients can be uniformly applied when mixed with a much larger volume of fertilizers.

Micro-organisms as extractants: See Diagnostic techniques

Microscope

A microscope is an instrument that provides magnified images of small objects. It is primarily used for study of the physical structure and identification of materials. A compound microscope, phase contrast microscope, dark field microscope, fluorescence microscope and electron microscope are some types of microscopes that cover a wide range of magnification requirements. For example, a compound microscope is used for observing micro-organisms used in the production of biofertilizers.

A simple microscope consists of a biconvex magnifying glass or an equivalent system of lenses, either hand-held or fixed in a simple frame. The widely used binocular microscope gives stereoscopic vision and reduces eye strain (Fig.M.12). Organic dyes of various types are used to stain samples for precise identification.

A compound microscope utilizes two lenses or lens systems, wherein the first forms an enlarged image of the object and the second further magnifies the image. The total magnification is then the product of the magnification of both the lens systems. Resolving power is a quantitative measure of the closest distance between two points that can still be seen as distinct points when viewed in a microscope field; it depends largely on the characteristics of the microscope's objective lens and the optimal illumination of the specimen. The image may be seen, photographed or sensed by photocells, or other receivers, depending on the nature of the image and the end-use of the information.

Although there is no limit to the theoretical magnifying power of the optical microscope, magnifications greater than about 2000× can offer no improvement in resolving power. The shorter the wavelength of the ultraviolet light, the better the resolution and the higher the useful magnification. For a still finer resolution, recourse to electron beams and electromagnetic focusing is resorted to. The field ion microscopes offer the greatest magnifications as of now.

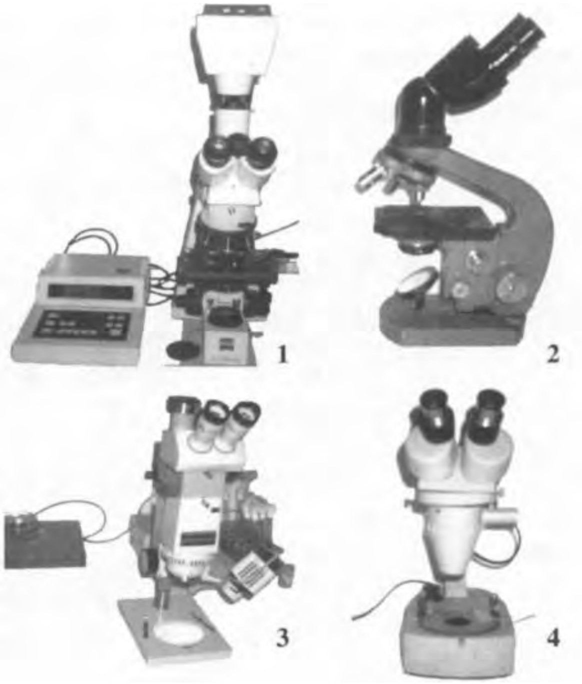


Fig.M.12: Types of microscopes: 1. Phase contrast microscope, 2. Research microscope, 3. Dissecting microscope, and 4. Stereoscopic microscope.

Micro sprayers: See Micro-irrigation

Middle lamella

The middle lamella is a sticky substance composed of calcium pectate and is a part of the cell wall, acting as cement, to glue the cells together (Fig.M.13). The cell wall, which is not a solid structure, has one or two layers and surrounds the cell membrane of plants, fungi and algae, but not of animals.

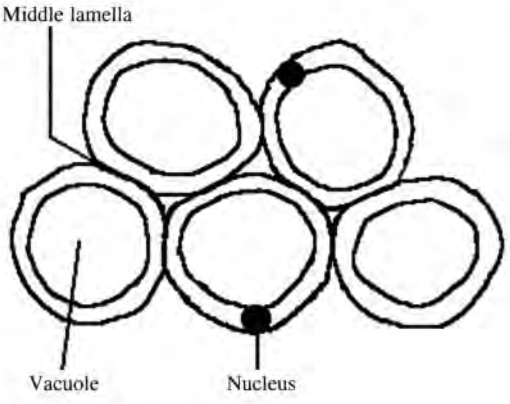


Fig.M.13: Middle lamella seen in the rounded parenchymatous cells of a plant.

Milliequivalent

The equivalent weight concept is based on the principle that the reagents react in their equivalents (that is, in the 1:1 ratio). The equivalent weight of a substance depends on the type of reaction it undergoes.

For an acid-base reaction, an equivalent weight is the quantity of a substance that will produce or react with one mole of hydrogen ion (H^+). The following examples illustrate the concept.

(i) Since 1 mole of HCl produces 1 mole of H^+ ions,

1 mole of HCl = 1 equivalent of HCl

(ii) Since 1 mole of H_2SO_4 produces $2H^+$ ions,

1 mole of H_2SO_4 = 2 equivalents of H_2SO_4

1 mole of H_2SO_4 = 98.08 g

1 equivalent H_2SO_4= 98.08 g/2 = 49.04 g = the equivalent weight of H_2SO_4.

A milliequivalent is 1/1000 of the equivalent weight, which is sometimes more convenient for use in calculations of exchangeable cations and cation exchange capacity. Currently, centimole per kg (cmol/kg) is the unit used.

Milk development: See Milk stage

Milk stage

The growth cycle of a cereal is divided into ten principal growth stages and each one is further divided into secondary growth stages. The milk stage is one of the principal growth stages in the growth cycle. In this stage of grain development, the grain yields a milky substance when pressed. This milky substance is the starch portion of the grain. The milk stage is also known as **milk development** or **milky ripe**.

The knowledge of the growth stage is useful in deciding the right time for agricultural operations, such as the top dressing of nitrogen and application of herbicides, insecticides and fungicides.

The growth stage is useful in order to identify the critical stages of the life cycle of plants. These are sensitive to environmental factors and help to improve the crop yield. For example, in cereals and for most crops, the reproductive and ripening stages are more sensitive to water deficiency than the vegetative stage.

The most common method for identifying growth stages in cereals is known as **Feekes' scale** which considers the external appearance of the plant or plant organs. In wheat, the embryo ear has its full complement of spikelets well before the ear emerges from the flag leaf sheath.

Milky ripe: See Milk stage

Millimho

Millimho is a unit of electrical conductivity, or a reciprocal of resistivity of the material. The conductivity is measured in Siemens/meter in the SI units. For fluids, the electrolytic conductivity is given by the ratio of the current density to the electric field strength.

1 millimho/cm = 0.1 Siemens per meter = 1 dS per meter

The electrical conductivity of the soil extract is used to categorize the soil as saline, sodic or saline-sodic. It can also be employed to estimate the soil moisture content. This technique is known as the **resistance block method** and is based on the principle that electrical conductivity decreases with a decrease in soil moisture.

Mineral

Mineral is a loose and inexact term that may be defined chemically as any element, inorganic compound or a mixture occurring in the earth's crust and atmosphere. Inorganic gases like nitrogen, oxygen, hydrogen, carbon dioxide, chlorine, etc are regarded as minerals. Biologists use this term to indicate the non-living 'kingdom' of nature. Carbon-rich substances and mixtures such as coal, petroleum and asphalt, often called minerals, are organic materials that are not original components of the earth's crust and thus are not true minerals. The term was wrongly used by many chemists for a variety of substances such as mineral acid, mineral black, mineral oil, mineral water, mineral wood, etc.

Nutritionists use this term for such components of foods as iron, copper, phosphorus, calcium, iodine, selenium, fluorine and trace micronutrients.

Mineral epsomite

Magnesium sulphate is a white compound that exists in both anhydrous (rhombic) and hydrated crystalline forms. The commonest hydrated form is the heptahydrate $MgSO_4 \cdot 7H_2O$ (rhombic) which occurs naturally as mineral epsomite.

Mineral fertilizers

Mineral fertilizers are artificial or synthetic inorganic chemical fertilizers either mined or made by chemical processes. These include urea, diammonium phosphate (**DAP**), monoammonium phosphate (**MAP**), single superphosphate (SSP), triple superphosphate (**TSP**), etc.

Mineral gypsum

Mineral gypsum, a non-metallic mineral, is the natural source of gypsum.

Gypsum deposits were formed millions of years ago, when oceans started receding from large portions of the land, leaving behind salt deposits mixed with minerals and organic matter. Gypsum deposits are found as flat stratified beds of rock with alternate layers of gypsum, limestone and shale. Gypsum beds are rarely more than 20 feet in thickness.

Gypsum is widely extracted since it is used extensively in various products such as a soil amendment, for construction, in toothpaste, as moulds in clay utensils and artefacts, as casts for making metal tools, car parts, instruments, as Plaster of Paris, in dentistry, etc.

Gypsum is composed of 79.1% of calcium sulphate and 20.9% of water by weight, and has a chemical formula $CaSO_4 \cdot 2H_2O$. The two water molecules known as "**water of crystallization**" for its crystalline nature, turn into vapor at 100°C, giving gypsum. Mineral gypsum has impurities which make the rock look grey, pink or brown.

The Michigan basin (USA) is well known for its gypsum deposits. Mineral gypsum assumes importance since gypsum plays an important part in reclaiming alkali soils. However, gypsum as phosphogypsum, being a major by-product of the phosphorus industry, is a source of anxiety from the point of view of the environment.

Mineralization: See Mineralization, biological

Mineralization, ammonium form

In non-fertilized soils, nitrogen is released by the decomposition of organic material. The conversion of organic nitrogen to ammonium (NH_4^+) is known as **mineralization**, which involves two reactions – aminization and ammonification, both occurring through micro-organisms that get the necessary energy from carbon compounds. A warm, moist, well-aerated soil is ideal for decomposition.

Mineralized ammonium ions have a short life. If the decomposing organic matter contains low nitrogen relative to carbon (C/N ratio > 20), the micro-organisms immobilize ammonium (NH_4^+) or nitrate (NO_3^-) in the soil by converting them into organic nitrogen, which is basically the **reverse of mineralization**.

The measurement of actual or gross rates of mineralization and immobilization requires the use of isotopes with ^{15}N being used almost exclusively. In general, ^{15}N can be used in two contrasting ways to examine **mineralization-immobilization turnover (MIT)**. These are the (a) **tracer methods** in which ^{15}N is added as the substrate to the process of interest, and (b) **pool dilution methods** in which ^{15}N or $^{15}NH_4^+$ is added to the product pool of the transformation of interest. Mineralization rates can be assessed by tracer techniques in which the ^{15}N labeled plant material or other ^{15}N organic substrates are added to the source pool, and the fate of the added ^{15}N, monitored. In the pool dilution approach, $^{15}NH_4^+$ is added and the dilution of its enrichment by the production of $^{15}NH_4^+$ by mineralization is monitored over a period of time.

Mineralization, biological

The conversion of large and complex organic nitrogen substances (like proteins) into smaller and simpler inorganic forms such as ammonium ions (NH_4^+) is known as **mineralization**. The conversion is brought about by the heterotrophic micro-organisms. Nitrogen is absorbed by plants, either in the cationic or the anionic form as ammonium (NH_4^+) or nitrate (NO_3^-) ion. This process is known as **biological mineralization**. Some specific enzymes like amidinohydrolases, amidohydrolases, dehydrogeneses, glycosidases, nucleases, proteinases, peptidases, etc. are involved in mineralization of nitrogen in soil.

Mineralization increases with the rise in temperature, soil moisture and also with a good supply of oxygen. Waterlogged conditions slow the rate of conversion. Since proteins and peptides are the major sources of mineralizable nitrogen, the enzymes degrading these compounds are produced abundantly and in a wide diversity by soil micro-organisms. The activity of urease in soils has been studied widely because of the use of urea as the most important fertilizer. Urease catalyzes the following reaction:

$$CO(NH_2)_2 + H^+ + 2H_2O \longrightarrow 2NH_4^+ + HCO_3^-$$

In warm moist soils, urea hydrolyzes to ammonium ion (NH_4^+) within a few days. The released ammonium ion (NH_4^+) is then readily available for immobilization, nitrification or volatilization.

Mineralization-immobilization turnover: See Mineralization, ammonium form

Mineralization of sulphur

Mineralization of sulphur is the conversion of organic sulphur into an inorganic sulphate ion. Most sulphur needs of plants are fulfilled by mineralization of sulphur as in the case of nitrogen. **Immobilization of sulphur** is the conversion of the sulphate ion to organic sulphur. The factors affecting the growth of micro-organisms also affect immobilization.

Sulphur mineralization depends on the sulphur content of the organic matter, as also the temperature. The process is almost stopped at 10°C and its rate increases with temperature from 20°C to 40°C, and decreases beyond 40°C. Mineralization of sulphur in soils is reduced at moisture levels below 15% and above 40%. Gradual moisture changes in the range between the **field capacity of soil** and the **wilting point** have little influence on sulphur mineralization. Generally, soils mineralize more sulphur in the presence of growing plants than without them.

Sulphur is immobilized in soil that has a very large C/S or N/S ratio. Above a C/S ratio of 200, immobilization or tie up of sulphate is favored and below this value, mineralization occurs. An appreciable immobilization of the added sulphate has been observed in uncultivated soils.

Mineral mascagnite

Ammonium sulphate $(NH_4)_2SO_4$ occurs naturally as mineral mascagnite. It can be stored for long periods. It offers many advantages as a fertilizer because of its low hygroscopicity, good physical properties, excellent chemical stability and agronomic effectiveness.

Mineral nutrients

A mineral nutrient is a general term used for all plant nutrients. Most nutrients occur naturally in various minerals.

Mineral phosphate

Mineral phosphate is a natural mineral found as a geological deposit. It is found on a large scale in sedimentary rocks. The largest constituent of mineral phosphate is calcium phosphate. It is also called **rock phosphate**.

Mineral potassium

Mineral potassium or **reserved potassium** are the terms used when more than 99% of the total soil potassium is in the non-exchangeable form.

Mineral soils

Most soils are mineral soils. Rocks on weathering, produce mineral soil material which may get translocated by wind, water and gravity. But wherever these loose and undeveloped materials are deposited, they are subjected to weather changes over the years. With the passage of time, there might be an addition of organic matter, leading to the development of some horizons. These developments finally lead to the mineral soil formation.

Mineral soils contain compounds of oxygen, silicon and aluminum with some iron, calcium, potassium or magnesium. They generally contain less than 20% organic matter which at its surface layer is less than 30 cm in thickness. In most mineral soils, the dominant colloids are clay minerals.

The thick and dark surface horizons of mineral soils which occur due to the accumulation of organic matter contain sizeable mineral soil material.

Minimum bulk density

Minimum bulk density or **loose pour bulk density** is defined by the ISO as mass per unit volume of the material after it is tipped freely into a container under clearly specified conditions.

Minimum tillage

Minimum tillage, also called **reduced tillage** or **conserved tillage**, means tilling the land to the barest minimum. In this cultivation practice, there is a conservation of energy, time, labor and machinery cost. Similarly, this practice also minimizes erosion by rain and wind and avoids damage to the soil structure. However, minimum tillage is not applicable under all farming situations, as it can accentuate weed problem. It is not suitable for poorly drained soils and for crops that require fine tilth, as in the case of nurseries, and small-seeded crops like sesame and mustard.

Minor nutrients

Minor nutrients is another term for **micronutrients**.

Mire

Mire is a term commonly used synonymously with **peat land** in Europe. Mire is peat land where peat is being formed and accumulated.

Miscellaneous adjuvants: See Adjuvants

Miscellaneous processes for producing ammonium chloride: See Ammonium chloride production processes

Miscibility

The ability of a liquid or gas to dissolve uniformly in another liquid or gas is termed miscibility. Gases mix with one another in all proportions. This may or may not be true for liquids, where miscibility properties depend on their chemical nature. Alcohol and water are completely miscible because of their chemical similarity, but some liquids are only partially miscible because of their chemical difference. For example, formaldehyde mixes readily with water, whereas carbon dioxide is only partially miscible with water.

Liquids that do not mix at all are said to be immiscible. Oil and water are immiscible with each other. The term 'solubility' is often erroneously used as a synonym of miscibility.

Miscibility criterion is considered for making compounds or complex and liquid fertilizers.

MIT

MIT is the short form of **mineralization-immobilization turnover**.

Mitochondria

Mitochondria are structures within the cytoplasm of cells of plants and animals which are responsible for aerobic respiration. Mitochondria synthesize most of the cell's adenosine triphosphate, and are the chief energy sources of living cells. They vary in shape, size and number but are normally oval or sausage-shaped and bounded by two membranes, the inner one being folded into finger-like projection.

Mitochondria contain their own DNA called mitochondrial DNA. Mitochondria are the most numerous cells with a high level of metabolic activity. They are highly plastic, mobile structures which fragment or fuse together at random. Many enzymes, especially those involved in converting food-derived energy into a form usable by the cell, are located in the mitochondria and DNA molecules.

Yeast is a particularly rich source of mitochondria for research purposes.

Mitscherlich b value

E. A. Mitscherlich and his co-workers conducted extensive studies on the effect of soil nutrient quantities on the dry matter yield. They found the two to be related by a simple exponential function, which could be fitted to the observed yields from incremental fertilizer applications. This has resulted in a yield-response curve that describes the expected yield as a continuous smooth function of the nutrient availability; its extrapolation to the X-axis gives the Mitscherlich b value which is the estimated quantity of an immobile but available form of the nutrient, such as phosphorus or potassium. Such estimates can be made from the field or greenhouse data. The availability index gives an assessment of the ability of the soil to supply nitrogen under given conditions.

Mitscherlich c values

Mitscherlich c values describe the efficiency of conversion of the added nutrient into the plant dry matter. The efficiency depends on the percentage of the applied nutrient actually taken up by plants and the amount of dry matter produced per unit of the nutrient uptake.

The significance of the term c is that it gives an indication of whether the maximum yield level can be achieved by a relatively low or high quantity of the specific growth factor. When the value of c is small, a large quantity of growth factor is needed and vice versa.

Mitscherlich equation for plant growth and nutrient supply

Mitscherlich's concept states that a plant produces maximum yield if all conditions are ideal. The absence of any essential factor results in corresponding reduction in the yield. Assuming that an increase in the yield per unit increment of the lacking factor is proportional to the decrement from the maximum, E.A. Mitscherlich developed an equation based on the relationship between the growth of plants and the supply of plant nutrients. The Mitscherlich equation is:

$$\frac{dy}{dx} = (A-Y)C$$

where dy is the yield increase from an increment dx of the growth factor X, A is the maximum possible yield, Y is the yield obtained for a given amount of X, and C is the proportionality constant or efficiency factor. This concept is known as the Mitscherlich's equation for plant growth and nutrient supply and is also used in the calibration of tests with crop response.

Mixed acid

Mixed acid is a mixture of sulphuric acid (61 %) and nitric acid (36 %) used for nitration.

Mixed acid process for nitrophosphate production

There are two processes used for making nitrophosphate fertilizers - the **Odda process** and the **mixed acid** process.

Ammonium phosphate nitrate (**APN**), nitric phosphates and ammonium nitrophosphates are nitrophosphate fertilizers produced by reacting phosphate rock with nitric acid.

In the mixed acid process, calcium nitrate does not precipitate and separate. The water-solubility of phosphate is increased by adding phosphoric acid to decrease the $CaO:P_2O_5$ ratio. The mixed acid route covers a range of formulations with the nitrogen to phosphorus ($N:P_2O_5$) ratio ranging between 0.5 and 2.0.

Mixed acid route: See Ammonium phosphate nitrate; Nitrophosphate production processes

Mixed farming

Mixed farming is a system of farming in which crops as well as animals are raised on the same farm.

Mixed fertilizer

A mixed fertilizer is any homogeneous product containing two or more plant nutrients. It usually contains two or more **major nutrients**. It is made chemically, or by blending, or by both methods. A mixed fertilizer may include micronutrients and secondary nutrients.

Mixed fertilizers, which are also called **compound fertilizers** or **complex fertilizers** or fertilizer mixtures, are generally granular, free flowing and easy to apply uniformly. They have a relatively high nutrient content. Among examples of mixed fertilizers are nitrophosphates.

Fertilizers may also be physically mixed, with or without an inert material necessary to make up the required grade, and without allowing a chemical reaction.

The physical mixture of a fertilizer is generally classified as **homogeneous** or **heterogeneous**. In homogeneous mixtures, the molecules are interspersed, as in a mixture of gases or in solution. Heterogeneous mixtures have distinguishable phases, like in a mixture of iron filings and sulphur. Unlike compounds, mixtures can be separated by physical methods like distillation, crystallization, etc.

Fertilizer solids of different densities and sizes are mixed in a double-cone blender or with agitators for a defined period; mixing for too long or too short a period causes the components of the fertilizer mixture to separate and this must be avoided.

Mixed salts production during ammonium sulphate manufacture

Mixed salts of ammonium sulphate and ammonium nitrate are made by ammoniating a mixture of sulphuric acid and nitric acid or by combining these ammonium salts in special ways to form three double salts identified below:

$(NH_4)_2SO_4 \cdot NH_4NO_3$, $(NH_4)_2SO_4 \cdot 2NH_4NO_3$, and $(NH_4)_2SO_4 \cdot 3NH_4NO_3$.

One German process produces $(NH_4)_2SO_4 \cdot NH_4NO_3$ containing 62% ammonium sulphate and 38% ammonium nitrate, by ammoniating the requisite mixture of sulphuric and nitric acids. The mixture is evaporated to a moisture content of 3%. About 1% ferrous sulphate is added to prevent caking. The double salt is granulated after spraying ammonia solution.

In a simpler process, ammonium nitrate solution is evaporated to 95% concentration, cooled to 130°C and reacted with solid ammonium sulphate in a pug mill granulator until a pH of 4.0 is attained. The product is then dried, cooled and bagged. Prilling can also be adopted.

The TVA (Tennesse Valley Authority) produced ammonium sulphate-ammonium nitrate contains 30% nitrogen. It is used mainly for sulphur-deficient soils. This product is also made by ammoniation of a mixed acid followed by pan granulation of the resulting slurry. Its storage properties are superior to those of ammonium nitrate or a mixture of solid ammonium nitrate-ammonium sulphate since free ammonium nitrate is absent.

When mixtures of sulphuric acid and phosphoric acid are ammoniated, a variety of mixed and double-salt products can be made. One of the popular compositions is '**ammophos**' containing 16% nitrogen (N) and 20% phosphorus (as P_2O_5). The ammoniated slurry is granulated in a pug mill or a drum unit, dried and screened. The mixed salt has good storage properties under normal conditions.

Many methods have been developed to recover sulphur from flue gas, involving scrubbing with ammonia or injection of ammonia into flue gas. From these reactions, ammonium sulphite, bisulphite, sulphate and their mixtures result. Because the demand for ammonium sulphate fertilizer is low, the sulphur from the flue gases is disposed of as calcium sulphate. (See also Ammonium sulphate production processes.)

Mixing

The process of agitating a set of ingredients until the dispersion reaches uniformity is known as mixing. Low-viscosity liquids and suspensions are mixed with impellers of a turbine. The mixing action results both from direct contact of the impeller blades with the liquid, and from the turbulence induced by the impeller in the outer portions of the liquid. For this reason, the diameter of the impeller must be only from one-fourth to one half of that of the container.

For medium viscosity liquids, various shapes of revolving paddles are used.

For very high viscosity liquids, helical rotors, sigma blades and similar devices are necessary. There are a number of ingeniously engineered types of mixers used for mixing plastic, rubber, food products and fertilizer mixtures. Dry solid particulates are mixed in rotating cylinders or tumbling barrels as in the case of NPK compound fertilizers. Urea, ammonium phosphate and potassium chloride or nitrate are mixed to get a NPK fertilizer.

Mixotrophs

Mixotrophs refer to organisms capable of utilizing both autotrophic and heterotrophic metabolic processes. The concomitant use of organic compounds as sources of carbon and energy is an example of mixotroph.

Mixtatol

Mixtatol, a plant growth regulator, is a mixture of long-chain fatty alcohols, and is popularly used in the USA. Mixtatol controls the lateral shoots of tobacco plants by inhibiting the development of the axillary buds. Alcohols commonly used in mixtatols are octanol, decanol, n-octa cosanols, n-triacontanol and their substitutes. Mixtatol affects the rate of photosynthesis. In ornamentals, this 'chemical pruning' leads to more abundant flowering and improved branching.

Plant growth regulators are non-nutrient chemicals which do not occur naturally in plants, but influence their growth and development. Growth regulators have been found as having the greatest potential for increasing corn yields in the USA.

Mixture

A mixture is a heterogeneous association of substances which cannot be represented by a chemical formula. Its components may or may not be uniformly dispersed, and can usually be separated by mechanical means.

Liquids that are uniformly dispersed are called **solutions**. Mixtures may be natural or artificial. Natural mixtures are air, petroleum, milk, latex, vegetable oils and sea water. Artificial mixtures include, for instance, glass, paint, fertilizers, plastics, alloys and cements.

Mobile element

A mobile element is an available element. The availability of a biogenic element is difficult to determine as the availability depends on (a) the plant itself, (b) the force of retention of the element by the soil colloids, and (c) the content of the element at that instant in the soil water.

Mobility

Mobility refers to the ease with which a liquid moves or flows. Hydrocarbon liquids with a low viscosity, surface tension and specific gravity respond more readily to an applied force than does water (a polar liquid). For this reason fires involving hydrocarbon liquids should be extinguished with foam rather than with water.

Mobility of a nutrient

The mobility of a nutrient is the rate of movement of a nutrient ion toward the plant roots. Mobility can be achieved by **mass flow** or by **diffusion**. The mobility of ions such as nitrate and chloride is high as the ions are held loosely by soil particles; the mobility of ions like dihydrogen phosphate ($H_2PO_4^-$) is low because the ions tend to hold on tightly to soil particles.

Mobility of nitrogen in plant

The tendency of the younger upper leaves to remain green even as the lower ones turn yellow or die indicates the mobility of nitrogen in the plant. When plant roots are unable to absorb nitrogen, proteins in the old leaves are converted into soluble nitrogen for synthesis of new proteins.

Mobility zone, fertilizer: See Fertilizer mobility zone

Moder

There are three principal types of forest humus - moder, **mor** and **mull**. Moder is forest humus of aerated soils with moderate incorporation of slightly transformed organic matter.

Besides the main types, there are two transitional types of forest humus: **Moder-mor humus** and **moder-mull humus**. These layers exhibit overlapping features of moder, mor and mull. (See also Forest humus types.)

Moderately well-drained soil

The classification of soils depends upon factors like the level of water table, the permeability of soil and the topographic conditions. Moderately well-drained soil is one of the soil drainage classes, and shows slight gleying.

Moder-mor humus: See Moder

Moder-mull humus: See Moder

Modified Morgan's method

The **Morgan reagent** is a multi-nutrient extractant primarily used for estimation of P, S, Ca, and Mg in acid soils, and in soils with a low cation exchange capacity. In the modified Morgan method, the extractant is 0.62M ammonium hydroxide (NH_4OH) or 1.25M acetic acid (CH_3COOH), with pH 4.8. Morgan's method as well as his modified method are unsuitable for calcareous soils.

Modified Solvay process

In the conventional Solvay process, an ammoniated solution of sodium chloride (30%) is treated with carbon dioxide in absorption towers to form ammonium carbonate, which on further carbonation produces ammonium bicarbonate. The sodium chloride present gets converted to sodium bicarbonate and ammonium chloride. The sodium bicarbonate is separated by filtration or centrifuging. In **Solvay process**, the reaction reaches equilibrium at about 75% completion and mother liquor is reacted with lime to recover ammonia for reuse.

$$2NH_4Cl + Ca(OH)_2 \longrightarrow CaCl_2+2NH_3+2H_2O$$

In the modified Solvay process, instead of recovering ammonia, the mother liquor is chilled below 15°C and salted out by adding washed sodium chloride. The precipitated ammonium chloride is centrifuged, washed and dried. This is used in compound fertilizers.

$$\begin{aligned} 2NH_3 + H_2O + CO_2 &\longrightarrow (NH_4)_2CO_3 \\ (NH_4)_2CO_3 + CO_2 + H_2O &\longrightarrow 2NH_4HCO_3 \\ NH_4HCO_3 + NaCl &\longrightarrow NaHCO_3 + NH_4Cl \end{aligned}$$

Mohs' scale

Mohs' scale is a scale of hardness used in classifying minerals. The scale, introduced by German scientist, Friedrich Mohs, ranges from 1 to 10 with talc as the softest and diamond, the hardest. The position on the scale depends on how easily a mineral can be scratched. The positions are not of equal value. The difference in hardness between 10 and 9 is much larger than that between 1 and 2.

Diamond	10
Corundum	9
Topaz	8
Quartz	7
Orthoclase	6
Apatite	5
Fluorite	4
Calcite	3
Gypsum	2
Talc	1

A recent addition is Fused Zirconia - 11.

Moisture absorption-penetration characteristics

Hygroscopic properties of a substance can be quantified by measuring the critical relative humidity and its moisture absorption-penetration characteristics. Factors such as chemical composition, particle porosity, particle surface area and degree of crystallinity affect the moisture absorption-penetration characteristics of the fertilizer. Knowledge of these characteristics is important in order to decide the storage conditions, and to predict the flowability of a fertilizer during handling and movement for field application.

Moisture barrier: See Barrier, moisture

Moisture content of fertilizers

The percentage of water by weight in a fertilizer (as measured by one of the standard methods) is known as the moisture content of the fertilizer. It is also described as the **moisture percentage**.

Moisture deficit index

The moisture deficit index is a measure of the dryness of a region and is given by

$$\text{Moisture deficit index} = \left[\frac{P - PE}{PE}\right] \times 100$$

where P is the mean annual precipitation and PE is the mean annual potential evaporation.

Moisture holding capacity

The moisture holding capacity represents the maximum amount of moisture that a granule can absorb before it becomes wet enough to transfer the moisture to the adjacent granules by capillary action. A high moisture holding capacity is a desirable characteristic in granules. It can offset effects of the high rate of moisture absorption, and may be related to both the chemical composition and the porosity of the granules.

Pure crystalline materials, like ammonium nitrate and urea, have a low moisture holding capacity. Impurities like iron and aluminum phosphates from the wet-process acid decrease the crystalline phase and increase the amorphous phase in fertilizers. They prove beneficial by increasing the moisture holding capacity.

Moisture index

A moisture index is an index of the relative aridity or humidity of a climate. It is given by the difference between the mean annual rainfall (P) and the mean annual potential evaporation (PE).

Moisture percentage

Moisture content of fertilizers is also called moisture percentage.

Moisture profile

A soil profile comprises a succession of layers, called the **soil horizons**, resulting from the transformation, migration or displacement (generally vertical) of certain constituent elements of the soil. The moisture profile of a soil indicates variations in the moisture content of the soil at a given point and time. By varying the time and by selecting the characteristic moisture contents, it is possible to draw up a moisture diagram of the soil.

Moisture regimes

Moisture regimes are different levels of the available soil moisture during the year, expressed as percentages. They are used in conducting irrigation experiments.

Moisture suction: See Soil moisture tension

Mol

Mol is the abbreviated form of **mole**.

Molal concentration

The molal concentration or **molality** is the amount of the substance in gm moles per unit mass of the solvent (mol/kg). Molality is yet another way of expressing the composition of a solution. Molality is the number of moles of solute per kilogram of solvent in a solution. In very dilute aqueous solutions, the molality and **molarity** are almost the same.

Molality: See Molal concentration

Molarity

Concentration is an important property of mixtures, because it defines the quantitative relationship of the components. It is measured in various ways. Molarity, which is defined as the moles of solute per unit volume of the solution in liters, is the most commonly used expression for concentration. One gram molecular weight of a substance dissolved per unit volume has units of mol per dm^3 or **mol** per liter. A solution of 1.0 molar (written as 1.0M) contains 1.0 mole of solute per liter of solution. A solution concentration is given in terms of the form of the solute before it dissolves.

Molasses

Molasses is the thick liquid left over after sucrose is removed from the mother liquid in sugar manufacture.

Blackstrap molasses is the syrup from which no more sugar can be obtained economically. It contains about 20% sucrose, 20% reducing sugars, 10% ash, 20% non-organic sugars and 20% water. It is combustive and non-toxic.

Mole

Mole (abbreviated as **mol**) is defined as the number of carbon atoms in exactly 12 grams of pure C. Techniques such as mass spectrometry (which counts the number of atoms), have been used to determine this number as 6.0221367×10^{23}.

Mole is also called **Avogadro's number**. The quantity of a substance that contains Avogadro's number of units, indicated by the formula of the substance, is called a mole. It can be applied to a wide variety of items such as atoms, molecules, ions, electrons, chemical bonds, etc.

A mole of $CaCl_2$ (111.1 MW) is 6.0221367×10^{23} $CaCl_2$ units, which when bifurcated, contains 6.0221367×10^{23} Ca^{2+} ions (40.1 g) and $2 \times (6.0221367 \times 10^{23})$ Cl^- ions (2×35.5 g). Thus, the mole of calcium chloride consists of one mole of calcium ions and 2 moles of chloride ions. The mass of one mole of an element is equal to its atomic mass in grams.

Moles of different elements or compounds contain the same number of molecules, called Avogadro's number, leading to the conclusion that moles of ideal gases occupy the same volume at the same temperature and pressure.

Molecular sieves

Molecular sieves are a group of adsorptive desiccants which are crystalline aluminosilicates, chemically similar to clays and feldspars, belonging to a class of minerals known as **zeolites**. The most important characteristic of these materials is their ability to undergo dehydration with little or no change in crystal structure. The dehydrated crystals are interlaced with regularly spaced channels of molecular dimensions, comprising almost 50% of the total volume of crystals.

The empty cavities in activated molecular sieve crystals have a strong tendency to recapture the water molecules that have been driven out. This tendency is so strong that if no water is present, they will accept any material that can enter or filter into them. However, only those molecules that are small enough to pass through the pores of the crystal can enter the cavities and be adsorbed on the interior surface. This sieving or screening action, which makes it possible to separate smaller molecules from the larger ones, is the most unusual characteristic of molecular sieves.

Molecular sieves are used in many fields of technology to dry gases and liquids. They are also used for selective molecular separations based on such size and polar properties as ion-exchangers, as catalysts and in petroleum industry to remove normal paraffins from distillates.

Molecular weight

Molecular weight is the sum of the atomic weights of the atoms in a molecule. The molecular weight of ammonia is 17.0031, based on the atomic weight of N (which is 14.007) and of H (which is 1.008). The chemical formula used in such a calculation must be the true molecular formula of the substance designated. For example, the molecular formula of oxygen is O_2 and its molecular weight is 31.998 (atomic weight of oxygen = 15.999). The molecular formula of ozone is O_3 and its molecular weight is 47.997.

The true molecular weight of a gas or vapor is found by measuring the volume of a given weight and then calculating the weight at 22.4 liters at 0°C and 760 mm of pressure. The molecular weight of many complex organic molecules runs as high as over a million (proteins and high polymers).

Molecular weight can be found directly by mass spectroscopy or deduced from the related physical properties. The other methods involve lowering of vapor pressure and freezing point, and raising of boiling point. For large molecules, an ultra centrifuge is used.

Molecule

Molecule is the smallest fundamental unit of a chemical compound that can take part in a chemical reaction. It is a chemical unit composed of one or more atoms.

Simplest molecules contain only one atom, as in helium. An oxygen molecule contains 2 atoms and the molecular formula of oxygen is O_2. An ozone molecule has three atoms of oxygen and its molecular formula is O_3. Molecules may contain several kinds of atoms.

Water (H_2O) contains two different kinds of atoms – hydrogen and oxygen. Dimethylamine [$NH(CH_3)_2$] has three kinds of atoms. Molecules of common gases like oxygen, nitrogen, hydrogen and chlorine have two atoms each. The atoms of a molecule are held by chemical bonds. Molecules have a wide range of size from less than 1 to more than 500 millimicrons and the weight varies from 4 (for helium) to 40 million (for tobacco mosaic virus).

Mole drainage system

The mole drainage system is a type of **sub-surface drainage system**. It uses shallow drainage channels of around 30 cm depth made in a fine-textured soil by pulling a sharp object (a mole) through it. This system is useful in cases where temporary drainage is needed, for example, during rapid reclamation of salty lands. Redoing of channels is possible easily and cheaply.

Mollic

Diagnostic **soil horizons** have descriptive names. They are divided into two categories: **epipedons** and **endopedons**. Mollic horizons are a type of epipedon, which are found on (or near) the surface, and are 20 to 30 cm thick, except in sandy soils when they are around 18 cm thick. They become saturated with water during some seasons and contain at least 1 percent organic matter.

Mollic horizon or mollic epipedon is formed out of **mollic soils**. This surface horizon has a thick and dark layer, has more than 50% base cation saturation, and is not hard and massive when dry.

Mollic horizon, when plowed, has a non-massive structure, and a color of chroma value darker than 3.5 when moist and 5.5 when dry. The mollic horizon has less than 250 ppm of phosphorus (as P_2O_5) which is soluble in 1% citric acid.

Mollic epipedon

Mollic epipedon is another word for **mollic horizons**. (See also Mollic.)

Mollic horizon: See Mollic

Mollisols

The soil order mollisols is one of the 12 soil orders in the US soil classification system. They are among the most important soils for food and fiber production. They are dark-colored, naturally fertile soils, which occur mostly in climates ranging from semi-arid to sub-humid.

Mollisols develop under grasses or under broad-leafed forest trees, are rich in calcium and have large amounts of organic matter. Mollisols have the largest number of suborders indicating the diverse nature of these soils.

Mollisols are commonly associated with calcareous deposits or high base glacial drift deposits. They are also associated with limestone and loess. Mollisols, especially the suborder udolls, are known as the breadbasket soils of America and Eurasia.

Mollisols are divided into 7 suborders – Albolls, Aquolls, Rendolls, Xerolls, Borolls, Ustolls and Udolls.

Molybdenosis: See Molybdenum

Molybdenum

Molybdenum (Mo) is a plant micronutrient, absorbed by the plant roots only in the form of molybdate ion MoO_4^{2-}.

Molybdenum, belonging to Group 6 of the Periodic Table (Fig.M.14), is a vital component of the enzyme, nitrate reductase (a soluble molybdoflavoprotein) in plants.

Molybdenum is present in the chloroplasts of leaves. It is also a structural component of nitrogenase which plays an active role in nitrogen fixation by ***Rhizobium***, ***Azotobacter*** and some algae and actinomycetes. Molybdenum is also involved in the absorption and translocation of iron in plants.

Molybdenum is present in soils in extremely small quantities (about 2 ppm or less) which is adequate for

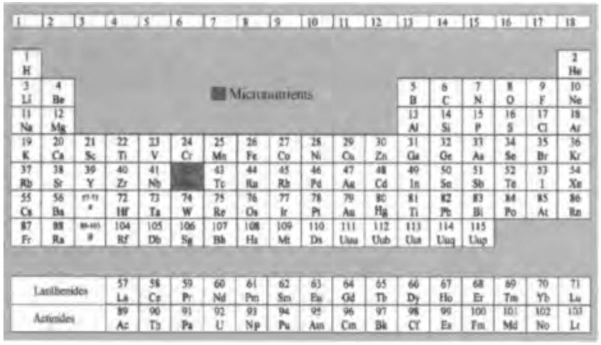


Fig.M.14: Position of molybdenum, a micronutrient, in the Periodic Table.

plants. Its availability increases as the soil pH increases when the conversion of molybdenum oxide to molybdate is favored.

The presence of aluminum, iron and titanium in soil increases the absorption of molybdenum. Nitrate nitrogen encourages molybdenum uptake, while ammoniacal nitrogen reduces it. A heavy application of phosphatic fertilizers increases the uptake of molybdenum while that of sulphates has the reverse effect. The addition of lime increases the availability of molybdenum. A dose of concentrated soluble manganese and/or copper reduces molybdate absorption by plants.

When the molybdenum content of plants is less than 0.2 ppm, **molybdenum deficiency** occurs. The deficiency is determined by the ammonium oxalate extraction procedure. Acidic soils, fibrous peat soils and acidic sandy soils are generally molybdenum deficient. Molybdenum concentration is high at the soil surface, and decreases with depth; the deficiency is severe under dry soil conditions, probably owing to reduced diffusion or mass flow.

Molybdenum deficiency resembles nitrogen deficiency in legumes, because of the role molybdenum plays in nitrogen fixation. The deficiency causes stunting and yellowing of plants. In legume crops, the deficiency manifests itself by marginal scorching, curling and crinkling of leaves (Fig.M.15), the first symptom being an interveinal chlorosis followed by the plant turning pale yellow and becoming stunted.

Mo deficiency, manifested in cauliflower, is known as **whiptail** and that in cashew, the **yellow leaf spot** (as seen in Fig.M.16). The deficiency is most common in acidic sandy soils because of the leaching losses. Molybdenum availability is low in soils with high metal oxides. Cauliflower, Brussels sprouts, broccoli and citrus fruits are sensitive to low molybdate levels (Fig.M.17). Cotton, leafy vegetables, corn, tomato and sweet potato are moderately sensitive to lower molybdate levels.

Molybdenum deficiency also causes nitrate accumulation, thereby lowering the activity of ascorbic acid oxidase, known for activating enzymes, namely, nitrate reductase and xanthine oxidase.

Fig.M.15: A leaf of cauliflower showing molybdenum deficiency. A healthy leaf is seen on the right. (Source: "Handbook on Fertiliser Usage", 1994, S.Seetharaman, et al. (Ed). The Fertilizer Association of India, New Delhi. Picture used with permission.)

Molybdenum deficiency can easily be corrected by adding 40 to 400 g Mo/ha to the soil. It can also be corrected by a foliar spray of sodium molybdate or molybdic acid, or by coating seeds with sodium molybdate before planting. Even a 0.03% foliar spray on cashews can correct the deficiency. Soil is limed to increase plant uptake of molybdenum.

Fig.M.16: Molybdenum deficiency on leaves showing yellow-orange spots. Affected areas extrude resinous gum through the lower surface.

A trace of molybdenum as impurity in superphosphate is often adequate for plant growth. A material carrying at least 38% molybdenum, such as sodium molybdate, is employed to coat the seed, about 17 g/ha of which is used for legumes on molybdenum-deficient soils. Such seed treatment is the most practical way for augmenting the molybdenum content of the soil.

Ammonium molybdate is recommended for potato at the rate of about 1 kg/ha for soil application, 0.5 kg in 1000 liters of water for sprays and 200 g for soaking seed tubers. A disease, called **pencil point**, in coconut can be cured with a 0.25 g/l of ammonium molybdate as a component of the fertilizer mixture.

Many fertilizers contain molybdenum. The common ones are ammonium molybdate (54%), sodium molybdate (39%) and molybdenum trioxide (66%) – the

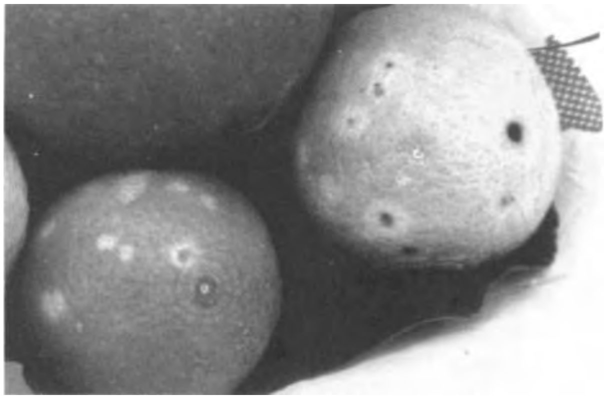


Fig.M.17: Molybdenum deficiency symptoms on citrus fruits.

figures in brackets indicating the molybdenum percentage. Among these, only ammonium molybdate is recognized under the Fertilizer Control Order (FCO) in some countries (like India), although sodium molybdate is the most commonly recommended molybdenum carrier. Molybdenum is mixed with NPK fertilizer and then applied. It was demonstrated in Australia that soaking seeds in sodium molybdate solution before sowing was as effective as applying molybdenum in the fertilizer. In the United States, the seeds are often coated with sodium molybdate.

Molybdenum toxicity is associated with vein clearing, necrosis, and golden yellow dissolution in the middle of the lamina in plants because of the formation of molybdeocatechol complex. Excess of molybdenum is toxic to animals feeding on forage rich in molybdenum. **Molybdenosis**, is a cattle disease, caused by a copper and molybdenum imbalance in the diet, with the molybdenum content exceeding 5 ppm. Molybdenum toxicity provokes stunted growth and bone deformation in animals. This disease is also known as '**teart**' in England and '**peat scours**' in New Zealand. Injecting copper or adding copper fertilizer to the grazing areas can correct the imbalance.

As already mentioned, soils generally contain very low quantities of molybdenum. In most Indian soils (other than acidic soils), for instance, the total available molybdenum ranges from traces to a fraction of 1 ppm, and even with this minute quantity the soil exhibits no molybdenum deficiency.

Molybdenum deficiency: See Molybdenum

Molybdenum frits

Molybdenum frits are melted soluble glass particles containing measured quantities of molybdenum. Frits are a source of effective soluble micronutrients for many crops, especially because of their slow-release property.

Molybdenum toxicity: See Molybdenum

Monoammonium and diammonium phosphate production processes

Monoammonium phosphate (MAP) and diammonium phosphate (DAP) both contain nitrogen and phosphorus nutrients and have good physical properties. The standard grade or commodity grade for DAP is 18-46-0, whereas there is no such standard grade for MAP. Compounds containing both MAP and DAP are also produced.

Pure DAP and MAP are made by crystallization processes using phosphoric acid, the latter being made from an electric furnace process or while purifying phosphoric acid from the wet-process.

The ease of granulation and the storage property of the granules depend on the impurity content. The presence of gel-like impurities as well as aluminum and iron phosphates promote granulation and serve as conditioners in preventing caking. The citrate-soluble P_2O_5 is more influenced by operating conditions than by metallic impurities.

TVA basic process: Granular DAP is generally produced by slurry process using wet-process phosphoric acid of about 40% concentration. The acid reacts with ammonia in a preneutralizer in a mole ratio of NH_3 to H_3PO_4 of about 1.4. The heat of reaction raises the temperature to the boiling point (115°C) and evaporates some moisture. The hot slurry containing 16 to 20% DAP is pumped to the granulator where more ammonia is added to increase the mole ratio to 2.0. The moist granules from the granulator are dried and screened, while the undersized and oversized ones are recycled. The usual ratio of recycle to product is 5:1. The escaping ammonia from the process is scrubbed with water.

The same equipment is used for MAP either by using an NH_3:H_3PO_4 mole ratio of 0.6 with the balance ammonia being added to the granulator, or by operating the preneutralizer at a mole ratio of 1:4 and adding phosphoric acid to the granulator to reduce the mole ratio to 1.0. During the production of MAP, there is no ammonia scrubbing.

The improvements in the TVA-type process for DAP is to replace the preneutralizer with a pipe reactor. Ammonia and phosphoric acid react in the pipe reactor which discharges directly into the granulator. Steam generated by the reaction is released in the granulator and swept out with a current of air. The modification of the process is simpler and less expensive. Also, this process uses more concentrated acid (and hence, less water) at the granulation stage and the recycle ratio is decreased. A pipe reactor plant, working in Australia, has a recycle ratio of 3:1 compared to 5:1 for tank preneutralization. Another process modification of the T-reactor in DAP production was carried out by Danos of Jacob Engineering Group Inc., which eliminated the need for drying.

Jacobs-Dorrco industrial process: The Dorr-Oliver (now Jacobs) slurry granulation process for DAP is almost similar to the TVA process except in (a) ammoniation which is carried out in three reaction vessels operating at NH_3:H_3PO_4 ratios of 0.6, 1.4 and 1.85, and (b) granulation of the slurry which is carried out in the blunger. The recycle ratio is about 8:1 and ammonia losses are recovered by acid scrubbing. Both MAP and the grades between DAP and MAP could be produced by this process.

The efficient use of pipe reactor for the production of ammonium phosphate and NPK provides a means of improving the water balance and the energy efficiency compared to those in the preneutralizer process. Because the reaction is confined in such a small space, the heat balance of the process is generally improved as well.

Major advantages of the pipe reactor process, compared to the preneutralizer process are summarized as follows: (a) low investment cost with no preneutralizer and a low recycle ratio, (b) a lower operating cost with no heating energy, low electric power consumption and a high efficiency of ammonia consumption, (c) a high adaptability in the use of feed stocks - phosphoric acids from various origins and concentrations can be used, (d) a higher operating flexibility and stability with a well proven scrubbing system and effective control of granulation conditions, (e) a wide range of products like MAP, DAP and various grades of NPK, and (f) a low environmental impact because of the low emission of gases, in accordance with the stipulations of the **Environmental Protection Agency** (**EPA**, USA). The P_2O_5 in DAP, made by the pipe reactor process, is almost completely citrate-soluble.

TVA pipe-cross reactor: The pipe-cross reactor is very similar to T-reactor. Ammonia enters the pipe along the horizontal axis and phosphoric acid enters at right angles. There is an additional inlet through which another feed can be added, at right angles to the ammonia stream. Pipe-cross reactors are operated at below one atmosphere gauge (0.2 to 0.7 MPa) pressure. The major advantages are the following: (i) Because of a higher boiling point of the slurry, ammonia losses are less when material is sprayed into the granulator. (ii) The viscous slurry makes the distribution more uniform, as also the quality of the product. (iii) Because of a low moisture content (4 to 6%), the recycle rate can be reduced in the granulation. The discharge from the reactor is fed directly into the granulator. The granules are cooled partially before screening and final cooling takes place during storage.

The pipe-cross reactor is made of a 316L stainless steel pipe of 25.4 cm diameter and 13.72 m length. 10.36 m of the pipe is outside the granulator and is inclined at 10 degrees. The slurry discharges from the pipe about 0.90 m above the bed of the material in the granulator. The airflow through the granulator is about 1.22 m per sec.

Uhde GmbH process: This process is also a pipe reactor process, automated (by a computer program) to provide stable operating conditions. The acid from the scrubbing section together with the main acid stream is fed to the pipe reactor to which ammonia and sulphuric acid are added. Two pipe reactors are used to produce 1000 tons of DAP per day. Slurry from the pipe reactors discharges on to the recycle in the granulator. The recycle ratio is between 3 and 4 and the granulation temperature is from 100 to 110°C. Moisture content of the product is around 2.6 to 2.8%.

The product from the granulator is dried and cooled in a counter current flow of air at ambient temperature. After screening, the oversized granules and the fines are recycled and the correct sized materials are cooled in a fluid bed cooler. The process has a recycle conveyor and the recycle takes place only by gravity. Single deck screens and a lump crusher are provided outside the main recycle stream. The same plant can produce a wide variety of NPK products with additional raw materials. A recycle ratio of 1.5 to 2.0 may be achieved in NPK production.

S.A Cros technology: A number of plants are using this technology developed by S.A. Cros. A pipe reactor is used for DAP production. The slurry leaving the pipe reactor contains 4 to 5% moisture. The recycle ratio is about 2. The temperature for granulation is kept below 90°C. Though a multinutrient NPK production is possible in a pipe reactor, the Cros technology uses a mixed process that uses both a pipe reactor and a preneutralizer depending on the product capacity.

ERT-Espindesa technology: In this process, the reactions of MAP and DAP are completed within the pipe reactor and hence no further ammoniation is necessary. Since additional ammonia is not needed, a powdered or granular product can generally be made easily. The pipe reactor is located near the top of the 17 m high tower and fed with phosphoric acid and ammonia. The NH_3 to phosphoric acid ratio is adjusted to give the required product with a moisture content of 4 to 6%. Powdered MAP is removed from the bottom of the tower at 60°C.

The DAP process has the unusual feature where all the phosphoric acid feed is used in the two stage ammonia scrubber to recover the lost ammonia.

Depending on the impurities in the phosphoric acid, the reactor can be made of 316L stainless steel or Uranus B6. The pipe diameter and length are variables depending on the production process. For example, a 25 ton per hour DAP plant has a diameter of 10.2 cm and a length of 6.1 m, of which 1.52 m is inside the granulator. The discharge from the pipe reactor is directly fed to a rotary drum granulator for recycling. The recycle ratio is between 2.5 and 3.5. The moisture content is below 3%. The ammonia gas in the exhaust is passed through the scrubber before venting.

AZF process: AZF process also uses pipe reactors. They have a high recycle ratio for higher analysis products, such as 17-17-17 or 23-23-0. This high recycle rate is due to admission of the slurry and the steam at a high temperature into the granulator to raise the temperature of the granulating material, increase the solubility and the liquid phase. The situation calls for some heat release elsewhere, which is accomplished by placing a second reactor system. In the dryer, the pipe reactor is fed with ammonia and phosphoric acid and the N:P ratio is controlled at 1.05 to produce MAP. The backpressure fluctuates from 3 to 5 bar. The gases from the granulator and dryer are scrubbed in venturies by recirculating ammonium phosphate, ammonium sulphate or a mixture of their solutions.

While producing DAP, about half of the phosphoric acid is fed to the pipe reactor in the dryer. Most MAP formed in the dryer of the pipe reactor crystallizes in the dryer or adheres to the fine particles and is removed by screening and/or sent for recycling to the granulator. The DAP is actually formed in the granulator. However, by producing a part of the MAP in the dryer, the recycle ratio can be reduced to about 3 and the heats of reaction and crystallization are used fully in drying the product.

Norsk hydro process: Another attempt to limit energy consumption is the use of a pressure reactor as developed by Norsk Hydro Fertilizers. The advantages of this process are that the solubility of ammonium phosphate increases with temperature, and the boiling point of the solution increases with an increase in pressure. By applying pressure to the reaction system, the boiling point is increased and hence reactors can be operated with a much lower water content.

Raytheon process: This is basically a TVA process incorporating industrially proven developments. Some of the developments attributed to Raytheon are as follows: (i) A two stage reactor-granulator scrubbing system to ensure high ammonia recovery, a good control for water balance and for reducing fluoride emissions. (ii) A discharge trommel or dryer, which destroys lumps without a lump crusher. (iii) An improved dryer lifting mechanism. (iv) Improved process screen arrangement that permits a higher efficiency. (v) Adjustable venturi throats on scrubbers, which can improve environmental emissions while in operation. (vi) A simplified and effective dust control system. (vii) A large sump to collect wash water for recirculation, as also for heating water and supplying to total plant washing. (viii) Distributive control system with auto-sequential startup and shutdown features including data logging, graphing process variables and printing periodic production reports.

Non-granular MAP: The process of making non-granular MAP has been developed by **Scottish Agricultural Industries** (**SAI**), Fisons Ltd., Swift Agricultural Chemicals, Nissan and ERT-Espindesa. All processes aim at a simple, low-cost method of eliminating granulation, recycling and drying. Though MAP production is declining, MAP is still used as a cheap and efficient method of solidifying sludge phosphoric acid. MAP is important for the production of complex fertilizers in developing countries.

Fison's minifos process: In the Fison's process, phosphoric acid (50% P_2O_5) is reacted with ammonia under pressure (gauge pressure 2.1 kg/cm^2). The heat of reaction drives off part of the water as superheated steam. The remaining slurry containing 9 to 10% water is at a temperature of 170°C and has a pH of 3.5 to 4.0. The hot slurry is sprayed from the top of the tower to get products in the range of 10-50-0 to 12-50-0, having a 6% moisture and a size of 0.1 to 1.5 mm.

Swift process: In the Swift process, phosphoric acid (50% P_2O_5) and liquid ammonia are injected into a pipe reactor to get a mixture of finely divided MAP and steam which are injected into a cooling tower where counter current air stream carries away the water vapor formed. This cools the product. The moisture content is around 3 to 5%. In the **Nissan process**, droplets of phosphoric acid and ammonia react in a spray tower in an ascending air stream.

Scottish Agricultural Industries process (**SAI Process**): In the SAI process, phosphoric acid (50% P_2O_5) is neutralized in a reaction vessel with ammonia to a mole ratio of about 1.35 and the resulting hot slurry is mixed with more phosphoric acid in a specially designed twin-shafted mixer (like a pug mill). This helps in disintegrating lumps into small particles, releasing water vapor. The product, called "**PhoSAI**", generally contains 6% moisture, 11% nitrogen and 50% water soluble P_2O_5. The process is also modified to produce non-granular diammonium phosphate, called **Di-PhoSAI**. The storage and granulating properties of MAP depend on the manufacturing process used. Better properties of MAP, made by a low temperature SAI process, are attributed to impurities forming a gelatinous coating on the MAP crystals.

Monoammonium phosphate

Solid or liquid phosphorus fertilizers are manufactured by reacting anhydrous ammonia with orthophosphoric acid or superphosphoric acid. Anhydrous ammonia added to liquid phosphoric acid gives monoammonium phosphate (**MAP**), a phosphorus fertilizer, which contains about 11% nitrogen and 21% phosphorus. The reaction is :

$$NH_3 + H_3PO_4 \longrightarrow NH_4H_2PO_4$$

Pure monoammonium phosphate is completely water soluble and contains 12% nitrogen and 21% phosphorus (52% P_2O_5). Monoammonium phosphate is prepared popularly by the ERT Espindesa process. (See also Monoammonium and diammonium phosphate production processes.)

Monoammonium phosphate, ERT-Espindesa process for: See ERT-Espindesa process for non-granular monoammonium phosphate

Monoammonium phosphate production process: See Monoammonium and diammonium phosphate production processes

Monocalcium phosphate

Monocalcium phosphate is one of the components (the other being calcium sulphate) of single superphosphate. Single superphosphate is a principal phosphate fertilizer. It also supplies two secondary elements, namely sulphur and calcium as it contains 21% calcium.

Monocalcium phosphate of single superphosphate dissolves in soil moisture and in that form the roots absorb phosphoric acid. The rest of the solution of monocalcium phosphate precipitates in soil pores and forms different phosphate compounds which are not water-soluble and do not leach out.

Monocarpellary

Carpel is the female reproductive organ of a flower, comprising a stigma, style and ovary. When flowers have a single carpel, the condition is termed as monocarpellary.

Monocot plants: See Monocotyledonous plants

Monocots: See Seed

Monocotyledonous plants

Plants which posses only one seed lobe are known as monocotyledonous or **monocot plants**. Upon germination, the seed lobe serves as a food reservoir for germination process, but it stays in the soil. Example of monocot plants are maize, rice, wheat, grasses and other grain crops.

Monoculture, crop

Monoculture refers to the practice of planting the same crop on the same plot of land for several consecutive years. (See also Crop monoculture.)

Monodentate ligands

Monodentate ligands such as water, ammonia, carbon monoxide, halides are ligands which have only one point (bond) of attachment to the metal. Hexaquacopper (II) ion $[Cu(H_2O)_6]^{2-}$ and tetrachloroplatinate (II) ion $[PtCl_4]^{2-}$ are complexes containing monodentate or unidentate ligands.

Monohydrate of zinc sulphate

Zinc sulphate is the most common zinc salt (about 35% of zinc) used for preventing zinc deficiency in plants. The most common form of zinc sulphate is **zinc sulphate heptahydrate**, $ZnSO_4 \cdot 7H_2O$. This, above 70°C, forms monohydrate. Monohydrate of zinc sulphate is used as a fertilizer to prevent zinc deficiency.

Monosaccharides

Monosaccharides are non-hydrolysable sugars, for example, glucose and fructose. These are sweet in taste and soluble in water, and are the building blocks of various carbohydrate molecules.

Monosaccharides containing an aldehyde group are called **aldoses**, whereas those containing a ketone group are called **ketoses**.

The most important monosaccharides contain five carbon atoms (pentoses) or six carbon atoms (hexoses). An important hexose is fructose which is found as sugar in honey and fruit.

Generally, monosaccharides have one isomer that is more common in nature than the others.

Monsanto Enviro-Chem process for sulphuric acid manufacture: See Sulphuric acid production processes

Monsanto Enviro-Chem's heat recovery system: See Sulphuric acid production processes

Monsoon

Monsoon is a wind system in which the prevailing wind direction reverses the course of the seasons, which occurs when large temperature differences arise between the ocean and the land masses. The best known monsoon is that of South-East Asia. In summer, moist winds associated with hurricanes blow from the Indian Ocean into the low pressure region of north-western India caused by intense heating of the land. In winter, cold dry winds sweep southwards from the high pressure region of southern Siberia.

The moisture laden air is responsible for much of the rains in the tropical and subtropical regions. The monsoon rains are generally torrential during this period and vary from year to year. There are two monsoon seasons in India: the South-West monsoon in summer and the North-East monsoon in winter. The South-West monsoon enters the state of Kerala around May and withdraws around the end of September. The North-East monsoon is cyclonic and bimodal in nature.

Monsoon forest

The forests in the region where rainfall is restricted to a certain period of the year are monsoon forests. Monsoon forests in SouthEast Asia receive heavy rainfall interspersed with periods of drought.

Montmorillonite

Clays exist in many forms, of which montmorillonite is one form. Kaolinite and montmorillonite, which are clay minerals, have different layer structures with differing abilities to absorb and retain water, and to adsorb and exchange cations.

Montmorillonites have an expanding structure (2:1) and have high cation exchange capacity (80 to 120 mg per 100 g). They have abundant black clay soils. Other minerals in this group are biedellite and nontronite. (See also Smectite; Bentonite.)

Mor

One of the three principal types of forest humus is mor. Mor or acidic humus is found in coniferous forests. (See Forest humus types.)

Morgan reagent

The Morgan reagent, a mixture of 0.7M sodium acetate and 0.54M acetic acid with pH 4.8, is a multi-nutrient extractant. It is primarily used for the estimation of P, S, Ca and Mg in acidic soils and in soils with low cation exchange capacity. The critical value for extraction is in the range of 4 to 6 mg/kg of nutrients.

The extractant can also be used for estimating nitrate (NO_3^-) content. The process of estimating NO_3^- in the extractant involves taking 5 cm^3 of air dried soil sample (< 10 mesh sieved to 2 mm) in a flask containing 25 ml of extractant. The sample is then shaken for 5 minutes in a mechanical shaker and filtered immediately.

In the **modified Morgan method**, the extractant is 0.62M NH_4OH and 1.25M CH_3COOH, with pH 4.8. Both methods are unsuited to calcareous soils.

Morphology of roots: See Root morphology

Mosaic

Mosaic is a leaf symptom in which numerous small areas of discoloration stand-out against a background of a different tint. It leads to a clearly defined boundary, delineated by veins, and a pattern of green angular areas against a predominantly yellow background. Alternatively, the areas bounded by the veins may be chlorotic giving a yellow-on-green mosaic. If discrete areas of color later coalesce, a mottle symptom may result.

Most probable number method for estimation of VAM population

Estimation of **VAM** (vesicular arbuscular mycorrhizae) propagule populations in soils can be carried out by two methods: the most probable number (**MPN**) method, and the **mycorrhizal soil fertility (MSF) method**. These methods evaluate the number of viable propagules (number of micro-organisms per gram of soil) based on the proportion of plants found to be mycorrhizal after growth in a series of soil dilutions. These methods eliminate single-spore counts which are very time consuming and which require several weeks of plant growth before evaluation of the plant root colonization.

Mother plant

A plant from which progeny is produced either by seed or by vegetative propagation is called a mother plant.

Mottle

Mottle is a leaf symptom in which small but numerous areas of discoloration, commonly chlorotic and irregularly shaped and without sharply defined boundaries, stand out against a background of different tints, the pattern being unrelated to the vein network. Leaf mottles indicate deficiency of some nutrient, for example, zinc deficiency.

Also the soil that undergoes periods of inadequate aeration because of waterlogged conditions, gets spots of rust color called mottles.

Mottle leaf

Zinc deficiency is known by various names in different crops. In citrus crops, zinc deficiency is called mottle leaf or **frenching**.

Mould

A mycelial micro-fungus or a visible growth of such a fungus is called mould. A blue mould or a green mould is caused by *Penicillium* spp., a grey mould by *Botrytis cineria*, a sooty mould by one of the members of family Capnodiaceae.

The term is, however, sometimes used incorrectly for the growth of *Cladosporium* spp. and other fungi giving black powdery appearance on foliage.

Movement of fertilizer

The relative mobility of a nutrient in soil is of prime importance. N, S, B and Cl are considered to be mobile in soils.

Nitrogen is mobile in soil but can easily be lost from the root zone. Phosphorus is considered relatively immobile in soils. It is subjected to a number of reactions and transformations that can reduce its availability to plants. Placement techniques of phosphorus-containing fertilizers can minimize the effects of these transformations, enhancing the phosphorus availability. Nutrients reach the roots by **mass flow**, by diffusion and/or by the root interception.

The movement of soluble fertilizer salts from the point of application differs from one salt to another. Soil properties and climatic conditions influence the movement. The movement of phosphorus is generally limited since the $H_2PO_4^-$ ion is only slightly mobile in soil. The nitrate ion moves more readily than nitrogen in the ammonium ion (NH_4^+) form. Potassium is also relatively immobile because, like ammonium, it is adsorbed on the soil colloidal complex. As the soil dries out, the soil water moves upward and deposits salts on the surface. The soluble salts move downward with rains.

Soluble salts in excessive concentration can be injurious to plant roots and germinating seeds. This occurs through **plasmolysis**, which is the contraction and leakage of the protoplast of a plant cell consequent upon the loss of water from the cell. Plasmolysis results in a limited moisture availability or actual toxicity, known as **fertilizer burn**. Free ammonia, urea, DAP, ammonium carbonate [$(NH_4)_2CO_3$] and ammonium hydroxide (NH_4OH) may cause more damage than MAP, ammonium sulphate [$(NH_4)_2SO_4$] and ammonium nitrate (NH_4NO_3).

Broadcast application or fertilizer placement is effective in avoiding salt injury. Potential problems related to fertilizer salts are the greatest in coarse-textured soils.

MPN method

MPN is short for **most probable number method** for the estimation of VAM population.

MRR

MRR is short for **marginal rate of return**.

MSF method for estimation of mycorrhizal population

One of the two methods for the estimation of VAM propagule populations in soils is the MSF or **mycorrhizal soil fertility method** (the other being the **MPN method**). (See also Mycorrhizae.)

Mucilage

Mucillage refers to a viscous or gelatinous solution obtained from plant roots, seeds, etc.

Mucilages are slippery or gelatinous solutions, like those from cluster beans, linseed, locust bean and related leguminous plant seeds.

Generally plant mucilages are insoluble in alcohol, but some are partly soluble in water and alcohol. From various types of salt-water algae, the so called **seaweed mucilage**, such as agar, algin and carrageenin (algal polysaccharides) may be obtained by extraction with hot water. Mucilages are closely related to gums, however the distinction between them is not always clear.

Muck

Muck is a soil in which organic material is decomposed almost beyond recognition. Muck contains more mineral matter than **peat** or **bog**, and has a darker color.

Mulch

A natural or artificial cover placed on the soil surface, to protect it from rapid drying, erosion or compaction is called mulch. Mulch may be soil, gravel, paper, asphalt, plastic sheeting or plant residues (like leaves, straw, groundnut hulls, peat, etc.). A loose surface horizon that forms naturally or is produced by cultivation, consisting of organic or inorganic materials, is also called mulch.

Some soils (such as vertisols) swell when wet and shrink when dry. Year after year, the surface layer of this soil churns and remixes. Such soils are called **self-mixing soils**. As a result of this movement, loose, crumby crusts form on the soil surface and protect the soil structure from the impact of raindrops. This phenomenon is known as **self-mulching**. Successive freezing and thawing also cause self-mulching.

Mulch acts as a temperature modifier. It acts like a barrier to the loss of moisture from the soil. In cold areas or during cold seasons, a good plastic cover helps to increase the soil temperature and plant growth (Fig.M.18). Mulches in the form of plant residues act as insulators and retard warming in very hot summers.

Wet mulch in the form of organic matter reduces moisture loss effectively. But since such mulch is not suitable for longer periods of time, artificial mulches are often used.

During sprouting and early periods of growth, moisture retention by mulch becomes critical for the survival of plants. It is reported that strips of petroleum mulches (15 to 22.5 cm wide and 10 to 20 mm thick) help the seeds planted in February and March in Southern California to germinate and develop into more vigorous seedlings. These mulches are reported to retain the moisture and increase the temperature of the soil.

Organic matter used as surface cover reduces soil erosion, keeps the soil cool even in very hot seasons and warm in severe winters. A thick layer of organic matter stabilizes the soils of the Arctic Circle. The destruction of that layer causes very serious soil erosion.

Mulching with organic matter is very useful in areas where wind and water cause extensive erosion of the

Fig.M.18: Use of plastic sheets for mulching is common in groundnut cultivation.

exposed soil. Coarse surface mulch increases the seepage of water into the soil. Straw mulch increases the penetration of rainwater. A surface organic matter cover insulates the soil from heat.

Mulch tillage is a kind of tillage where plowing partially incorporates the grain stubble. A part of the straw or other organic residue is not plowed back into the soil, but left standing on the soil surface to protect the soil against erosion from wind, rainfall and flowing water. It is also called **stubble mulch farming**. Following are examples of stubble effectively used for preventing erosion at different places. Cape Cod beach grass is used as a dune stabilizer; emerald crown vetch is useful in the Corn Belt; pink lady winterberry, a shrub from China, is used as a windbreaker (and also as food for wildlife); **tegmar** - a Turkish wheat grass, is used for diverting waterways. All these are referred to as stubble mulching.

For mulching the subsoil, a vertical band of mulching material is poured in a vertical slit in the soil. This is called **vertical mulching**.

A special technique called **hydro mulching** is used for covering of the slopes of road cuts by grass, to protect slopes from erosion. Here, the slurry of fibers, seeds, fertilizer and chemicals is sprayed on the slope. These materials help to hold the seed in place till it germinates, gets established enough to hold on to the soil and prevent erosion.

Placing an impermeable strip of plastic or other materials in the shape of an inverted U over banded fertilizer in rows is called a **strip mulch**. It is particularly effective in areas receiving heavy rainfall, or where excessive water is added by sprinklers. The strip mulch system is an economical and effective method to prevent fertilizers from being washed away from the plant beds during heavy rainfall on sandy soils. The system that keeps the percolating water away from the fertilizer and reduces leaching of the fertilizer is called **raincoat**.

Mulch tillage: See Mulch

Mull

There are three principal types of forest humus - **moder**, **mor** and mull. Mull or alkaline humus is found in grasslands and deciduous forests. (See also Forest humus types.)

Multicote : See Antifloat materials

Multimeter

A multimeter is an instrument used for measuring resistance in ohms. It also measures both the current and the voltage.

Multi-nutrient fertilizer: See Compound fertilizers

Multiple proportions, law of: See Chemical combination, laws of

Multiplication factors: See Recommended dosage of fertilizer

Municipal compost

When sewage sludge and municipal garbage are composted, municipal compost or **town compost** is formed. It contains typical nutrients like nitrogen (1.5 to 2.0%), phosphorus as P_2O_5 (around 1.0%) and potassium K_2O (1.5%). However, it may also contain pathogens, viruses, parasite eggs and non-organic harmful material. The compost can, therefore, be a health hazard which can be partially overcome by heating the compost during decomposition. But heating does not remove non-organic materials like lead, strong acids, etc. which harm plants. While some toxic substances, harmful to plants and animals, are produced during composting, municipal compost is still used as **manure**.

Munsell color code

Soil color is an important diagnostic tool widely used to describe and classify soils. Soil colors are easily and accurately determined by comparing them with the Munsell color charts scheme devised in the USA.

The Munsell color code consists of a certain number of sheets, each one representing a hue. Each hue consists of small, colored rectangles, with a value given on the Y axis and the chroma on the X axis. A uniform soil color can be determined easily. However, if there is any mottling, it is necessary to designate the color of the matrix and then of the spots. It is proper to specify whether the color is in the dry or moist state and, if possible, to state the color in both the conditions. The color is noted for each horizon, which in some cases is of fundamental importance at certain levels in the classification.

Muriate of potash

Muriate of potash or potassium chloride (KCl), is a major potash fertilizer. It is water soluble and is generally blended with other components to make it a multi-nutrient fertilizer (Fig.M.19). It has a higher salt index than potassium sulphate and is recommended for most crops except tobacco, potato and grapes, which are sensitive to chloride ions.

Muscovite

Muscovite is a mineral of the mica group and has a structural formula [$KAl_3Si_3O_{10}(OH)_2$]. It is also called **white mica** or **potash mica**.

Muscovite occurs in some granites and is abundant in pegmatites which are the chief commercial deposits. It occurs as tetrahedral sheets with a negative charge distributed over 3 surface oxygen atoms. The isomorphous substitution in the dioctahedral mica muscovite makes one quarter of the tetrahedral silicon being replaced by aluminum and resulting in negatively charged net 2 moles per unit cell. The layer charge and its localization are sufficiently large to cause cations of

Fig.M.19: Muriate of potash.

relatively low ionic potential, such as potassium ion (K^+), to lose the water of hydration.

Muscovite is widely used as a source of soil potassium, apart from its use in electrical equipments.

Muscular dystrophy: See White muscle disease

Mutagens: See Mutation

Mutation

The process or an instance of alteration or a genetic change which, when passed on to offsprings gives rise to heritable variations, is known as mutation. It can occur in any type of cell at any stage in the life of an organism, but only those changes present in gametes are passed on to offsprings. A physical or chemical agent causing mutation is known as **mutagen**.

Mutation may be dominant or recessive, viable or lethal. Often, these changes are in individual genes, but in some cases, changes in the structure or numbers of chromosomes may also be seen. The formation of structural chromosome is used to test drugs for mutagenic activity.

Mutation normally occurs very rarely, though certain mutagens (such as x-rays, gamma rays, neutrons and mustard gas) greatly accelerate mutation.

Mutualism

Mutualism represents a doctrine that mutual dependence is necessary to social good. In the present context, it refers to a relationship between two or more species (such as in the root and leaf nodules interacting with a wide range of microbial systems) that benefits all interacting parties.

MWHC

MWHC is short for **maximum water-holding capacity**.

Mycelium

Mycelium is the vegetative part of a fungus consisting of microscopic threadlike hyphae. It is more or less elongated, septate or aseptate, with branched filaments. The individual filament is called **hypha** (plural - **hyphae**) and a group of hyphae or collectively the entire thallus is known as mycelium (Fig.M.20).

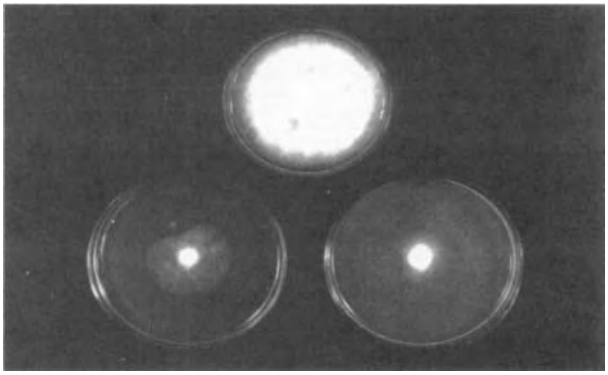


Fig.M.20: Mycelial growth of a fungus on different growth media.

The development of mycelium is initiated by the germination of a spore (seed) which is formed either by sexual or asexual means. A germ tube emerges from the spore, grows and develops to form mycelium.

A mycelial (or hyphal) cell consists of a cell-wall, the protoplasm and the nucleus. A mycelium may be unicellular or multicellular. The composition of the cell-wall is highly variable among the different groups of fungi or within the same species at different growth periods. The chief components of the cell wall are various types of carbohydrates such as cellulose, pectose, callose, etc. or their mixtures, and chitin.

There are two main types of mycelium, normally, septate and aseptate (or coenocytic) mycelium. The septate mycelium is divided mostly by transverse walls, called **septa** (singular **septum**; in rare cases, oblique or longitudinal septation is observed) into uni-, or multinucleate segments. The coenocytic mycelium has a number of nuclei but is not divided into a number of cells. In this case, septa may develop in very old mycelium or to separate spores or other reproductive structures.

The thickness of the mycelium varies from less than 0.5 μm to over 100 μm. In size, the entire body may measure to only a few microns in length (e.g., in lower fungi) or the mycelium may develop into large sporophores covering several centimeters to meters, as in the case of wood rotting fungi (higher fungi) or into long strands extending several meters, as in the case of **mycorrhizal fungi**.

Among parasitic fungi, the mycelium may be ectophytic (mycelium living on the surface of the host) or endophytic (mycelium living within the host tissues). The endophytic mycelium may be inter-, or intracellular.

Mycobacterium

Mycobacterium is a bacterium which produces and gives out an easily detectable amount of niacin into an agar medium. It is a member of a group of bacteria which include human pathogens responsible for diseases like tuberculosis or leprosy.

Mycorrhizae

The term mycorrhiza is derived from two Greek words 'mykoes' (meaning, mushrooms or fungus) and 'ryezee' (meaning, root). These fungi form colonies on the roots of the host plant and spread in the soil through hyphae, and are called **mycorrhizal fungi**.

Mycorrhizae are beneficial soil fungi which exist in association with plant roots and establish a symbiotic relationship with them. Such fungi form a 'mutualistic relationship' with the roots of almost all higher plants.

Some fungi form a 0.3 mm thick sheath around the root cylinder which sometimes give it a hairy, cottony appearance and protect the roots from other organisms that might harm the plant. The roots transmit beneficial substances to the fungi and the fungi aid in transmitting water and nutrients to the plant roots (Fig.M.21).

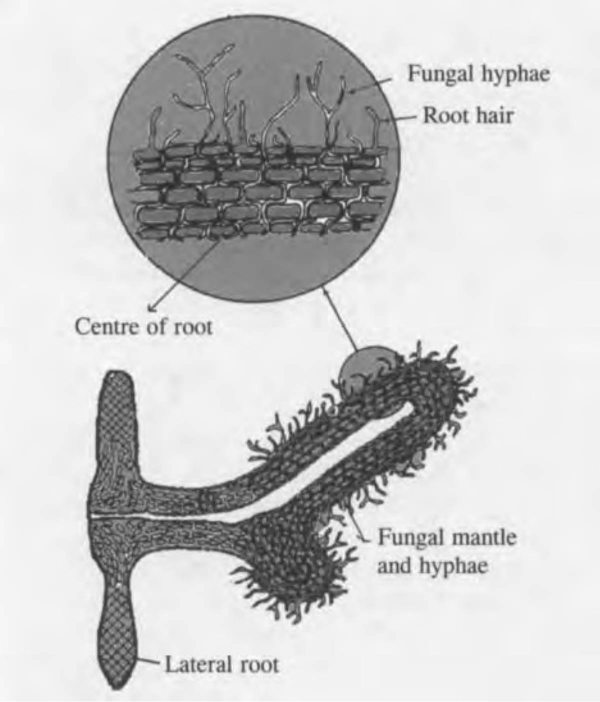


Fig.M.21: A schematic showing the association of mycorrhizal fungi with plant roots. The inset shows the penetration of fungal hyphae in root tissues.

Mycorrhizae are present on almost all plants. They help increase the phosphorus uptake from low phosphorus soils and generally protect the roots against many stress conditions like drought, adverse pH, plant pathogens, low nutrition, adverse temperatures, etc.

Based on the fungal growth, mycorrhizae are divided into two kinds: (i) **Ectomycorrhizae**: These are the fungi which cover the host root and penetrate only the outer layer of the root cell walls. These are found on most stress-tolerant plants such as willow, eucalyptus, oaks and many forest trees. These fungi tend to be host-specific and prefer acidic soil with good drainage. (ii) **Endomycorrhizae**: These are the fungi which actually penetrate some host roots. These fungi are particularly helpful in phosphate absorption and are most commonly found in plants but are the least visually obvious mycorrhizae. These are also known as arbuscular mycorrhizae (**AM**) or **vesicular arbuscular mycorrhizae** (**VAM**). Endomycorrhizae are found in soils containing low phosphorus and organic matter, like deserts, grasslands and tropical forests. These fungi are not particularly host-specific and are found on a wide range of plant roots.

A transition stage between ectomycorrhizae and endomycorrhizae is called **arbutoid mycorrhizae**. Arbutoid mycorrhizae form a fungal sheath around the root.

In highly weathered tropical soils, (like leached **oxisols** and **ultisols**), plants show highest growth response to mycorrhizae. These soils are acidic, low in basic cations, low in phosphorus and may have high toxic levels of aluminum. On the contrary, soils that are being constantly moved, compacted, heavily amended (with say, a heavy dose of fertilizers), and/or soils having pH imbalances are unsuitable for growth and development of mycorrhizae. Mycorrhizae are destroyed if the soil is fumigated, sterilized, solarized or drenched with pesticides.

Arbuscular mycorrhizae are the commonest and oldest type of mycorrhizae. Most plant families contain the AM species which are believed to have ancestral characteristics of all vesicular plants and other mycorrhizae types.

The AM nomenclature has changed recently, and is now referred to as vesicular arbuscular mycorrhizae (VAM), because a group of AM fungi forms vesicles on hyphae, which are sac-like structures, inside the plant roots. This group (VAM) of mycorrhizae belongs to the suborder Glomineae. However, the members of another AM suborder, Gigasporeae, do not form vesicles. The term arbuscular mycorrhizae, is used for this group.

Vesicular arbuscular mycorrhizae (VAM) can vastly improve nutrient cycling. They are formed by non-septate (coenocytic) zygomycetous fungi belonging to the genera, *Glomus, Gigaspora, Acaulospora, Entrophospora*, and *Sclerocystis* (Fig.M.22). These are obligate symbionts and have been unsuccessfully cultured on nutrient media.

VAM, occurring over a broad ecological range (from aquatic to desert environments), are commonly found in most plant species belonging to plant families Graminae and Leguminoseae, which are of major economic importance. Many experiments have shown improvement in plant growth through VAM inoculation which facilitates the uptake of water, P, Zn, Cu, K, S, Al, Mg, Mn, Fe, etc. Mycorrhizal colonization also allows the population of beneficial soil micro-organisms like *Azotobacter*, *Azospirillum* and phosphate-solubilizing bacteria to maintain higher counts, and

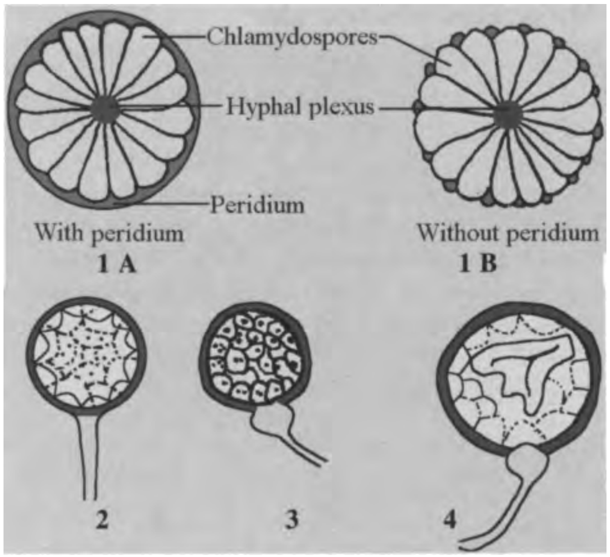


Fig.M.22: Mycorrhizal spores of 1. A & B. Sclerocystis, showing cross-section of sporocarps with and without peridium, 2. Glomus, 3. Gigaspora, and 4. Scutellispora.

thereby exert synergistic effects on plant growth. There is evidence that a dual inoculation with *Glomus* and *Rhizobium*, results in efficient solubilization of rock phosphate in soil.

Because of the extensive extra-matrical and intra-matrical distribution of VAM fungi, techniques for mycorrhizosphere analysis must include those suitable for investigations on both the plant roots and the soil. The approach to estimate mycorrhizal infection is based on the concepts of colonization, propagule numbers, and VAM capacity of the soil to colonize plants. Important steps and issues for a complete analysis of VAM in soil consist of (a) harvesting and storage of soil and root samples, (b) extraction and estimation of fungal propagules, (c) evaluation of mycorrhizal infection potential, and (d) estimation of root colonization.

As VAM structures inhabit both bulk soil and cortical root cells, their harvest consists of gently excavating and preserving roots of the chosen plant and recovering the first few centimeters of the **mycorrhizosphere**. The VAM fungal population of a site may vary considerably over a small area (up to a few square meters). Precise soil sampling strategies have to be adapted to suit every experimental requirement. Spore number and root colonization decline with depth; not many propagules are found at depths lower than 40 to 50 cm. Spore numbers seem to increase as roots get senesced. Optimum storage conditions range from 2 to 10°C and 1 to 2% RH. High temperatures and humidity increase hyper parasite activity and stimulate the germination process, thereby reducing the long-term VAM propagule viability.

The spore and spore-cap counts have been used in the estimation of VAM propagules. But this approach does not consider the VAM inoculum potential of other types of propagules, such as fragments of colonized roots, hyphae, or networks of mycelium. The estimation of spore population has the advantages of facilitating the separation of VAM species for identification and study of the diversity of species, as well as the isolation of spore inoculum for VAM propagation or pure culture synthesis.

Estimation of VAM fungi in fragments of colonized roots can be obtained by extracting, clearing, staining and mounting root fragments for microscopic observation. Staining techniques like acid fuchsine and trypan blue are most utilized.

The level of root colonization is estimated by its frequency and by evaluating the intensity of colonization. Colonization by VAM fungi is restricted to the root cortex and is usually most prevalent in young feeder roots. There is no visible gross morphological change in roots due to infection, except in certain plants which develop a yellow pigmentation when highly colonized. As a result, the most common method used to detect VAM root colonization is by the microscopic examination of the stained fungal structures.

Other quantitative and qualitative bioassays such as chitin estimation and electrophoresis use unstained roots, but have not yet been extensively tested on a variety of plant and fungal species.

Quantification of root colonization can be done by (a) the **slide method**, which indicates the length of the colonized roots, (b) the **grid line intersect method** which estimates the percentage of the roots colonized, and (c) non-systematic root scanning under a dissecting microscope, which rapidly gives broad categories of root colonization and intensity of their infection.

The extraction methods have to be tailored to the specific needs of an experiment, depending on the amount of soil to be analyzed, the soil texture, the organic matter content and the taxonomical approach. They generally consist of sieving, followed by flotation-bubbling in glycerol, differential sedimentation in gelatine, separation by density-gradient centrifugation in sucrose, radiopaque media or centrifugation in solutions (such as sucrose) having a higher specific gravity than the spores or in colloidal silica solutions. A mix of these techniques and a number of replications are needed to obtain representative results.

Other techniques include spore adhesion on a glass surface, the plate method and the dry separation of spores method. Wet sieving, followed by flotation-bubbling and/or floatation-centrifugation technique, have been accepted because of the ease and accuracy they give.

The VAM infection potential of a soil is obtained by the estimation of propagule number. Estimation of VAM propagule populations in soils can be carried out by the **'most probable number' (MPN) method** or by the **'mycorrhizal soil fertility' (MSF) method**. These methods evaluate the number of viable propagules based on the proportion of plants found to be infested by mycorrhizae in a series of soil dilutions. These methods eliminate single-spore counts, which are very time consuming. However, it is only after several weeks that mycorrhizal colonization of the plant root can be estimated, because it takes time for the plant root system to be developed.

VAM is recognized as an effective biofertilizer and is available in granular form. The plant roots, along with the soil adhering to the mycorrhizal spores and pellets containing inoculums, and sedimentary clay are the ingredients for producing VAM inoculums. There are different methods of producing the VAM biofertilizer.

VAM fungi can save the use of synthetic fertilizer P to the extent of 20 to 30%, and can improve plant yield. Crop response to VAM inoculation is governed by the soil type, the host variety and the VAM strain, in addition to some other biotic and abiotic factors (which affect both the host plant and the mycorrhizal fungi).

Commercial inoculum mixes of mycorrhizae containing a variety of spores are becoming available for soil applications. Bio-Organics Supply Center in Camerillo (USA) sells a 'cocktail' containing spores of *Glomus intraradices, G. deserticola, G. etunicatum, G. clarum and G. mosseae.*

Mycorrhizal fungi: See Mycorrhizae

Mycorrhizal influence value

The mycorrhizal influence value is derived by assigning a value of 100 to the mean for non-inoculated plants and calculating the treatment means as integers relative to 100. These values could be reported not only for dimensional and mass parameters, but also for chemical and physical variables.

Mycorrhizal soil fertility method for estimation of VAM population: See Mycorrhizae

Mycorrhizosphere

Mycorrhizosphere is the soil adhering to the roots and the soil around the roots colonized by the mycorrhizal fungi.

Myosin

Myosin and actin are the principal fibrous proteins of muscle, having molecular weights above 500,000. Their interaction brings about muscle contraction.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

N

Naphtha

Naphtha is a flammable oil containing various hydrocarbons and is obtained by dry distillation of organic substances, such as coal, shale or petroleum. Naphtha is used as a raw material for producing hydrogen required for the manufacture of nitrogen fertilizers. It is also one of the favored feedstocks for ammonia production. Its average molecular weight is 88, H:C atomic ratio is 2.23, and boiling point ranges between 40 and 130°C. During this boiling range, naphtha boils off to its various fractions. The composition and properties of typical naphtha are given in Table-N.1.

The **straight run naphtha** is preferred to the naphtha produced from higher hydrocarbons by '**cracking**' (or '**hydrocracking**') because naphtha produced by 'cracking' contains sulphur compounds which are difficult to remove. Naphtha is produced by the reforming process, developed by the Imperial Chemical Industries (ICI) of the U.K. Many plants have been set up around the world based on the process developed by ICI. As naphtha prices continue to increase, the primary feedstock for ammonia production is shifting from naphtha to natural gas, although the former still predominates.

The main technical problem with naphtha, other than the cost, is the carbon formation on the catalyst if steam is used inadequately. A recent modification of the catalyst composition has solved this problem. The flow sheet of ammonia production based on naphtha as the starting material is shown in Fig.N.1. In addition to being a source of hydrogen, naphtha is a good solvent used for degreasing, extraction in plants, drycleaning, etc.

Table-N.1: Composition and properties of naphtha.

Constituent or property	Average value
Specific gravity (at 15.5°C)	0.686
Initial boiling point (°C)	41
Final boiling point (°C)	131
Unsaturates (percent volume)	1
Aromatics (percent volume)	4
Saturates (percent volume)	95
Total sulphur (ppm)	368
H_2S	2
RSH	146
R_2S_2	119
R_2S	80
S	1
Non reactive S	20
C (percent)	84.4
H (percent)	15.7
Molecular weight	88
Heating value, kcal/kg	10,500

Source: "Fertilizer Manual", 1998. UNIDO, IFDC and Kluwer Academic Publishers. With permission.

NAR

NAR is short for **net assimilation rate**.

Native nutrients

Nutrients present in the soil are known as native nutrients. Since they are used up by plants and crops, they get depleted. Soil nutrient reserve status, environmental

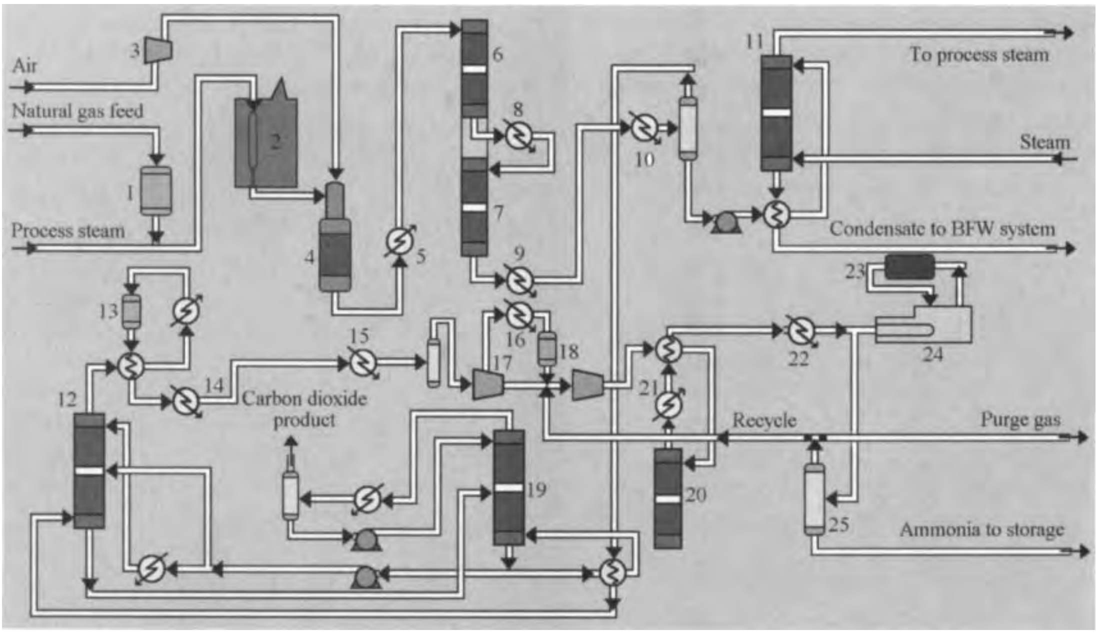


Fig.N.1: Flow chart of ammonia production using naphtha.1. Sulphur removal, 2. Primary reformer, 3. Air compressor, 4. Secondary reformer, 5. Heat recovery, 6. HT shift converter, 7. LT shift converter, 8.and 9. Heat recovery, 10. Cooler, 11. Condensate stripper, 12. CO_2 absorber, 13. Methanator, 14. and 21. Heat recovery, 15. and 22. Cooler, 16. Syn-gas cooler, 17. Syn-gas compressor, 18. Dryer, 19. CO_2 stripper, 20. Ammonia converter, 23. NH_3 refrigeration, 24. Chiller, 25. HP separator. (Source: "Fertilizer Manual", 1998. UNIDO, IFDC and Kluwer Academic Publishers. With permission).

conditions, and the need and ability of plants to absorb nutrients are some factors considered while determining the need for additional fertilizers.

Natric horizon

The natric horizon is a special kind of argillic horizon containing 15% or more of exchangeable sodium, or when the **sodium adsorption ratio (SAR)** of the saturation extract of soil is 13 or higher within a depth of 40 cm. This is an alluvial horizon of silicate clay accumulation and has a columnar or prismatic structure. (See also Argillic horizon.)

Natrium

Natrium is the Latin name of the element sodium, the chemical symbol of which is Na.

Natro argillic

The clay accumulation horizon is called **argillic horizon**. It is divided into many subtypes, and natro argillic is one of them.

Natural erosion

Natural erosion is also called **geological erosion**.

Natural gas

Natural gas is the feedstock for 78% of the world's ammonia produced. It is a naturally occurring mixture of gaseous hydrocarbons found in porous sedimentary rocks in the earth's crust, usually in association with petroleum deposits. It is a colorless, odorless, flammable gas or liquid.

Natural gas contains methane (about 85%), hydrogen sulphide and carbon dioxide in varying percentages, and a small percentage of ethane and higher hydrocarbons. Natural gas has its origin, like petroleum, in the decomposition of organic matter. It is widely used as a fuel and in the production of carbon black and some organic chemicals. Natural gas is transported by large pipelines or in refrigerated tankers.

Nitrogen fertilizers originate from ammonia. Ammonia is produced from the industrial synthesis of the two elements, hydrogen and nitrogen. Hydrogen is mostly obtained through the reaction between water and fossil fuel (natural gas), and nitrogen from the air. The overall reaction is:

$$\underset{\text{Air}}{\tfrac{1}{2}O_2 + N_2} + \underset{\text{Natural gas}}{CH_4} + \underset{\text{Water}}{H_2O} \longrightarrow \underset{\text{Ammonia}}{2NH_3} + \underset{\text{Carbon dioxide}}{CO_2}$$

Natural gas is classified as **associated gas** and **non-associated gas**. Associated gas occurs with crude oil from which it is liberated when the pressure is released in the gas separation plant. The composition of natural gas varies with pressure at which the separator is opened. The gas from the 'non-associated' deposits can be nearly pure methane, while in other deposits the gas may contain a higher percentage of hydrogen sulphide and carbon dioxide.

Methane is a preferred feedstock (preferred over higher hydrocarbons) for ammonia manufacture because all carbon in the feedstock is converted into CO_2 or CO which must be removed from the ammonia synthesis gas. Therefore, the lower the carbon:hydrogen ratio in the feedstock, the smaller and less expensive the purification units in the preparation of synthesis gas.

Natural gasoline: See Gasoline

Natural moisture content

The moisture content of a soil sample in its natural state (without drying or wetting in laboratory) is known as the natural moisture content.

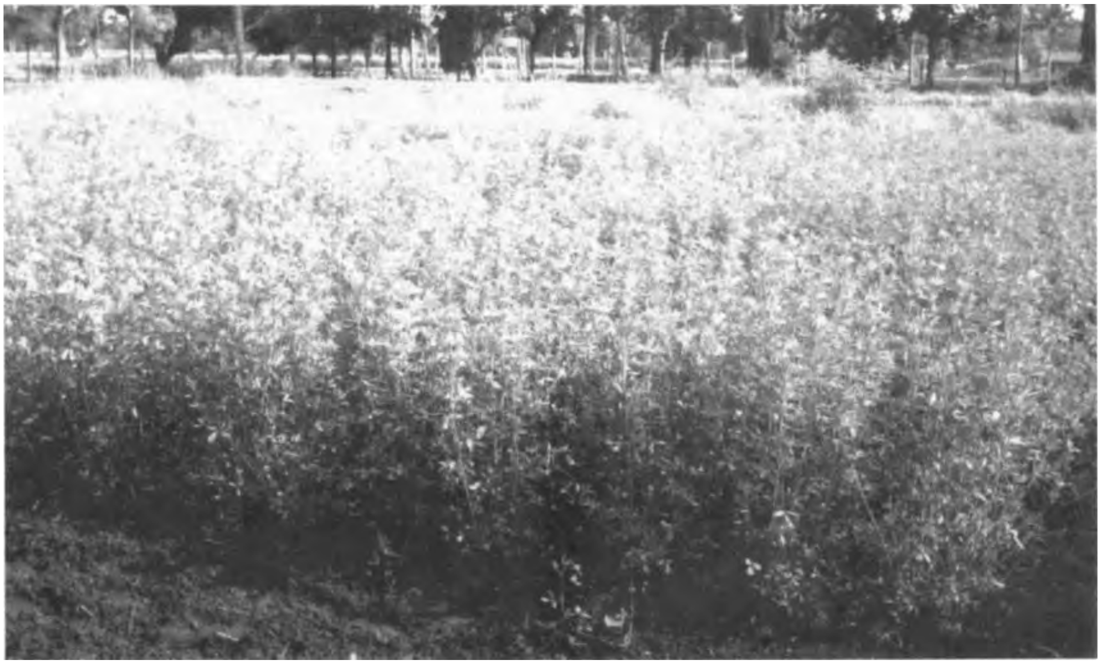


Fig.N.2: Surface soil of the earth's crust, formed by natural processes, supports vegetation.

Natural soil

The thin top layer of the earth's crust formed mostly because of natural processes involving biological, chemical, climatic and geological changes is called natural soil (Fig.N.2). It is this natural soil that supports vegetation.

Natural water table

When hydrostatic pressure of ground water is equal to the atmospheric pressure, the water table is known as the natural water table, below which water moves freely under the influence of gravity.

Natural zeolites: See Zeolites

NBPT

NBPT is short for **N-(n-butyl) thiophosphoric triamide**.

NCF

NCF is short for **net cash flow**.

NDFF

NDFF is short for nitrogen derived from fertilizer. The percentage of nitrogen in a plant derived from the applied fertilizer is calculated as:

$$\%\text{NDFF} = \frac{\%\,^{15}\text{N excess in sample}}{\%\,^{15}\text{N excess in fertilizer}} \times 100$$

Nebraska potash

Nebraska potash is a salt obtained by evaporating brine, in a process being followed in Nebraska (USA). This salt is highly alkaline and contains 20 to 30% potash as carbonate and sulphate.

Necrosis

Necrosis refers to the death of plant tissue caused by disease or injury. The terms like holonecrotic (completely dead) and plesionecrotic (nearly dead) are used to describe the central area of dead tissues and the surrounding zone of damaged (but not dead) tissues respectively in leaf spots that are not delimited by cork barriers. Fig.N.3 shows veinal necrosis on a plant.

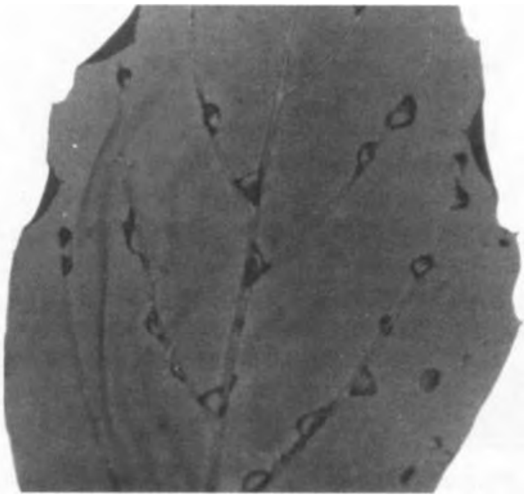


Fig.N.3: Veinal necrosis caused due to a plant virus.

Neem

The tree *Azadirachta indica* of family Meliaceae is known as neem in the Indian subcontinent (Fig.N.4). All parts of the tree have beneficial value; the leaves and the berries are used as insecticides, the seeds contain triterpenes which retard nitrification, and neem-coated urea is used as a slow-release nitrogen fertilizer which increases rice yield.

Fig.N.4: Neem tree.

Neem cake

The process of extracting oil from neem berries results in a residue called neem cake. Neem cake retards nitrification. Urea is either blended or coated with neem cake to act as a slow-release nitrogen fertilizer which is known as **neem cake coated urea**.

Neem cake coated urea

Urea is highly soluble in water. Although it is valued as a fertilizer, it is lost quickly because of its solubility. Solubility, nitrification and denitrification reduce the efficiency of urea. If urea is coated by appropriate material, the loss is reduced.

Coating urea makes it a slow-release fertilizer, making it available to plants for a longer period. A reduced solubility of urea keeps the contamination of ground water under control. The coating reduces ammonia volatilization and controls atmospheric pollution. There are several coating materials used effectively.

Indian agricultural scientists have long been working on neem (*Azadirachta indica*) and **neem cake** (the residue of neem seeds after the extraction of oil), and have proved it to be an effective coating material.

When neem cake coated urea is used as a fertilizer, the yields of rice, potato, sugar cane, cotton and finger millet have demonstratively increased. The residual effect of neem cake coated urea is apparent in the succeeding wheat crop, in a rice-wheat cropping system. Neem cake coated urea can increase the nitrogen uptake of plants by 4.5 to 19.4%. This shows an increased nitrogen recovery in rice-wheat cultivation.

An extract from the press cake of the neem seed has a reversible effect on nitrification by the bacteria *Nitrosomonas* spp. Active compounds in this biological nitrification inhibitor are various terpenes or triterpenes (epinimbin, deacerylnimbin, salanin, azadiractin, deaceylsalanin). A product containing 5% active ingredients of this extract is mixed with urea in the ratio of 1:100, and used as a fertilizer.

Besides the above, there are also other advantages. The neem cake coating has herbal properties, insecticidal qualities, and is eco-friendly. Neem coated urea does not irritate the skin of farm workers. Coating makes the handling safe and storing easy. Unlike other oil seed cakes, neem cake is not used as cattle feed, and hence may be freely used as a coating material, without depriving the need of the cattle.

The coating technique is simple. A solution of coal tar (2 kg) and kerosene (2 liters) is added to 100 kg of urea in a rotating drum. While rotating, 15 to 20 kg of neem cake is added, which makes the product ready for use. This simple procedure can be carried out at the individual farmer's level. But it may be difficult to use the technique industrially, simply because the huge quantities required by a factory may not be available easily.

Neem seed extract

The neem tree (*Azadirachta indica*) has held sway over most parts of India because of its anti-bacterial, anti-inflammatory, anti-viral, anti-fungal and germicidal properties. Thus, neem leaves and seeds have been used for medicinal applications (skin applications, anti-septic creams and as an input in birth control treatments) for hundreds of years. Similarly, neem has significant benefits for agriculture because of its insecticidal, fungicidal and germicidal properties.

The neem seed has active compounds (*azadirachtin*) in high concentrations, which are useful. Depending on the exact purpose of use, neem seeds are extracted either by steam distillation, aqueous or organic solvent methods.

Neem seed extract is used in manufacturing organic pesticides and insecticides. An experiment, using neem seed kernel extract (with concentrations upto 4%) on a guava fruit (*Psidium guajava* L) was found to prevent the oriental fruit fly from laying eggs on it. Similarly, a two-year study in Burkina Faso found that egg and larval mortality of sorghum shoot fly (*Atherigona soccata* Rond) was markedly lower in plots treated with neem seed extracts (around 20 kg/ha neem seeds per 500 liters of water) compared with plots treated only with adhesol or carbofuran.

Negative catalyst

A catalyst is a substance which, when used in a small quantity, facilitates or increases the rate of a reaction, without itself undergoing any permanent chemical change. Generally, a substance that slows down the rate of reaction or stops an undesired chemical reaction is known as a negative catalyst. For example, acetanilide retards the decomposition of hydrogen peroxide, or salycilic acid is used to prevent the pre-vulcanization of rubber.

Negative effect: See Negative interactions

Negative interactions

When the effect of two combined nutrients is lesser than that obtained when the same nutrients are applied separately, the interactions of the said nutrients are considered to be negative. For example, the effects of lime + P, lime + Mo + P and Na + K are lesser than those of the same nutrients applied individually. The negative interaction is due to substitution or interference of one treatment with the other. A changed pH results in many interactions when one ion or one nutrient interferes with, or competes with, the uptake and utilization of the other nutrients. Negative interaction is also called **negative effect** or **antagonistic effect**.

Negatively charged ion

An ion is an electrically charged atom or group of atoms. A negatively charged ion is called an **anion**.

Negative staining

Negative staining involves treating the cells with a dye so that the background, rather than the cell itself, is made opaque. It is used to demonstrate bacterial capsules or the presence of parasitic cysts in fecal samples.

Nemagation

Any parasitic or free-living worm of the phylum Nematoda with a slender unsegmented cylindrical shape is known as **nematode** or **roundworm**.

The application of pesticides or fertilizers through irrigation waters in open or closed system is **chemigation** or **fertigation**. When the pesticide is applied through irrigation waters to treat nematodes, it is called nemagation.

Nematodes

Nematodes are tiny, wormlike multicellular animals.

Nematodes, also called **roundworms** or eelworms, are characterized by a smooth narrow cylindrical unsegmented body tapered at both the ends (Fig.N.5). They shed their tough outer cuticle four times during their lifetime to enable growth. Most of them live on decaying organic matter, but some infest plant roots and live as parasites. Nematodes play an important role in the destruction and recycling of organic matter.

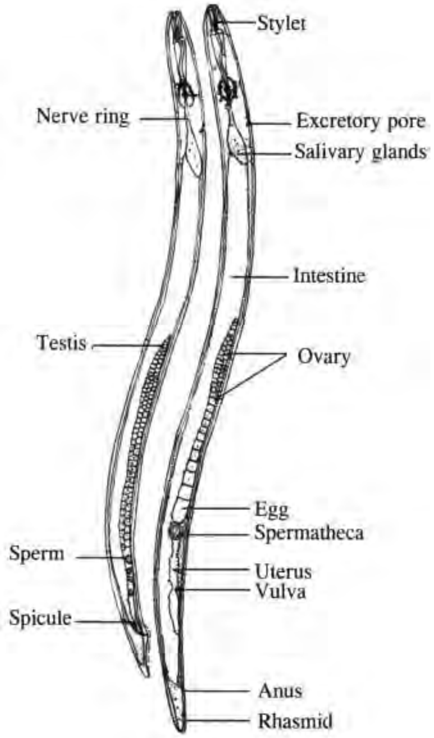


Fig.N.5: Schematic of male and female plant parasitic nematodes.

Many parasitic nematodes are much larger than the other varieties. They include filarial and guinea worms which cause serious disease in humans. Soil nematodes are the most highly developed of the pseudocoelomates belonging to the phylum Nematoda.

Several hundred species of nematodes are plant parasites and cause a variety of plant diseases. Major plant parasitic nematodes include root knot, cyst and root lesion nematodes. Some of the important parasites are *Meloidogyne* (the root-knot nematode), *Pratylenchus* (lesion or meadow nematode), *Scutellonema* (a pest of yams), *Aphelenchoides* (bud and leaf nematode causes wrinkling and discoloration of groundnut) and *Heterodera* (cyst nematode).

Crop rotation prevents nematode population from reaching levels beyond which nematodes affect the economics of the crop. Biological methods can be used to control nematodes. Microbial pathogens like ***Bacillus thuringiensis*** and *Pasteuria penetrans* are found to be effective against nematodes. Oilcakes, sawdust, sugar cane baggase, **bonemeal**, **compost** and **green manure** are known to be natural nematode suppressants. Neem products like **neem cake**, neem oil and **neem seed extract** can be applied to control nematodes.

Soil solarization reduces nematode population. In this technique, plastic sheets are laid over plowed, moistened soil for six to eight weeks. This traps the solar heat and raises the soil temperature, which is a bio-fumigation process that controls nematodes.

Cover crops (like castor, marigold, chrysanthemum and sesame) suppress nematodes through their allelopathic effect.

Neosol

A soil of recent formation is referred to as neosol.

Nephelometry

Nephelometry refers to the measurement technique of light. The measurement of the intensity of the scattered light (at right angles to the direction of the incident light) as a function of the concentration of the dispersed phase is the basis of nephelometric analysis.

Nephelometry is a valuable technique in certain types of quantitative chemical analysis. Nephelometry is commonly used for the detection and quantification of unwanted particles or haze in liquids, like in the determination of sulphate or phosphate in the soil extract. In this technique, which is more sensitive than **turbidimetry**, the intensity of the transmitted light is measured as a function of the concentration of the dispersed phase. The traces of haze can be accurately measured in highly colored fluids, which is an additional advantage.

Unlike turbidimetric analysis, nephelometric analysis is most sensitive to very dilute suspensions (not more than 100 mg/liter) but needs calibration curves as the relationship between optical properties of the suspensions and the concentration of the dispersed phase is at best semi-empirical.

Nernst equation for dissolution

Dissolution of a solid in a liquid is a heterogeneous process in which the solid (solute) passes into solution because of its interaction with the liquid (solvent).

The **William Nernst equation for dissolution** of a solid in a liquid is controlled by diffusion and is defined as :

$$\frac{dc}{dt} = kS\,(Cs-C)$$

where dc/dt represents the time dependence of concentration, S is the surface area of the solid, C is the concentration, Cs is the concentration at the surface determined by the solubility of the compound and k is the rate constant.

Nesquehonite

Nesquehonite is the natural form of magnesium carbonate trihydrate ($MgCO_3 \cdot 3H_2O$).

Nessler's reagent: See Nessler's solution

Nessler's solution

Nessler's solution or **Nessler's reagent** is an alkaline solution of mercuric iodide and potassium iodide. It is used for colorimetric determination of ammonia.

Ammonia is liberated when Nessler's reagent is added to a dilute ammonium salt solution and this ammonia reacts rapidly with the reagent to form an orange-brown product in colloidal solution. The latter is then quickly estimated by colorimetry as it flocculates on long standing.

The reaction between Nessler's reagent and ammonia is represented as:

$$2K_2(HgI_4)+2NH_3 \longrightarrow NH_2Hg_2I_3+4KI+NH_4I$$

The method is used to determine ammonia in very dilute aqueous solutions (as low as 0.1 mg/l) and can be applied for the estimation of nitrates and nitrites, after reducing the alkaline solution (with Devarda's alloy) to ammonia and distilling the ammonia.

Net area sown

The net area sown is the actual area of the land cultivated during the year. The land area sown more than once is counted only once. Thus, the net area sown may be equal to or less than the actual geographical area of the plot. However, the area sown more than once when added to the net area sown, gives the total area sown.

Net assimilation rate

The net assimilation rate **(NAR)** or the **unit leaf rate** shows the photosynthetic efficiency of the plant. The rate of dry matter production per unit leaf area is estimated using the equation:

$$NAR = \frac{(W_2 - W_1)(\log L_2 - \log L_1)}{(t_2 - t_1)(L_2 - L_1)}$$

where L_1 and L_2 are the total leaf areas at times t_1 and t_2 respectively; W_1 and W_2 are the total dry weights at times t_1 and t_2, expressed as g/m^2/day. This equation estimates NAR accurately only if the relationship between L and W is linear between the two intervals t_1 and t_2.

Plants like wheat, millet and rice that produce three-carbon compounds (C_3) on carbon dioxide fixation are photosynthetically less efficient compared to those like sugar cane and maize which produce four-carbon compounds (C_4) on CO_2 fixation. NAR decreases with crop growth owing to mutual shielding of leaves and a reduced photosynthetic efficiency of older leaves.

Net Cash Flow

Cash flow is money payments into and from a firm. Net cash flow is understood as the difference between cash inflows and cash outflows over a given time period. Net cash flow of a project is defined as the net earning after taxes have been paid, expenditure on maintenance and repairs carried out, adjustments made to the working capital etc. It is a measure of a company's financial health and indicates how much cash can actually be accessed or worked with. Expenditure is sometimes referred to as negative cash flow as it represents an outflow of cash.

Net photosynthesis

The net photosynthesis is the total photosynthesis minus respiration and can be used in determining the crop yield.

Net profit: See Net returns

Net returns

The net return from a crop, for instance, is the value of the crop after deducting all expenditure costs. This is another name for **net profit**.

Net profit (before tax) is the residual profit after deduction of all money costs. That is, the sales revenue minus wages, salaries, rent, fuel and raw materials, interest on loans and depreciation.

Net weight of fertilizer

The net weight of a fertilizer is the weight of the material alone, exclusive of the weight of the container and the packing material. The actual weight (net weight) of any fertilizer appears on the container of the fertilizer.

Neutral interaction: See Interaction between nutrients

Neutralization

Neutralization refers to a combined reaction of an acid (H^+) and a base (OH^-).

$$H^+ + OH^- \longrightarrow H_2O$$

The neutralization products are salt and water.

$$\underset{(Base)}{NaOH} + \underset{(Acid)}{HCl} \longrightarrow \underset{(Salt)}{NaCl} + H_2O$$

Neutralization occurs with both organic and inorganic compounds as:

$$2HCOOH + Na_2CO_3 \longrightarrow 2HCOONa + CO_2 + H_2O \text{ (Organic)}$$
$$Ca(OH)_2 + H_2SO_4 \longrightarrow CaSO_4 + H_2O \text{ (Inorganic)}$$

Neutralization can also occur without the formation of water as:

$$CaO + CO_2 \longrightarrow CaCO_3$$

Neutralization does not mean reaching pH 7. It is the equivalence point for an acid-base reaction. A strong acid and a weak base give a pH lower than 7 and vice versa. The **neutralization number** is the measure of acidity and is expressed in milligrams of potassium hydroxide required to neutralize the acid in one gram of the sample, say soil, under standard conditions.

Neutralization number: See Neutralization

Neutralizing value

For neutralizing an acidic soil, liming materials with different neutralizing capacities are used. The neutralizing value (NV) of a liming material is the quantity of acid that neutralizes a unit weight, which is related to the molecular weight, composition and purity of the neutralizing agent (Table-N.2). Taking the neutralizing value of pure calcium carbonate ($CaCO_3$) as 100, the values of other liming materials are calculated. For example, the neutralizing values for CaO, $Ca(OH)_2$ and $MgCO_3$ are 179,136 and 119, respectively. The neutralizing value, also called **calcium carbonate equivalent** (CCE), is estimated as:

$$NV = \frac{M_{CaCO_3}}{M_x} \times 100$$

where NV is the neutralizing value, M_{CaCO_3} is the molecular weight of calcium carbonate and M_x is the molecular weight of the substance under consideration.

Table-N.2: Neutralizing value or CCE of the pure forms of different liming materials.

Substance	Mol. Wt.	Neutralizing value%
CaO	56	179
$Ca(OH)_2$	74	136
$CaMg(CO_3)_2$	184	109
$CaCO_3$	100	100
$CaSiO_3$	116	86

Neutral stain

The staining technique facilitates the observation of a substrate. In staining, normally the transparent cells or thin sections of a biological tissue are immersed in one or more colored dyes to make them more clearly visible through a microscope. Neutral stains have a colored cation and a colored anion (e.g., Leislmans' stain).

Neutrophilic cell components

Cell components are classified as **acidophilic** and neutrophilic, the latter being receptive to neutral dyes.

Newton: See Pascal

Nicholas' concept of functional nutrient: See Functional nutrient concept of Nicholas

Nickel

Nickel (Ni) is a silver-white, ductile, malleable, yet tough metallic element of Group 10 (formerly Group VIII) of the Periodic Table (Fig.N.6). Mostly, nickel goes into the making of steel and other corrosion resistant alloys. Finely divided nickel is used as a hydrogenation catalyst. Nickel is a beneficial trace element for plants. Its presence in the urease enzyme underlines its importance as a functional element. It is essential for grain viability, in barley and at concentrations less than 100 µg/kg, the grain level and the germination frequency decrease progressively. The quantity of Ni in a few fertilizers is as given: 2 ppm in nitrochalk, 13 ppm in superphosphate and 10 ppm in FYM.

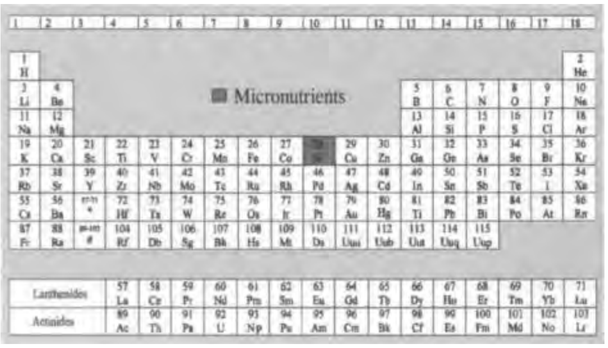


Fig.N.6: Position of nickel in the Periodic Table.

Nickel is the metal component of urease that hydrolyzes urea to give ammonia and carbon dioxide. Compounds that react with nickel in the urease molecule inhibit the hydrolysis of urea.

Nickel enhances the nodule weight and the seed yield of soybeans, chickpeas and temperate cereals. It is present in plants in the range of 0.1 to 1.0 ppm of the dry weight.

High levels of Ni may induce Zn or Fe deficiency because of cation competition, and may create **nickel toxicity**. The browning and necrosis of the leaf tips and margins are the toxicity symptoms on the plant. High Ni content also causes the distortion of young leaves and the death of the terminal shoots of the plant. The emerging leaves may fail to unroll and become necrotic, with the necrosis starting from near the base and spreading toward the leaf tip. Nickel toxicity in cereals and grasses varies in the intensity of chlorosis along the length of the leaf with a series of transverse bands.

Sewage sludge contains heavy metals like Ni, Cd, etc. that are absorbed by plants grown in soils contaminated with these heavy metals. The toxicity caused by these metals is in turn, passed on to animals that feed on such plants. Any regulation for sludge use should ensure that the soil pH is not lower than 6.5, as heavy metals are insoluble at pH greater than 6.5.

Nickel toxicity : See Nickel

Night soil

Human excreta is called night soil. It contains 5.5% nitrogen, 4% phosphorus (as P_2O_5) and 2% potash (as K_2O) when oven-dried. When left on soil, it gets absorbed by the soil. In many places, it is converted into town compost. In cities with sewage treatment systems, the sewage water and sludge are used directly to raise crops.

Nimin

Nimin is made from neem *(Azadirachta indica)* seed extract, and is used for coating fertilizers. The triterpene compound in the extract reduces the nitrification and consequently increases the efficiency of the fertilizer.

Nissan process for nongranular monoammonium phosphate: See Monoammonium and diammonium phosphate production processes

Nitosols

Nitosols is one of the 106 soil units of the FAO-UNESCO system of soil taxonomy. These have shiny surfaces as the clay is removed from them. Nitosols have an argillic B horizon in the top 150 cm where the distribution of clay does not decrease more than 20%. Nitosols have neither vertic nor ferric features nor plinthite at less than 125 cm depth. The moisture regime of nitosols is not arid.

Nitrammoniacal

Calcium ammonium nitrate is marketed under different trade names, one of which is nitrammoniacal.

Nitrammonkalk

Nitrammonkalk is a granulated fertilizer, composed of a mixture of ammonium nitrate and calcium nitrate.

Nitrapyrin

Nitrapyrin, also called **N serve**, is a **nitrification inhibitor**.

Nitrate and ammonium fertilizers

Ammonium nitrate, calcium ammonium nitrate and ammonium nitrate sulphate belong to the category of nitrate and ammonium fertilizers. They are readily soluble in water and are suitable for a variety of soils and crops. They leave an acidic residual effect on the soil.

Nitrate fertilizers

A nitrate fertilizer generally denotes all nitrogenous fertilizers - the term being specifically used for salts containing the nitrate ion which combines with other elements. These fertilizers are available either as natural or as manufactured products (processed from synthetic ammonia).

In low-rainfall areas, soil sampling is done to measure the contents of nitrate and moisture in the profile, which is generally correlated with crop response to nitrogen fertilization. The nitrate measurements are used to predict the fertilizer nitrogen requirement of the crop.

Nitrogen in many compound fertilizers exists as an ammonium ion (NH_4^+) which is quickly converted to nitrate by soil bacteria. Most of the crops in their early growth stage absorb nitrogen as nitrate. It is readily absorbed by some roots.

Potassium nitrate is used in fertilizers for intensively grown crops such as tomato, potato, tobacco, leafy vegetables, citrus fruits, peaches etc. Calcium nitrate, or **nitrate of lime**, with its fast acting nitrate component, is a useful fertilizer. Manufactured by treating nitric acid with lime, calcium nitrate is used in foliar sprays for celery, tomato and apples, and vegetables in winter. Care has to be taken to prevent leaf scorching during foliar spray.

Nitrate ions are very mobile. When nitrate fertilizers are applied to the soil, the nitrate ions reach the root zone quickly. These fertilizers are better suited to dry soils as the extent of leaching in dry soils is less compared to that in wet soils. Some nitrate fertilizers tend to leave behind alkaline residues and reduce the soil acidity. Nitrate fertilizers are commonly applied as top or side dressings.

Ammonium nitrate, sodium nitrate, potassium nitrate, sodium potassium nitrate and calcium nitrate are a few major nitrate fertilizers. The nitrate salts of sodium (Na^+), potassium (K^+) and calcium (Ca^{2+}) are not acid forming, whereas the nitrate salts of ammonium are. Every 100 kg sodium nitrate produces 2 kg of calcium carbonate. Nitrates are lost as nitrogen or nitrous oxide since aerobic bacteria like *Pseudomonas, Bacillus* and *Paracoccus* denitrify in acidic and alkaline soils.

Nitrate of lime

Nitrate of lime is another word for calcium nitrate. (See Nitrate fertilizers.)

Nitrate of potash

Nitrate of potash is another name for potassium nitrate.

Nitrate of soda potash

A mixture of Chilean nitrate of soda and nitrate of potash, produced from naturally occurring caliche with a high nitrate content, is called nitrate of soda potash. It contains not less than 15% nitrogen, 10% potash (K_2O) and 18% sodium.

Nitrate poisoning

An excess of nitrate or nitrite in water and food is harmful. The nitrite ion transforms oxyhemoglobin (the oxygen carrier in blood) into an inactive form of methemoglobin which is incapable of carrying oxygen in blood. When this conversion exceeds 40%, the condition can be fatal. The nitrite gets into the blood stream and causes suffocation or blue coloring in babies. It causes a disease called **methemoglobinemia** in animals, which is the result of nitrate poisoning. (See also Fertilizer nitrogen, an environmental perspective.)

Nitrate reductase

The enzyme nitrate reductase (NR) is a metalloflavoprotein, which catalyzes the reduction of nitrate in plants, essential for the synthesis of plant proteins, as:

$$\underset{\text{Nitrate}}{NO_3^-} \rightarrow \underset{\text{Nitrite}}{NO_2^-} \rightarrow \underset{\text{Hyponitrite}}{HNO} \longrightarrow \underset{\text{Hydroxylamine}}{NH_2OH} \longrightarrow \underset{\text{Ammonia}}{NH_3}$$

In waterlogged soils, there is anaerobic oxidation as there is hardly any oxygen. Some organisms, belonging to genera *Pseudomonas*, *Bacillus* and *Paracoccus*, take oxygen from the nitrate and give out nitrogen and nitrous oxide. Denitrification is strongly influenced by several soil-related and environment-related factors, such as the amount and nature of the organic matter and moisture content.

The factors necessary for nitrate reduction are: an anaerobic environment, the presence of nitrates and soluble carbons, and denitrifying organisms. Several factors control nitrate reduction directly and indirectly. Soil denitrification is controlled by three primary or proximal factors, namely, oxygen, nitrate and carbon, which in turn are affected by several physical and biological factors (distal factors). Thus, it is necessary to focus on distal rather than proximal factors as controllers of denitrification. Furthermore, oxygen, nitrate, carbon and soil pH also influence the reduction of nitrate. Denitrification is maximum when the pH is between 6 and 8, and the temperature between 25 and 60°C.

Nitrate reduction

Nitrate reduction occurs when the nitrate is reduced to ammonia using enzymes. The numbers indicate the oxidation state of nitrogen.

$NO_3^- \longrightarrow$	$NO_2^- \longrightarrow$	$HNO \longrightarrow$	$HN_2OH \longrightarrow$	NH_3
Nitrate	Nitrite	Hyponitrite	Hydroxylamine	Ammonia
+5	+3		+1	+3

(Electron transfer)

Nitrates

Nitrates, a combination of nitrogen and oxygen, are salts of nitric acid and metals. When used as fertilizers, nitrates are generally salts of ammonium, sodium, potassium and calcium. Nitrates are monovalent ions used as fertilizers, either individually or as mixtures. Most nitrates are water-soluble and when applied to the soil as a fertilizer, are easily leached out because of their weak binding to soil particles.

Because nitrate contains nitrogen in its highest oxidation state (+5), it is a useful oxidizing agent and is often a constituent of matches and explosives. Leaching of nitrates causes low efficiency of nitrogen use. Principal issues relating to nitrates are: (a) surface water **eutrophication**, (b) increased production of nitrous oxide from the received waters, and (c) increased nitrate concentration in drinking water.

The excess of nitrate in drinking water is harmful. The allowable limit of nitrates in Europe is 50 mg/liter. The upper limit is set, particularly, to protect infants from the possible risk of acute methemoglobinemia (blue baby syndrome), arising from their consumption of water containing excess nitrates. If excessive nitrates get consumed, the nitrite (NO_2^-) reacts with food components in the stomach and can give rise to carcinogenic nitroso compounds.

A plant gets the required nitrogen for its growth mostly as nitrate (NO_3^-) and partly as ammonium (NH_4^+). The nitrate uptake is high in acidic soil. Under anaerobic conditions, micro-organisms reduce nitrates to nitrites, then to ammoniacal salts and finally to gaseous nitrogen which is lost to the atmosphere.

Nitrating bacteria

Plants absorb nitrogen in the form of nitrates. The bacteria responsible for nitrating or converting nitrites to nitrates are nitrating bacteria. *Nitrobacter*, *Nitrospira* and *Nitrococcus* are nitrating bacteria and they oxidize nitrite to nitrate in weakly acidic or neutral soil conditions but not in highly acidic soils. The conversion takes place as follows:

$$2HNO_2 + O_2 \longrightarrow 2HNO_3 + 18 \text{ cals}$$

Nitration

Nitration is the conversion of nitrite to nitrate by soil bacteria like *Nitrobacter*, followed by the uptake and incorporation of nitrates into amino acids by higher plants.

The conversion of ammonium ion to nitrite by *Nitrosomonas, Nitrosolobus* and *Nitrospira*, and the subsequent oxidation of nitrite to nitrate is called **nitrification**, which is a critical part of the nitrogen cycle. The process of incorporation of the nitro (NO_2) group in a molecule, especially organic compounds, is also called nitration and is carried out by a mixture of concentrated sulphuric and nitric acids.

Commonly, there are 3 types of nitration, classified according to their chemical structure, as

(a) C-nitration in which the nitro group attaches itself to a carbon atom:

$$R\text{-}CH_2\text{-}H + HNO_3 \xrightarrow{H_2SO_4} R\cdot CH_2\cdot NO_2 + H_2O$$

(b) O-nitration in which the nitro group attaches to an oxygen atom forming an O-N bond (esterification).

$$R\cdot CH_2\text{-}O\text{-}H + HNO_3 \longrightarrow R\cdot CH_2\text{-}O\text{-}NO_2 + H_2O$$

(c) N-nitration in which there is a formation of an N-N bond.

$$R\text{-}CH_2NH_2 + HNO_3 \longrightarrow R\text{-}CH_2NHNO_2 + H_2O$$

Nitre

Commercial potassium nitrate (KNO_3) is known as nitre or **saltpeter**. It contains about 46% potassium, as K_2O. Nitre is commonly found in small amounts, as a surface efflorescence in arid regions, in caves and other sheltered places. Nitre is associated with soda nitre in the desert regions of Chile, Italy, Egypt and the USA.

Nitric acid

Nitric acid (HNO) is a mineral acid which combines with metals or alkalis to form nitrates. It can be made synthetically by passing ammonia and air over a metallic catalyst, the reaction being:

$$2NH_3 + 4O_2 \xrightarrow{\text{Catalyst}} N_2O_5 + 3H_2O$$

The dinitrogen pentoxide (N_2O_5) is absorbed in water when nitric acid is formed as:

$$N_2O_5 + H_2O \longrightarrow 2HNO_3$$

Nitric acid is used in the manufacture of ammonium nitrate for explosives and fertilizers. Two other types of nitric acid – red fuming nitric acid and white fuming nitric acid are known. White fuming nitric acid contains more than 97.5% nitric acid, less than 2% water and less than 0.5% oxides of nitrogen. Red fuming nitric acid contains more than 86% nitric acid, 6 to 15% oxides of nitrogen and less than 5% water. It is used as a rocket fuel and nitrating agent. Important production process for the manufacture of nitric acid are elaborated in the entry **Nitric acid production processes**.

Nitric acid plant, construction materials of: See Nitric acid production processes

Nitric acid, pollution and environmental laws: See Nitric acid production processes

Nitric acid production by ammonia oxidation: See Nitric acid production processes

Nitric acid production by GIAP high pressure process: See Nitric acid production processes

Nitric acid production by Grand-Paroisse dual pressure process: See Nitric acid production processes

Nitric acid production by Ostwald process: See Nitric acid production processes

Nitric acid production by Uhde medium pressure process: See Nitric acid production processes

Nitric acid production by Weatherly high pressure process: See Nitric acid production processes

Nitric acid production processes

About 75% of nitric acid produced in the world is used for producing fertilizers (and about 15% for explosives). The remaining acid is used in making synthetic fibers, dyes and plastic (Fig.N.7).

Nitric acid can be produced by (a) acidulation of natural sodium nitrate with sulphuric acid, (b) direct synthesis from nitrogen and oxygen, and (c) oxidation of ammonia.

Nitric acid is a strong acid and a powerful oxidizing agent. Concentrated nitric acid on distillation at atmospheric pressure starts boiling at 78.2°C but decomposes eventually to give 68% nitric acid with a boiling point of 120.5°C. The standard limit of chlorine is less than 5 ppmw and that of nitrous acid (HNO_2) less than 5 ppmw. Anhydrous nitric acid does not exist in liquid form.

Anhydrous ammonia and a platinum catalyst are required for the manufacture of nitric acid. The oxides of nitrogen that are used in the production of nitric acid are nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2) and dinitrogen tetroxide (N_2O_4). A mixture of nitrogen oxides, usually NO and NO_2, is commonly referred to as NO_X.

The production of weak nitric acid consists of the following three steps: (a) catalytic ammonia oxidation to nitric oxide, (b) oxidation of nitric oxide to nitrogen dioxide, and (c) acidic absorption of nitrogen dioxide in water.

The overall reaction in the production of nitric acid is strongly exothermic:

$$NH_3 + 2O_2(g) \longrightarrow HNO_3(aq) + H_2O + 437\ \text{kJ/gmol}$$

The absorber performance is improved by high pressure and low temperature, and a high oxygen content in the gas phase. However, in the ammonia converter, the oxidation of ammonia is favored by low pressure.

Methods of production: Many processes for producing nitric acid are now available. They differ not in fundamental principals, but primarily in design details of the plant, operating conditions for the plant size, cost considerations relating to raw materials, energy and installation.

The production of nitric acid by the **oxidation of ammonia** goes through the following steps or units: (a) ammonia preparation-vaporization, superheating and filtration of anhydrous ammonia, (b) process air preparation involving preheating, filtration and compression, (c) catalytic ammonia oxidation, (d) cooling of the reaction products with various media such as process air, boiler water, tail gas, etc., (e) oxidation of nitric oxide to higher oxides, (f) nitrogen oxides absorption in water to form nitric acid, (g) acid bleaching by additional air or other means, (h) tail gas treatment to reduce air pollution and to improve overall efficiency of the plant, (i) recovery of energy from the heated and compressed process gases, and (j) recovery of catalyst platinum.

The anhydrous ammonia and the process air used must be free both from the oil content and catalyst poisons to avoid fouling of the vaporizer and catalyst screens. The ratio of ammonia to air and the flow rate of each component must be carefully controlled to ensure maximum conversion efficiency, explosion prevention and plant output maximization.

The normal catalyst used in the process is a platinum-rhodium gauze or mesh. It not only promotes reaction but also meets the other operating criteria such as those to counter the severe corrosive and oxidation atmosphere, etc. The usual rhodium percentage in the catalyst is in the range of 4 to 10%. To achieve higher efficiencies and smaller platinum losses, knitted gauzes are used. Chrome-nickel alloy grids are used to support the fine screens.

Platinum catalysts can be poisoned by such elements as As, Bi, P, Pb, S, Si and Sn. These elements lead to the formation of inactive compounds in the wires and thus decrease the catalytic activity. In some instances contamination with traces of Cr, Ni or Fe temporarily reduces the conversion efficiency which can often be restored by treatment with hydrochloric acid.

Ammonia conversion efficiency is a function of pressure and temperature. As the pressure increases, higher temperatures are needed to obtain or maintain the

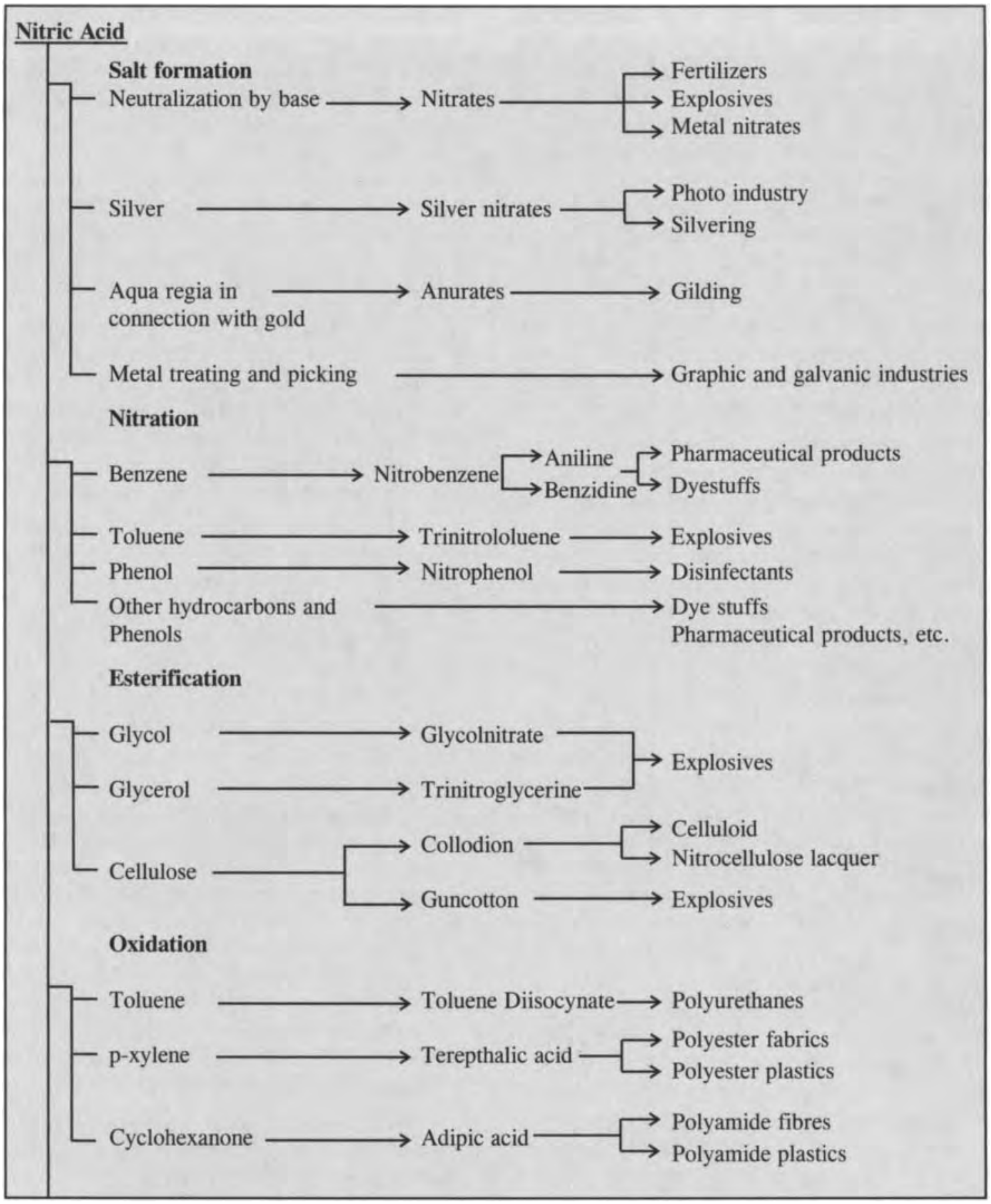


Fig.N.7: Nitric acid applications. (Source: "Fertilizer Manual", 1998. UNIDO, IFDC and Kluwer Academic Publishers. With permission).

high conversion efficiency. An increased flow rate and the presence of several layers of the catalyst help to minimize undesirable side reactions. However, high flow rates increase the catalyst loss – a situation that promotes search for non-platinum catalysts for ammonia oxidation. The most prospective non-platinum catalysts are based on oxides of Co, Fe or Cr.

Nitric oxide produced in the ammonia oxidation undergoes further oxidation in two steps that occur sequentially. These are (a) reaction of nitric oxide with oxygen to form nitrogen dioxide, and (b) a dimerization reaction to produce nitrogen tetroxide. Both reactions are homogeneous, moderately exothermic and non-catalytic. The reaction rate varies with the third power of absolute pressure. The dimerization reaction is instantaneous and is a direct function of pressure and inverse function of temperature.

The absorption of nitrogen dioxide requires (a) cooling down of the gaseous mixture below the dew point to remove the excess water and thus to increase the partial pressure of nitrogen oxides, and (b) absorption of nitrogen oxides in water. During the absorption reaction, additional NO (nitric oxide) is formed, which is further oxidized and absorbed. Lower temperatures improve the absorption rate and increase the acid concentration. At higher pressures, the nitric oxide oxidation reaction is quicker, the equilibrium moves toward nitrogen dioxide, and more concentrated nitric acid is produced.

As low temperature favors acid concentration, several cooling methods have been developed. These methods involve use of water curtains outside the tower, cooling coils strategically located inside the absorption column, and external units of a plate, drum or a cascade. Vaporization of ammonia is used in some cases to pre-chill the absorber feed water and cooling water. Modern pressure-absorption systems permit absorption efficiencies of more than 99%, resulting in an acid concentration in the range of 55 to 65%.

The acid produced in absorber units is invariably yellow or brown in color because of the dissolved nitrogen dioxide. As this color is not acceptable, nitrogen dioxide is removed either in a separate small bleaching tower or by means of compressed air injection.

The **tail gas of nitric acid plants** contains 1500 to 3000 ppmv nitrogen oxides which need to be reduced to meet the **pollution and environmental laws**. The methods employed to control the level of NO_x in tail-gas are: (a) extended absorption, (b) non-selective catalytic reduction with fuel such as methane or ammonia plant purge gas, and (c) selective catalytic reduction with ammonia. Other methods such as absorption by silica gel or molecular sieves or scrubbing with alkalis or urea solutions are also used by some manufacturers.

During the process operations, the surface of the platinum catalyst is damaged by abrasion and vaporization. Platinum from the catalyst passes into a gas stream as fine particles. This platinum loss increases the production cost. Two types of platinum recovery systems are developed - catchment gauzes and mechanical filters. In the catchment gauzes process for platinum recovery, platinum is collected at a high temperature.

However, the main portion of platinum loss is still in the vapor form. At this temperature, the platinum atoms strike the surface of the catchment metal and form an alloy for subsequent recovery. This system recovers upto 80% of the primary platinum losses. The catchment gauzes are mesh screens installed at the bottom of the burner. The mechanical filters composed of glass wool or silica fibers are installed downstream of the catalyst end where the gas temperature is below 300°C. A 50% recovery of platinum has been reported.

Because of the corrosive behavior of nitric acid, **construction materials of the nitric acid plant** are required to be selected with great care. The principal material, wherever nitric acid or wet nitric oxides are present, is chromium-nickel austenitic steel. The stainless steel used in nitric acid plants is standard austenitic steel of type AlSi 304 L, 321 or 347 or its equivalent. Various fluorocarbon plastic materials, because of their resistance to nitric acid, are used as flanges, gaskets and seals.

Industrially, nitric acid is produced by the ammonia oxidation process. Industrial plants are classified as monopressure plants and dual-pressure plants. The monopressure plants are of two types: low pressure (0.3 to 0.5 MPa) and high pressure (0.8 to 1.3 MPa). Dual pressure plants operate under lower pressure in the ammonia oxidation section than in the absorption section. In general, high-pressure operation permits smaller plant units for a given output and reduction in capital costs. Hence, most of the new plants use either mono-high-pressure or dual-pressure processes. High pressure processes generally involve the lowest capital cost and highest operating cost because of the higher platinum losses, less efficient ammonia conversion and lower steam recovery. Medium-pressure processes have the highest capital cost and the lowest operating cost. The dual-pressure process represents a compromise.

The **GIAP** (State Institute of Nitrogen Industry) **high pressure process** operates at around 0.7 MPa. The main feature is the air compressor driven by a high-temperature gas turbine. The process incorporates a non-selective catalytic reduction unit for the reduction of NO_x. The concentration of nitric acid is about 60% and the NO_x content in the tail gas may be 50 ppmv or less.

The **weatherly high pressure process** operates typically at about 1 MPa pressure for both ammonia oxidation and absorption steps. The absorption tower is cooled to about 4°C by using refrigerated potassium carbonate brine as the coolant. The NO_x concentration in tail gas may be less than 200 ppmv. The nitric acid concentration is 58 to 60%.

In the **Uhde medium-pressure process**, the air required for ammonia oxidation is supplied by an uncooled air compressor operating at a pressure of 0.4 to 0.5 MPa in case of radial compressors and 0.5 to 0.6 MPa with axial flow compressors. The air compressor may be driven either by a steam turbine or electrical power. The acid produced with this type of plant is up to 68% nitric acid, whereas the NO_x content in the tail gas is around 500 ppmv. Ammonia refrigeration is used to cool the tail gases. The NO_x concentration can be further reduced to less than 200 ppmv by selective catalyst reduction using a non-noble metal catalyst and ammonia as the reducing agent. Uhde also offers a high-pressure process (0.8 to 1.0 MPa) and a dual-pressure process.

The **Grand-Paroisse dual pressure process** operates at a pressure of 0.35 to 0.6 MPa for ammonia oxidation and 1.0 to 1.5 MPa for the absorption step. The nitric acid concentration is up to 68% and the NO_x content of the tail gas is 200 ppmv or less.

Ostwald process of nitric acid manufacture has an overall efficiency of 94 to 96%. In this, up to 80% of the platinum catalyst losses can be recovered. Direct synthesis of nitric oxide in low-temperature plasma was investigated. The two methods employed were (a) under high temperatures (2000 to 2700°C) in equilibrium plasma, and (b) in non-equilibrium plasma, at relatively low temperatures. The consumption of electricity in the new process is high and hence cannot compete with the existing Ostwald process at the existing cost of raw materials and utilities.

Nitric acid storage

Nitric acid, a powerful oxidizing agent is an important input to the fertilizer industry. Nitric acid is stored in stainless steel vessels and transported in stainless steel tankers when the quantities are large, and in stoneware bottles or glass carboys when the quantities are small.

Nitric phosphate

Nitric phosphate is a granulated fertilizer and contains 20% nitrogen and 8.7% phosphorus. The water solubility of nitric phosphate varies from 0 to 80%, depending on the process used for its manufacture. Nitric phosphates used as fertilizers are effective on acid soils and give best results on crops such as turf and sod crops or sugar cane, which have relatively long growing seasons.

Nitrification

The conversion of ammonia and nitrites to nitrates is called nitrification. This is a biological process for which soil micro-organisms are responsible. The conversion happens in two stages:

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+$$
$$2NO_2^- + O_2 \longrightarrow 2NO_3^-$$

Nitrification inhibitor

A nitrification inhibitor is a non-phytotoxic substance which inhibits the conversion of ammonium ion to nitrate ion (**nitrification**). Several chemicals inhibit nitrification. Some of the best known nitrification inhibitors are nitrapyrin or N-serve, AM (2-amino-4-chloro-6-methyl pyridine), DCD (dicyandiamide), thiourea, ATC (4-amino - 1,2,4 - triazole), potassium azide, neem (*Azadirachta indica*) seed extract, etc. Generally, 0.2 to 2.0 kg/ha of the inhibitor, when placed near the stored nitrogen fertilizer, is sufficient for retarding nitrification. This selectively inhibits the activity of *Nitrosomonas*, and is safe to use. The added inhibitor prevents rapid nitrification of fertilizers and remains effective throughout the fertilizer-soil reaction zone, thereby reducing the nitrogen loss (through leaching and denitrification) and improving the recovery of the applied nitrogen.

Nitrobacter

Nitrobacter is a genus of family Nitrobacteriaceae of chemolithotrophs. The bacterium is Gram negative, non-motile, rod-like in shape and has a gelatinous membrane. The bacterium can be cultured on an artificial medium, free of organic matter. These bacteria are sensitive to heat with their optimum growth occurring at 37°C. The medium, rich in organic matter, slows down their growth. For growth, bacteria derive energy by oxidation of nitrites to nitrates, and carbon from carbon dioxide. Ammonium ions in the soil are selectively oxidized to nitrite and then to nitrate. The autotrophic bacteria, *Nitrobacter* selectively oxidize nitrite to nitrate, and hence are called **nitrating bacteria**.

There are 7 genera, of which *Nitrosomonas*, *Nitrosococcus*, *Nitrosospira* and *Nitrosolobus* oxidize ammonia to nitrite and the remaining three, namely, *Nitrobacter, Nitrospira* and *Nitrococcus* oxidize nitrite to nitrate.

Nitrocalcite

Nitrocalcite is another name for calcium nitrate. It was the first chemical nitrogenous fertilizer to be marketed.

Nitro-carbonic process for calcium carbonate

In manufacturing nitrophosphate fertilizers by **Odda process**, calcium nitrate is left behind in the solution. It is highly hygroscopic and is thus very inconvenient to use as a fertilizer. It has, therefore, to be removed or modified to some other form, which is done by the nitro-carbonic process. The process converts calcium nitrate to calcium carbonate by injecting carbon dioxide into the calcium nitrate solution. (See also Nitrophosphate fertilizers.)

Nitrocellulose

When cellulose is acidulated with a mixture of concentrated nitric acid and sulphuric acid, nitrocellulose is formed, which is also called **cellulose nitrate**. The nitrocellulose is used in explosives and celluloid, since it is highly inflammable. Nitrocellulose is not a nitro compound, but an ester containing -$CONO_2$ groups.

Nitro-chalk

Nitro-chalk is a trade name under which the fertilizer calcium ammonium nitrate (**CAN**) is marketed. CAN is sold under many trade names.

Nitrocysts

Nitrocysts are thick and dark cells that intervene in the nitrification process, especially in its first phase called **nitrosation**.

Nitrogen

Nitrogen is the most crucial and major nutrient element in plant growth. It is a gaseous element of Group 15 (formerly VB) of the Periodic Table, having an atomic number of 7 (Fig.N.8). There are two stable and four radioactive isotopes of nitrogen. Nitrogen is a part of all amino acids, proteins, chlorophylls, enzymes, alkaloids, phosphotides, vitamins, hormones, nucleic acid and other plant substances. With as much as 78% in the atmosphere and 98% in the soil organic matter, nitrogen is abundant in nature. Yet, it is most deficient in all cultivated soils because (a) nitrogen is lost in many ways, (b) both microbes and plants compete for soil nitrogen,

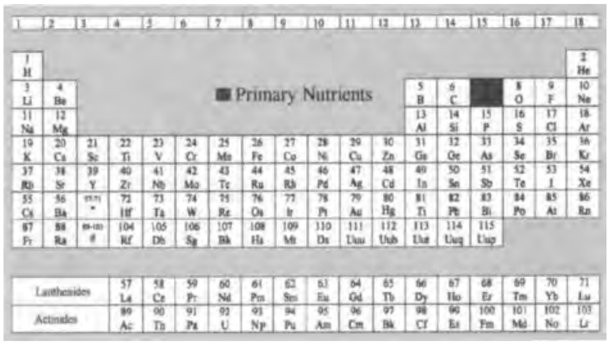


Fig.N.8: Position of nitrogen in the Periodic Table.

and (c) soil has little capacity to hold nitrogen in oxidized forms. With all vital processes being associated with functionally reactive plasma in the nitrogen-containing proteins, it is obvious that life is inconceivable without nitrogen.

Nitrogen in adequate quantity often leads to the desirable thin cell walls and leads to more tender and succulent plants, resulting into a better crop yield. Nitrogen is absorbed by plants either in the cationic or the anionic form as ammonium ion (NH_4^+) or nitrate ion (NO_3^-). These ions are soluble in water and are, therefore, very easily leached. If fertilizer is applied when it rains, obviously a lot of it will be washed away, and in this way, the annual nitrogen loss can be as much as 50 to 80 kg/ha.

Nitrogen loss occurs through leaching, volatilization, immobilization and ammonium fixation. Denitrification or conversion of nitrate to nitrogen gas by bacteria is another cause for extensive loss of gaseous nitrogen. Ammonium ions in a basic solution leads to ammonia loss by volatilization. Surface applications of any ammonium or urea fertilizer on calcareous soils cause the largest ammonia losses.

The mineralized ammonium ions have a very short life, whereas the nitrification process is rapid. So, slowing down of the oxidation of ammonium ions to the nitrate form reduces the nitrate (and nitrogen) loss by leaching or denitrification. Several nitrification inhibitors such as nitrapyrin and dicyandiamide (DCD) are used to inhibit nitrification.

Nitrogen fixation provides a major source of soil nitrogen. Nitrogen fixation involves the action of microbes that convert the relatively inert nitrogen of the soil air into such forms as are useful to plants. The natural biological and chemical processes through which inorganic and organic nitrogen are inter-converted, are collectively known as the **nitrogen cycle**. It includes ammonification, ammonia assimilation, nitrification, nitrate assimilation, nitrogen fixation and denitrification.

Materials supplying nitrogen are (a) anhydrous ammonia (NH_3) which is hazardous and difficult to handle, (b) urea [$CO(NH_2)_2$] which is a good, cheap and the most popular fertilizer, (c) ammonium nitrate (NH_4NO_3) which is a relatively cheap source of solid nitrogen fertilizer, and (d) ammonium sulphate [$(NH_4)_2SO_4$] which is not as popular as urea and ammonium nitrate.

Since fertilizer nitrogen efficiency is determined by the biomass yield and nitrogen uptake by the crop, all factors affecting these also affect the efficiency of nitrogen usage. These factors are classified into five groups such as the soil, crop, environment, agronomic practices and fertilizer management.

Nitrogen deficiency symptoms are most prevalent and the easiest to identify. Young plants exhibit yellowish green foliage and stunted growth while older plants show yellowing or falling of leaves (Fig.N.9).

Fig.N.9: Nitrogen deficiency in sorghum showing yellowing of leaf. The healthy leaf (right) is completely green. Source: "Handbook on Fertiliser Usage" 1994, S.Seetharaman, et al, (Ed). The Fertilizer Association of India, New Delhi. With permission.

Nitrogen deficiency impedes good yield. An effective, integrated approach employs organic manures, biofertilizers, chemical fertilizers, nitrification inhibitors, coated and long-persisting nitrogen fertilizers. Such practices hold the key to sustainable agriculture. Nitrogen is used in the production of ammonia, acrylonitrile, nitrates, cyanamide, cyanides and nitrides. It is used in the manufacture of explosives and as an inert gas for purging. It is also used in cryogenic preservation, as a source of pressure in oil wells, inflating tires and as a component of fertilizer mixtures. However, overuse of nitrogen fertilizers is responsible for increased quantities of nitrates in the soil water, posing a serious threat to the environment (See also Fertilizer nitrogen, an environmental perspective.)

Nitrogenase

The enzyme nitrogenase fixes inert nitrogen in soils. It lowers the activation energy required for the conversion of nitrogen (N) to ammonia (NH_3). The complete process of nitrogen fixation taking place in root nodules is illustrated in Fig.N.10. Nitrogen fixation by micro-organisms can be symbiotic and non-symbiotic.

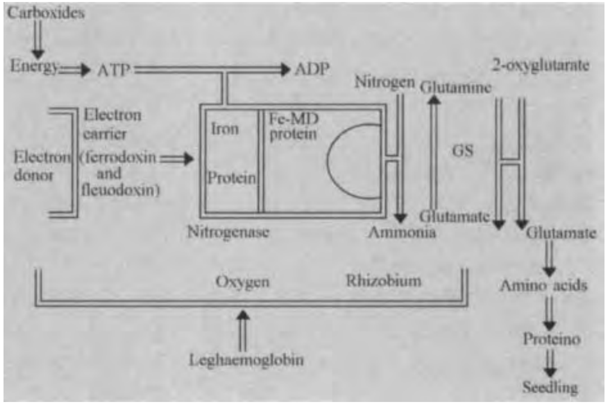


Fig.N.10: Complete process of nitrogen fixation in root nodules.

The nitrogenase enzyme complex consists of two proteins. The first is a larger molybdenum-iron protein of 2 to 2.7 $\times 10^5$ molecular weight, containing 1 or 2 atoms of molybdenum, 17 to 36 atoms of iron and 14 to 28 acid labile sulphur atoms. The second is an iron-protein molecule of 55 to 67 $\times$ 10^3 molecular weight, containing four atoms each of iron and acid labile sulphur.

Nitrogenase activity: See Acetylene reduction assay

Nitrogen availability index

Nitrogen availability index is a quantitative value index of the soil property (or a group of properties) that correlates with the amount of nitrogen that the soil makes available to the crop, during its growing season. Such indices are useful management tools to assess the nitrogen fertilization rate.

Total soil nitrogen and the soil organic matter were among the first indices used and are still in vogue to indicate the available nitrogen. The determination of the total soil nitrogen by the **Kjeldahl method** is too costly and time consuming for routine soil testing. This is unlike the method widely used for the quick estimation of soil organic matter. Other popular indices are chemical extractants or hydrolysis agents such as 1N or 6N ammonium sulphate [$(NH_4)_2SO_4$], calcium hydroxide [$Ca(OH)_2$], barium hydroxide [$Ba(OH)_2$], alkaline potassium permanganate ($KMnO_4$), 0.01N calcium chloride ($CaCl_2$) and 1N sodium hydroxide (NaOH). The electro-ultrafiltration (EUF) procedure, which is a form of electrophoresis, is used in Germany to determine the fertilizer requirement for sugar beets. Many biological tests have also been proposed, such as those based on the nitrate-nitrogen (NO_3-N) liberated in 14 to 78 days of incubation, the nitrogen mineralized in 14 to 112 days of incubation and the inorganic nitrogen released by autoclaving and anaerobic mineralization. None of these has, however, been accepted universally.

To measure the residual soil NO_3-N profile, soil samples are taken from a depth of 60 to120 cm just before planting or soon after the harvest. This is the **pre-plant nitrate test (PPNT)**. In addition, there is a **pre-side dress soil nitrate test (PSNT)**. It involves sampling of the soil (from 30 cm depth) before side dressing and analysis for the NO_3-N. This provides a more reliable index of the available soil nitrogen and is used for deciding the amount of nitrogen to be side-dressed. A major drawback in this procedure is the lack of sufficient time (only 2 to 3 weeks) for many important tasks, namely collecting soil samples, analyzing for NO_3-N, deciding the rate of nitrogen to be applied, and then applying the fertilizer nitrogen. Besides, there is a task of determining the degree of nitrogen stress by measuring the chlorophyll content of leaves using a handheld chlorophyll meter.

Different methods are used to estimate the available nitrogen in soils. Some of these relate to (a) determination of Mitscherlich b value, (b) the percentage sufficiency concept or Mitscherlich c value, (c) tissue tests for nitrogen sufficiency evaluation, (d) carry-over of nitrogen fixed by legumes, (e) Fried and Dean A values, (f) Dean A values, (g) determination of available nitrogen from animal manure and of mineralizable nitrogen, (h) guaranteed analysis of fertilizers, and (i) tests for mineral nitrogen.

Mitscherlich *et al.* conducted extensive studies on the effect of soil nutrient quantities on the dry matter yields, and found these to be related by a simple exponential function, which could be fitted to the observed yields from incremental applications of a fertilizer. This study has led to a yield response curve that describes the expected yield as a continuous smooth function of the nutrient availability. Its extrapolation to the X-axis gives the **Mitscherlich b value**. The latter is the estimated quantity of soil nitrogen available to the plant. Such estimates can be made from the field or greenhouse data. The availability index gives an assessment of the ability of the soil to supply nitrogen under the given conditions.

Mitscherlich c values describe the efficiency of conversion of the added nutrient into plant dry matter. The efficiency depends on the percentage of applied nutrient actually taken up by plants and the amount of dry matter produced per unit nutrient uptake. If both factors remain reasonably constant across a range of conditions (that is, if the c value is reasonably constant), the problem of relating the soil nutrient availability indices to the yield level can be greatly simplified by transforming the absolute yields to relative values. The measured quantities of the available soil nitrogen can thus be related to the nitrogen levels sufficient for plant growth. The minimum measurable quantity of nitrogen needed to avoid the yield limiting deficiencies is an important reference point.

Plant tissues are often analyzed to evaluate nitrogen sufficiency and the new variations in tissue testing methods include the use of chlorophyll meters and remote sensing.

Fried and Dean A values use isotope dilution technique to estimate nitrogen availability in soils. In this method, known quantities of the ^{15}N labeled nitrogen are added to the soil, the crop grown, and the soil analyzed to determine the relative uptake of the labeled nitrogen. An assumption is that plants take up the soil nitrogen and the labeled nitrogen, in proportion to their effective quantities in the soil. Isotope dilution techniques are used to estimate the availability of the soil nitrogen in absolute units.

Various nitrogen availability indices are used for different purposes. Most of these are directly or indirectly useful in identifying the appropriate rates of nitrogen fertilization for plant growth. For economic and environmental reasons, the nitrogen application rates should complement the quantities of the available soil nitrogen. Various indices allow the estimation of the plant available nitrogen supplied by soil, organic materials or inorganic fertilizers.

The increase in yield by fertilizers varies greatly with the nature of the soil, agro-climatic conditions, crop management, etc. However, other things being equal, it is useful to have an idea of the expected yield increase brought about by fertilizers. It is reported that the application of 1 kg of nitrogen leads to a harvest increment of 16 feed units, that of phosphorus, to 10 feed units, and of potassium, to 4.5 feed units (1 feed unit is equivalent to the energy of 1 kg of barley).

Nitrogen cycle

Biochemical or physico-chemical modification of nitrogen is a cyclic phenomenon. The modifications are influenced by plants, animals, micro-organisms and other living organisms as well as by physical processes, such as ammonification, ammonia assimilation, nitrification, nitrate assimilation, nitrogen fixation and denitrification, through which inorganic and organic nitrogen are inter-converted.

Organisms can metabolize nitrogen compounds in three ways: (a) as a nitrogen source, which means converting them first to ammonia, (b) as an energy source, such as in the oxidation of ammonia to nitrite and nitrite to nitrate, and (c) like nitrate, as terminal electron acceptors, under conditions where oxygen is absent or is available in limited supply. The reactions and products involved in these metabolically different pathways collectively make up the nitrogen cycle. Fig.N.11 shows inter-conversions of nitrogen compounds in a soil-water pool.

The nitrogen cycle is a major cycle in the environment. Most non-legume cropping systems require nitrogen inputs. Nitrogen deficiency is the most relevant issue to crop production. To make up for this deficiency, many nitrogen sources are available. In addition to inorganic nitrogen, the organic nitrogen derived from animal manure and other waste products, and that available from nitrogen fixation by leguminous crops also supply sufficient nitrogen for plant growth.

About 78% of the earth's atmosphere is nitrogen gas, which is in dynamic equilibrium with various fixed forms in the soil, such as that fixed by micro-organisms, produced by electrical discharge in the atmosphere to form nitrogen oxide, and synthetic fertilizers like ammonia. Plants and soils cause many transformations of nitrogen from the inorganic to the organic forms.

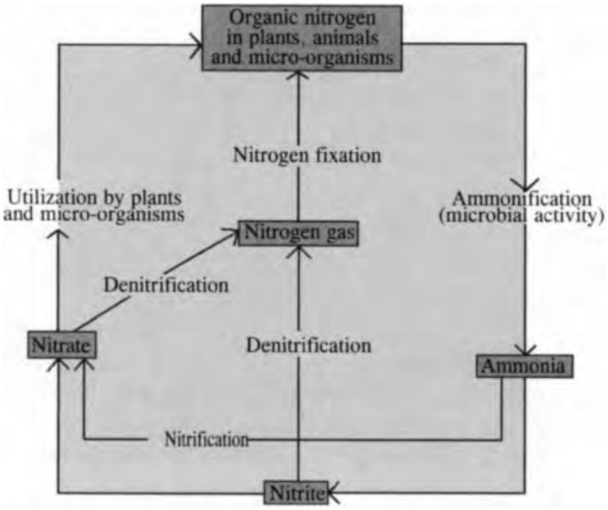


Fig.N.11: Pathways in a simple nitrogen cycle.

The nitrogen cycle is divided into three sub-classes, identified on the basis of the N-input (gain), the N-output (loss) and N-cycling within the soil as shown in the Table-N.3.

Table-N.3: Stages of N-cycle.

N-gain	N-loss	N-cycling
Fixation - biological electrical industrial	Plant uptake Denitrification Volatilization Leaching	Immobilization Mineralization Nitrification
Combustion	Ammoniation	
Animal manure		
Crop residue		

Approximately, 140 million tons of newly fixed nitrogen is deposited annually on land; that derived from legume crops, fossil fuel burning and fertilizers exceeds the natural N-inputs. The increased nitrogen in the N-cycle through tillage, vegetation burning and wetland draining is the core environmental issue in agricultural operations. Despite all agricultural sectors aiming to increase the nitrogen use efficiency, substantial nitrogen losses are unavoidable owing to the complexity of the N-cycle.

Nitrogen deficiency symptoms

When there is nitrogen deficiency, chlorophyll production is reduced and yellow pigments, carotene and xanthophylls appear. The nitrogen deficiency produces pale green or yellow leaves as seen in Fig.N.12. The symptoms are most prevalent and the easiest to identify. Young plants exhibit yellowish green foliage and stunted growth while the older plants show yellowing or falling of leaves.

Fig.N.12: Nitrogen deficiency symptoms on leaves.

Nitrogen estimation by Subbiah and Asija method: See Subbiah and Asija method for estimating available nitrogen in soil

Nitrogen fertilizers

Organic and inorganic nitrogen sources are available for supplying the nitrogen required for optimum crop productivity. The average nitrogen concentration in natural organics is generally between 1% and 13%.

Synthetic or chemical fertilizers are the most important sources of nitrogen. For convenience, various nitrogen compounds are grouped under three categories: the ammoniacal nitrogen, the nitrate nitrogen and the compounds making nitrogen slowly available.

Nitrogen fertilizers originate from ammonia (Fig.N.13) which is made by a synthesis of the hydrogen and nitrogen elements in an industrial process. In the **Haber-Bosch process**, for instance, hydrogen is obtained mostly through the reaction of water with fossil fuel (natural gas or coal) and nitrogen is taken from the air. The overall reaction is:

$$\underset{\text{Air}}{\tfrac{1}{2}O_2 + N_2} + \underset{\text{Natural gas}}{CH_4} + \underset{\text{Water}}{H_2O} \longrightarrow \underset{\text{Ammonia}}{2NH_3} + \underset{\text{Carbon dioxide}}{CO_2}$$

Carbon dioxide from this conversion can be combined with ammonia to form urea which is a major fertilizer. Ammonia, on oxidation, produces nitric acid, which when combined with ammonia, gives ammonium nitrate. Ammonium nitrate is another major fertilizer product and a key component of complex fertilizers.

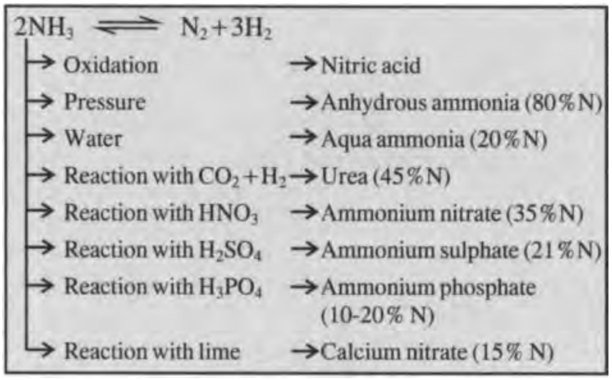


Fig.N.13: Nitrogen synthesis.

Some ammoniacal fertilizers have a variety of elements which then become very useful for application in many cases. While calcium cyanamide is a nitrogen source (around 20%), it has 54% of CaO and minute quantities of sulphur. Similarly, ammoniated ordinary superphosphate has 4% N, 16% P_2O_5, 23% CaO, 0.5% MgO and 10% S. Monoammonium phosphate contains 2% CaO, 0.5% MgO and around 2% of S, besides a large proportion of P_2O_5 (around 50%) and 11% N.

Typical compositions (in percentages) of some of the chemical sources of nitrogen are given in Table-N.4. Also refer to Table-A.2 under **Ammoniacal fertilizers**.

In addition to the nitrogen uptake by crops, it is also desirable to have sources capable of releasing nitrogen over extended periods, so as to avoid repeated applications of the conventional water-soluble fertilizers. Most of the materials developed for controlled nitrogen availability are grouped under (a) those of low solubility which release nitrogen after undergoing chemical or microbial decomposition [like urea formaldehyde (**ureaform**), sulphur or **neem coated urea**, etc.], and (b) nitrification and urease inhibitors (for example, nitrification inhibitors like N-serve, Dwell or Eltridiazol, dicyandiamide, and urease inhibitors like quinones, etc.).

Table-N.4: Composition of some chemical sources of nitrogen.

Source	N %	P_2O_5%
Ammonium chloride	26	-
Ammonium polyphosphate solution	11	35
Calcium nitrate	15	-
Diammonium phosphate	20	50
Urea ammonium nitrate solution	28-32	-
Urea - ammonium phosphate	21-38	13-42
Urea phosphate	17	43-44
Sodium nitrate	16	-

Nitrogen fertilizers, classification of: See Classification of nitrogen fertilizers

Nitrogen fixation by legumes

Symbiotic bacteria, like *Rhizobium* sp., fix nitrogen in the root nodules of legumes. The host plant uses the fixed nitrogen from nodules, whereas other plants can use the fixed nitrogen released by the decomposition of the nodules or dead legume residues. The rhizobia obtain energy (for growth) from (as much as 35%) photosynthetic products formed in the legume. Thus, in the absence of other growth limiting factors, the biomass production by a nitrogen-fixing legume is seldom as great as that from cereal crops. The amount of nitrogen fixed by rhizobia depends on the effectiveness of inoculation, soil-derived nitrogen and the environment.

Nitrogen fixation is an anaerobic process. There is a strain-specificity between *Rhizobium* and the legume, and their compatibility is essential for successful nodulation. The leghemoglobin around the bacteria gives pink color to the root nodules. The leghemoglobin pigment limits the oxygen supply near the bacteroid. The amount of leghemoglobin and the number of nodules on the roots decide the amount of nitrogen fixed. In general, nodule bacteria fix 25 to 80% of the total plant nitrogen. The yield benefit of rotations with some legumes is not necessarily related to the supply of nitrogen.

Nitrogen fixation by different legumes varies considerably. Perennial legumes, cut for forage, generally fix more than 100 kg N/ha, sometimes as much as 400 to 600 kg N/ha. As compared to forage legumes, grain legumes fix less nitrogen because of their shorter growing season and, also because the nitrogen left in the stalk of the plant is usually not recorded. Intercropping with legumes grown in between widely placed cereal crops (such as maize, sorghum, millet, cotton and sugar cane) permits the production of grain legumes as a bonus crop with nitrogen fixation as a bonus.

Growing legumes to a certain vegetative stage and then incorporating them into the soil is called **green manuring**. This is another way of utilizing biological nitrogen fixation *in situ*. A large number of green manuring field experiments show increased grain yield for rice equivalent to 50 to 120 kg N fertilizer/ha or even more, depending upon the amount of the incorporated green manure biomass and the total nitrogen content. With forage legumes, only a part of the fixed nitrogen returns to the soil as most forage is harvested. Forages as green manure or winter cover crops return significant amounts of nitrogen to the soil.

The choice between legumes or fertilizer nitrogen is a matter of economics. Generally, fertilizers supplement the amount fixed by legumes, although the actual quantity depends on the nitrogen available from the legume and the nitrogen required by the non-legume crop.

Nitrogen fixing bioinoculants: See Biofertilizers

Nitrogen in soil, Fried and Dean method for estimation of: See A value

Nitrogen loss

Nitrogen is abundant in nature - around 78% in the atmosphere and 98% in soil organic matter. Yet, it is most deficient in all cultivated soils because (a) nitrogen is either lost to the atmosphere or is leached, (b) both microbes and plants use up soil nitrogen, and (c) the soil has little capacity to hold nitrogen in oxidized forms.

Nitrogen is lost through volatilization, denitrification, leaching, immobilization and ammonium fixation (Fig.N.14). In denitrification, the nitrate is converted to ammonia or nitrogen gas which is lost to the atmosphere. In soils, denitrification occurs mostly by the action of certain anaerobic and facultative microbes, whereas in acid soils, denitrification is chemical in nature. The conditions required for denitrification are nitrates, soluble carbons, denitrifying organisms and an anaerobic environment. Nitrogen losses by denitrification vary from 3 to 62% of the applied nitrogen in arable soils.

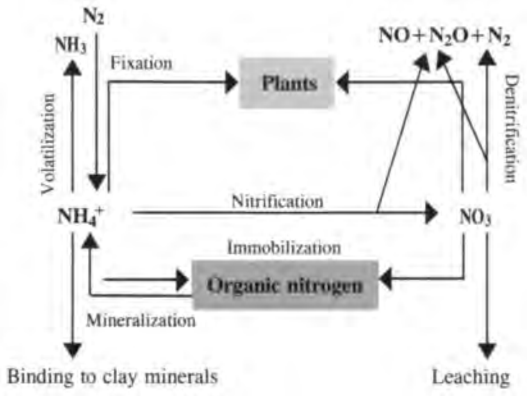


Fig.N.14: Nitrogen loss.

The ammonium ion in a basic soil loses ammonia by volatilization, which can vary from 0 to 50% of the applied nitrogen. The factors controlling ammonia loss include the form of fertilizer and the method of its application, the soil pH and water content, the cation exchange capacity of the soil, the crop and its growth stage, the wind velocity and the air temperature.

Surface applications of any ammonium or urea fertilizer on calcareous soils cause the largest ammonia loss. Enzymes, like urease, hydrolyze urea resulting in the loss of nitrogen, but urease inhibitors reduce this loss by retarding the urea hydrolysis.

Nitrate leaching depends on the amount and intensity of rainfall, the quantity and frequency of irrigation, the soil properties, the type of land, the cropping and tillage practices and the amount and form of nitrogen applied.

When the application of fertilizer nitrogen is followed by heavy rains, a part of the fertilizer may be lost by surface run-off. This is particularly so with urea and nitrates which are very soluble in water and not retained by soil particles.

Unwanted crop residues are often burned in the field, and this leads to loss of nitrogen. However, bush burning prior to a new cultivation cycle stimulates fresh vegetative growth for grazing.

Immobilization refers to the unavailability of an element. During the decomposition of organic residue in the soil, nitrogen is deposited into microbes. This is microbial immobilization, in which soluble nutrients are converted to their non-available forms. Large amounts of nitrogen get tied up in this manner, at least temporarily. The immobilized nitrogen is released when micro-organisms die and decay, which is a slow process. A low carbon to nitrogen (C/N) ratio in the residue tends to shift the process toward mineralization. In a normal moist soil, both mineralization and immobilization processes proceed simultaneously; the most predominant being determined by the amount and the nature of the organic matter that returns to the soil.

A slowing down of the oxidation of ammonium ions to nitrate ions results into a reduced loss of nitrate and nitrogen by leaching or denitrification.

Nitrogen mobility in plants: See Mobility of nitrogen in plants

Nitrogen oxygen demand

Nitrogen oxygen demand (**NOD**) is the amount of dissolved oxygen required for biological oxidation of nitrogenous material like ammonia nitrogen or organic nitrogen in waste water. NOD is measured after the carbonaceous oxygen demand has been satisfied. NOD is included in the **chemical oxygen demand (COD)**.

Nitrogen porosimeter

A porosimeter is an apparatus used to determine the distribution of pores, according to their diameter, in a natural medium (soil aggregate, rock, fiber, etc.). A nitrogen porosimeter is a gas phase chromatograph that determines volumetrically, the adsorption of nitrogen at low temperatures.

Nitrogen solution

An aqueous solution of ammonia, ammonium nitrate and/or urea is known as nitrogen solution. Liquid fertilizers are used either as a solution or suspension. The solution can be of a pressure or non-pressure type. **Anhydrous ammonia** and **aqua ammonia** (20 to 25% nitrogen) are pressure type solutions, whereas the water solution of urea ammonium nitrate (**UAN**) is a non-pressure type nitrogen solution. The UAN solution is available with 28, 30 and 32% nitrogen content, each of which has a specific salting out temperature.

Most nitrogen solutions are for direct and broadcast applications. A non-pressure nitrogen solution and other fluids are added to irrigation systems (such as sprayers, sprinklers, gated pipes, drip tubes and ditches) using irrigation water several times a day during the growing season. This practice is called **spoon feeding of crops**. The nitrogen solutions are often mixed with other clear liquids like potash and ammonium polyphosphates (grades 10-34-0 and 11-37-0) to produce suspension mixtures.

The popularity of nitrogen solutions as fertilizers is due to their (a) ease of handling and application, (b) uniform and accurate applicability, (c) compatibility with many pesticides for simultaneous application, (d) easy transport through pipelines, barges, etc., (e) less corrosive property allowing low cost storage systems, and (f) low production cost and relatively safe handling.

The non-pressure nitrogen solutions can be used as a nitrogen source for making NPK formulations.

Nitrometer

Nitrometer is a glass apparatus used to measure the amount of nitrogen gas evolved during a chemical reaction.

Nitrophosphate crystallization: See Nitrophosphate production processes

Nitrophosphate dissolution: See Nitrophosphate production processes

Nitrophosphate fertilizers

Nitrophosphate is a granulated fertilizer containing nitrogen and phosphorus along with a stabilizer, and is made by reacting phosphate rock with nitric acid.

In **Odda process**, the acidulation reaction is:

$$Ca_3(PO_4)_2+6HNO_3 \longrightarrow 3Ca(NO_3)_2+2H_3PO_4+22.5\text{ kcals}$$

After evaporation, the residual phosphoric material is neutralized with ammonia to produce a nitrophosphate fertilizer. If calcium nitrate is left in the solution, dicalcium phosphate gets formed upon ammoniation as:

$$2H_3PO_4+Ca(NO_3)_2+4NH_3 \longrightarrow CaHPO_4+(NH_4)_2HPO_4+2NH_4NO_3+66.67\text{ kcals}$$

Calcium nitrate is highly hygroscopic and has to be removed from the solution or modified to some other form in order to effectively produce a range of grades of compound fertilizers using N and P with lower N:P ratio. Calcium nitrate can be removed by refrigeration and centrifugation (Odda process) or converted to calcium carbonate by reaction with carbon dioxide (**carbonitric process** or **nitro-carbonic process**).

$$Ca(NO_3)_2+2NH_3+CO_2+H_2O \longrightarrow CaCO_3+2NH_4NO_3$$

Dicalcium phosphate is water-insoluble but soluble in ammonium citrate solution.

In the Odda process, the calcium nitrate solution in phosphoric acid is cooled to crystallize calcium nitrate. About 60% of calcium salt is removed by cooling to 20°C and 85 to 90% at minus 5°C. Addition of ammonium sulphate to the solution removes calcium salts to produce higher N:P grades. It is also possible to precipitate calcium salts with carbon dioxide as in the nitro-carbonic process, provided reversion to tricalcium phosphate is suppressed, the latter being insoluble in citrate and water. The stabilizer here prevents the citrate-soluble phosphate from becoming insoluble. The amount of water-soluble phosphorus depends on the nitric acid to phosphoric acid ratio.

$$2CaHPO_4+CaCO_3 \longrightarrow Ca_3(PO_4)_2+H_2O+CO_2$$

Phosphate rocks, ground to a particle size of less than 1 mm, easily react with nitric acid. Two commercially important **nitrophosphate production processes** – the Odda process and the mixed acid process – differ essentially in the way they remove calcium nitrate from the slurry. In the Odda process, calcium nitrate is precipitated and separated. While in the **mixed acid process**, the water solubility of phosphate is increased by adding phosphoric acid to decrease the calcium to phosphorus ($CaO:P_2O_5$) ratio.

This nitrophosphate process is economically and environmentally more competitive than the other processes in respect of such parameters as energy efficiency, raw material flexibility, adaptation to stricter environmental requirements and amenability to by-product disposals. The granulated form of the fertilizer maintains good physical properties and the stabilizer prevents the citrate-soluble phosphate from changing to the insoluble form. The nitrophosphate process does not depend on sulphur but on carbon dioxide which is normally obtained from an ammonia plant. The water solubility of nitric phosphates varies from 0 to 80%, depending on the process used. Nitric phosphates give best results on acid soils and benefit crops such as turf and sod crops, or sugar cane which have a relatively long growing season. (See also Nitrophosphate production processes.)

Nitrophosphate neutralization: See Nitrophosphate production processes

Nitrophosphate particulaiton: See Nitrophosphate production processes

Nitrophosphate production by Kemira Oy process: See Nitrophosphate production processes

Nitrophosphate production by mixed acid process: See Nitrophosphate production processes

Nitrophosphate production by prilling of melt: See Nitrophosphate production processes

Nitrophosphate production by removal of calcium: See Nitrophosphate production processes

Nitrophosphate production processes

Nitrophosphate is a fertilizer that is produced by treating rock phosphate with nitric acid.

Erling Johnson originally developed a process of producing nitrophosphate in Norway. It was named after Odda, a small town where it was developed.

The shortage of sulphur shifted the interest to the nitrophosphate process. A number of variants of this process have been subsequently developed. The basic acidulation reactions in all the processes are as follows:

$$\begin{aligned} Ca_3(PO_4)_2 + 4HNO_3 &\longrightarrow 2Ca(NO_3)_2 + Ca(H_2PO_4)_2 \\ Ca(H_2PO_4)_2 + 2HNO_3 &\longrightarrow Ca(NO_3)_2 + H_3PO_4 \\ Ca_3(PO_4)_2 + 6HNO_3 &\longrightarrow 3Ca(NO_3)_2 + H_3PO_4 \end{aligned}$$

After removing the insoluble material, phosphoric acid is neutralized with ammonia to produce the nitrophosphate fertilizer. Calcium nitrate left in the solution reverts to dicalcium phosphate upon ammoniation as follows:

$$2H_3PO_4 + Ca(NO_3)_2 + 4NH_3 \longrightarrow CaHPO_4 + (NH_4)_2HPO_4 + 2NH_4NO_3$$

Dicalcium phosphate is insoluble in water but soluble in ammonium citrate. As fertilizers need to be water soluble, the water solubility of P_2O_5 in the product is improved to 50%.

Calcium is a diluent in this process and needs to be removed. With maximum calcium nitrate removed, one can get grades ranging from N:P ratios of 0.6:1 to 2:1. The N:P grade of 2:1 is achieved when all calcium nitrate is converted to ammonium nitrate. This is possible in the Odda process, in which the solution is cooled to 20°C to remove 60% of the calcium nitrate, and further to minus 5°C to crystallize out 85 to 90% of calcium nitrate. Alternatively, adding ammonium sulphate can precipitate calcium. It is also possible to precipitate only calcium as carbonate using carbon dioxide.

$$Ca(NO_3)_2 + 2NH_3 + CO_2 + H_2O \longrightarrow CaCO_3 + 2NH_4NO_3$$

However, in this process, care has to be taken to suppress reversion to tricalcium phosphate, which is insoluble in citrate as well as water.

$$CaHPO_4 + 2CaCO_3 \longrightarrow Ca_3(PO_4)_2 + CO_2 + H_2O$$

The advantages and disadvantages of nitrophosphate are as follows: Nitrophosphate is not dependent on sulphur and the process has a higher efficiency compared to DAP. There is no byproduct disposal problem as in the case of phosphoric acid or superphosphate where phosphogypsum is the main by-product and the disposal poses a major pollution hazard.

Commercial grades of phosphate rocks as well as large sized particles are acceptable as raw materials for nitrophosphate production. It is desirable that the $Ca{:}P_2O_5$ ratio in the rock phosphate is as low as economically feasible to minimize the amount of calcium that must be removed. Carbonates in rock cause foaming and is tackled by using mechanical foam breakers. Organic matter is not good for the process as it reacts with nitric acid with the emission of nitrogen as nitrogen dioxide. Iron and aluminum react with nitric acid and precipitate as citrate soluble phosphates on ammoniation. Up to 500 ppmw chloride is acceptable in the process.

Odda process: The principal developers of Odda process are BASF and Norsk Hydro. The process has the following steps: (a) dissolution, (b) crystallization, (c) neutralization, (d) particulation or forming, (e) prilling of melt, and (f) conversion of calcium nitrate to calcium ammonium nitrate.

(a) **Dissolution**: Phosphate rock is mixed with 60% nitric acid in a reactor at 60 to 70°C. Inerts are separated from the solution by gravity in lamella separators. The clean solution overflows into a storage tank and the thickened inerts are washed out to a belt filter or to hydro cyclones. Sand is washed with nitric acid and water. The liquid effluent is sent to an effluent treatment plant from this tank. The lower part of the reactor is made of a low-grade stainless steel and the top part is made of some good resistant material.

(b) Crystallization: The nitric acid phosphate solution is fed to batch-operated crystallizers. The evaporating ammonia and the calcium nitrate conversion cool the crystallizers. The final temperature of the crystallizer is around minus 2 to minus 5°C when 80% of calcium nitrate crystallizes out. Separation of crystals is done on a filter. Cold nitric acid and calcium nitrate are used as a washing liquid. To fine-tune nitric acid-phosphate quality, the dissolving solution (CaO/P_2O_5) is passed over the crystals.

(c) Neutralization: In this step, the nitrogen and phosphorus solution is converted to the desired form. The step controls the final $N{:}P_2O_5$ ratio of the product. Neutralization by ammonia gas occurs in a pressurized reactor at 1.5 to 2.5 bars and a temperature of 150 to 180°C or in forced circulation neutralizers. The heat of neutralization causes evolution of ammonia and water. This reduces the water content of the slurry. The operations of neutralization and evaporation have scrubbers for all gases.

(d) Particulation or forming: The final slurry is formed after ammoniation, evaporation and drying, using a pug mill (or blunger), or a rotary drum, or a spherodizer, or a spouted bed system, or by prilling of the melt. The main features of each are given below:

Advantages of drum granulation and pug mill are that ammoniation can be carried out in the bed. The heat of reaction causes water evaporation and a hotter feed for drying. The pug mill requires more energy than the drum, and the ammonia spurger must be firmly mounted in the pug mill.

The spherodizer is a proprietary granulator in which granulation and drying are combined. It can be operated both as "cold sphero" as well as "hot sphero", depending on whether the air used for drying is cold or hot. The spherodizer produces granules which are sized between 2 and 4 mm.

The spouted bed granulation system consists of injecting the slurry to be granulated upward into a spouted bed conical granulator concurrently with a stream of hot gas. At the center, the granules travel upwards and at the periphery of the bed they travel downwards, thus producing a circulation. The spouted bed process is suitable for nitrophosphates with the N:P_2O_5 ratio varying between 2:1 and 1:1. For products with a higher N:P_2O_5 content as in **MAP** or **DAP**, the spouted bed process is less advantageous as it has to operate with diluted slurries.

(e) Prilling of melt used by Norsk Hydro has the following advantages: (i) Very high single-train capacities are possible. (ii) Smooth and low dust producing prills are possible. (iii) 90% of the prills are between 2 and 4 mm size with an average diameter of 3 mm. (iv) The product spreads well. The dust content of the exhaust air is less than 5 mg/m^3, which is low and hence needs no cleaning.

(f) Conversion of calcium nitrate to calcium ammonium nitrate: The calcium nitrate conversion unit contains (a) an ammonium carbonate preparation section, (b) a calcium nitrate conversion section, and (c) a lime separation section.

The calcium ammonium nitrate unit, in turn, consists of five sections: (a) the ammonium nitrate concentration section, (b) the additives preparation section, (c) the mixing, granulation or prilling and drying section, (d) the cooling, screening and coating section, and (e) the off-gas treatment section.

The calcium nitrate conversion unit starts with the preparation of ammonium carbonate solution (in dilute ammonium nitrate solution) in a packed carbonation tower with external circulation. The temperature is controlled by heat exchangers. Carbon dioxide and ammonia are evaporated in the refrigeration section. The required ammonium carbonate is taken from the circulation. The ammonium nitrate solution obtained requires filtration before concentration.

The ammonium nitrate evaporation section consists of several falling film evaporators in series. The first part of this section produces 93 to 94 percent (by weight) ammonium nitrate. Each falling film evaporator set consists of a preheater, a heater/evaporator, a vapor separator and a transfer pump. A two-stage water ring vacuum pump provides the necessary vacuum, and a steam saturator operating at 0.9 MPa (absolute) provides the necessary energy for the concentration unit.

The 93 to 94% ammonium nitrate is pumped to the second part of the falling film evaporator with a separator operating at 0.3 bar (absolute) and concentrating up to the required concentration of about 98 percent (by weight). Steam is removed from the separate steam saturator at 9 bar (absolute).

Calcium ammonium nitrate (CAN) slurry is produced in a mixing section where the dissolved additives, lime/gypsum mixture and concentrated ammonium nitrate melt are mixed in a mixing vessel with agitation. From there, it flows into a second vessel. CAN slurry for granulation is taken from the circulation loop. The CAN granulation uses a drum with internals to produce a screen of falling materials, on which CAN slurry is sprayed. The granules that are produced fall by gravity into a counter currently operated drying drum. The drying drum is operated auto thermally (no external heating). The off gases from the dryer and granulator are dedusted in cyclones, and then sent to the gas scrubber.

In the conversion section, dry granules are screened and the oversized and the undersized are returned to the granulator. A two-stage fluidized bed cooler is used to cool the product to the desired final temperature. To improve the product characteristics during storage, a coating is done in a drum-type coating unit.

The BASF granulation process for calcium ammonium nitrate (CAN) uses either 'AN-wet' lime or dry lime. The advantage of 'AN-wet' lime is that it saves considerable energy and capital. In prilling CAN, the AN solution is premixed with dry lime immediately before prilling. Prill towers for both CAN and AN are 46 to 56 m high. For high-density prills, 99.7% solution is used in 15 to 30 m tall towers. Cooling is provided by a rotary cooler or in a fluidized bed.

Mixed acid process: The mixed acid process, also called the **Kemira Oy process for nitrophosphate production** uses mixed acids. The process is flexible and able to produce various grades of fertilizers with varying degrees of phosphate water solubility.

The first step in the process is the digestion of phosphate rock with nitric acid forming phosphoric acid and calcium nitrate.

$$Ca_3(PO_4)_2 + 6HNO_3 \longrightarrow 3Ca(NO_3)_2 + 2H_3PO_4$$

Nitrogen oxides and fluorine compounds are formed during digestion, the scale depending on the type of phosphate rock. The overflows of the reaction products are ammoniated in the second reactor and the gases scrubbed.

$$HNO_3 + NH_3 \longrightarrow NH_4NO_3$$

$$H_3PO_4 + 2NH_3 \longrightarrow (NH_4)_2HPO_4$$

$$2H_3PO_4 + Ca(NO_3)_2 + 4NH_3 \rightarrow CaHPO_4 + (NH_4)_2HPO_4 + 2(NH_4)NO_3$$

In the third reactor, final ammoniation takes place. KCl or K_2SO_4 (when NPK is required) along with sulphuric acid and phosphoric acid are added. The sulphate ions induce the precipitation of calcium sulphate according to the equation:

$$Ca(NO_3)_2 + H_2SO_4 \longrightarrow CaSO_4 + 2HNO_3$$

Generally, calcium sulphate is filtered but sometimes left as a diluent supplying calcium and sulphur nutrients. Any micronutrient to be incorporated in the formulation is added at this stage.

The water solubility of P_2O_5 in the product is adjusted by varying the ratio of phosphoric acid to phosphate rock. The standard grades produced are 17-17-17 or 23-23-0.

The reactor design can be varied, depending on the type of raw material, the amount of the gas scrubber liquid to be recycled and the degree of ammoniation. The water content of the slurry varies between 5 and 30% and the temperature from 100 and 140°C.

Granulation and drying of the slurry containing 10% water at 140°C takes place in a combined granulator-dryer called spherodizer. The hot gas from the exhaust is recycled.

In crushing and recycle handling, 2 to 4 mm size of the product from the granulator is screened. The oversized and the undersized are sent to the granulator for recycling. The correct sized product is sent to a fluidized bed type cooler. The product from the cooler is coated with an anti-caking agent in a small rotating drum. A multistage scrubbing system captures fumes from the reactors and any dust that escapes the cyclones.

The nitrophosphates produced from the Odda route and the mixed acid route result in product formulations with $N:P_2O_5$ ratios ranging from 0.5 to 2.0. The nitrophosphates are mainly manufactured in a granular form (2 to 4 mm) for direct application by the farmer or for use in bulk blending operations. The hygroscopic property of ammonium nitrate necessitates the storage of nitrophosphates in water tight plastic bags.

Removal of calcium: The calcium from the solution of the reaction mixture of nitric acid and rock phosphate is removed in different ways. The major ones are the following:

(i) Calcium removal by sulphate addition: In this method, the solution from the treatment of rock phosphate with nitric acid is treated with a soluble sulphate to precipitate calcium as calcium sulphate. Generally, ammonium sulphate, potassium sulphate, sulphuric acid and langbeinite ($K_2SO_4 \cdot 2MgSO_4$) have been used. Calcium sulphate may be separated by filtration or allowed to remain in the product. The chemical reactions are:

$$(NH_4)_2SO_4 + Ca(NO_3)_2 \longrightarrow 2NH_4NO_3 + CaSO_4$$
$$K_2SO_4 + Ca(NO_3)_2 \longrightarrow 2KNO_3 + CaSO_4$$

When ammonium sulphate is used to precipitate calcium as calcium sulphate, it can be treated with ammonia and carbon dioxide to regenerate ammonium sulphate which is recycled to convert calcium to calcium carbonate.

$$CaSO_4 + 2NH_3 + CO_2 + H_2O \longrightarrow CaCO_3 + (NH_4)_2SO_4$$

The TVA has developed a pilot plant based on this process. The major disadvantage of the process is that the $N:P_2O_5$ ratio is around 2:1.

(ii) Carbonitric process: In this process, calcium in the nitric acid and phosphate rock reaction solution is treated with carbon dioxide and ammonia to precipitate calcium as calcium carbonate. The final product consists of a mixture of dicalcium phosphate, ammonium nitrate and calcium carbonate. All P_2O_5 is citrate-soluble and not water-soluble.

(iii) Calcium removal by ion exchange: Kemira Denmark developed the process for removal of calcium by the ion-exchange process. The reaction product of phosphate rock and nitric acid is passed through a potassium loaded resin that absorbs calcium and releases potassium. The resin is regenerated by potassium chloride solution. Calcium chloride is discharged as waste.

$$2KCl + Ca(NO_3)_2 \longrightarrow 2KNO_3 + CaCl_2$$

After ion exchange, the solution containing phosphoric acid, potassium nitrate, some excess nitric acid and perhaps some calcium nitrate are ammoniated, dried and granulated. If the rock contains cationic impurities other than calcium, such as aluminum and iron, these elements may also be removed by an ion-exchange process.

The solution coming out of the ion exchange has a $K_2O:P_2O_5$ ratio of 1.8 to 1.0 by weight. Depending on the NPK ratio desired, the $K_2O:P_2O_5$ ratio is altered. To lower the ratio, either potassium nitrate is crystallized out by cooling or phosphoric acid is added to the product. The process has the advantage of producing a range of low chloride fertilizers. While doing so, phosphate rocks of high iron and aluminum content are used in the production.

Nitrosation

Nitrosation is the first step in nitrification, involving the oxidation of ammoniacal nitrogen into nitrite by micro-organisms. **Autotrophic bacteria**, *Nitrosomonas*, are responsible for this bioconversion. They obtain energy from the oxidation of nitrogen and obtain carbon from carbon dioxide. **Nitrocysts** are thick and dark cells that intervene in the nitrification, especially in nitrosation. Soils rarely contain significant amounts of nitrite because these are rapidly converted to nitrate.

$$2NH_4^+ + 3O_2 \xrightarrow{\textit{Nitrosomonas}\ \text{sp.}} 2NO_2^- + 2H_2O + 4H^+$$

Nitrosomonas

Nitrosomonas are the bacteria responsible for conversion of ammonium to nitrite, which is the first step in nitrification. These bacteria are Gram-negative, rod-shaped, non-motile, aerobic chemo-lithotrops.

Nivation

Soil erosion by the action of snow is known as nivation. Around the glacial zone of the poles, a thin cover of snow thaws during summer whereas the subsoil remains permanently frozen (**permafrost**). The slow flow of material in the form of mud over the frozen subsoil (particularly in cold climates in Greenland and high mountains) is known as **solifluction** or **soil creep**. The speed of the flow is 5 to 50 cm/year. Alternate thawing and freezing of snow in rock crevices break rocks.

N-m-t

N-m-t is short for **N-m-tolylphthalamic acid.**

N-m-tolylphthalamic acid

N-m-tolylphthalamic acid (N-m-t) is an auxin, a plant-growth promoting substance. It improves the yield of tomatoes, cherries, eggplants and lima beans by increasing fructification.

N-(n-butyl) thiophosphoric triamide

N-(n-butyl) thiophosphoric triamide (**NBPT**) is a **urease inhibitor**. It is a white crystalline solid. Among more than 146 triamide compounds, NBPT shows the best inhibition; it is prepared by a 2-step synthesis in tetrahydrofuran.

$$\mathrm{PSCl_3 + n\text{-}BuNH_2 + NEt_3 \longrightarrow n\text{-}BuNHPSCl_2 + HNEt_3Cl}$$
$$\mathrm{n\text{-}BuNHPSCl_2 + 4NH_3 \longrightarrow n\text{-}BuNHPS(NH_2)_2 + 2NH_4Cl}$$

This urease inhibitor product has a minimum purity of 85%, by weight. NBPT is waxy, sticky and sensitive to heat and water, which makes it difficult to handle and susceptible to decomposition during storage and distribution. Its excellent urease inhibiting property remains effective for 12 to 14 days on dry soil. When incorporated into the soil in combination with urea or urea-containing fertilizers, it significantly reduces seedling damage, when placed sufficiently above the seeds. For practical use in agriculture, NBPT is formulated as a green, clear liquid containing 25% NBPT as an active ingredient, 10% N-methyl pyrrolidone and 60 to 65% other non-hazardous ingredients. The recommended quantity of NBPT depends on the amount of amide-nitrogen present either as urea or in the NPK mixture (1.4 kg/ton of urea), because it is very specific to the amide type of nitrogen. NBPT is known commercially as **agrotain** and recommended primarily for its pre-planting surface application, but may be used in pre-emergence, side-dress, top-dress or other post-planting applications.

As NBPT inhibits free urease in soil without affecting bacterial growth, it is not classified as a pesticide. In soil, the product degrades into the fertilizer elements N, P and S. The application of urea or UAN solution modified with a urease inhibitor like NBPT reduces nitrogen loss substantially, thereby its additional applications.

NOD

NOD is short for **nitrogen oxygen demand**.

Nodosity: See Nodules

Nodulation

The process by which *Rhizobium* bacteria infect the roots of leguminous plants to form knob-like structures or nodules on roots is called nodulation or **nodule formation**. The rod-shaped bacteria enter the root hair through a thread-like structure called the **infection thread**. It penetrates the root cortex, ultimately ramifying in the root cortex cells. Here, the bacteria liberate and multiply making the cells swell and become knob-like. Such a protective structure with direct vascular supply of solutes from the roots is called a **nodule**.

Nodule formation

Nodule formation is another term for **nodulation**.

Nodules

A nodule is a small swelling or accumulation of cells in the body. The swellings on the root of a leguminous plant that contain bacteria which are capable of converting atmospheric nitrogen into ammonia are called **root nodules** (Fig.N.15). This is also referred to as **nodosity**. Soil bacteria and rhizobia multiply in the rhizosphere, a soil zone adjacent to the plant roots. At a very early stage of plant growth, bacteria penetrate the roots of the plant through the root hairs. A thread-like structure carrying rod-shaped bacteria, called **infection thread**, ramifies between the root cortex cells that swell and form knob-like structures or nodules on the roots. This process is called **nodule formation** or **nodulation** (Fig.N.16).

Nodules have conductive vessels for transporting solutes from the roots. In the nodules, rhizobia form bacteroids which are the sites of nitrogen fixation. Nodules protect the bacteroids and create a low oxygen

Fig.N.15: Nodules on the roots of a legume plant.

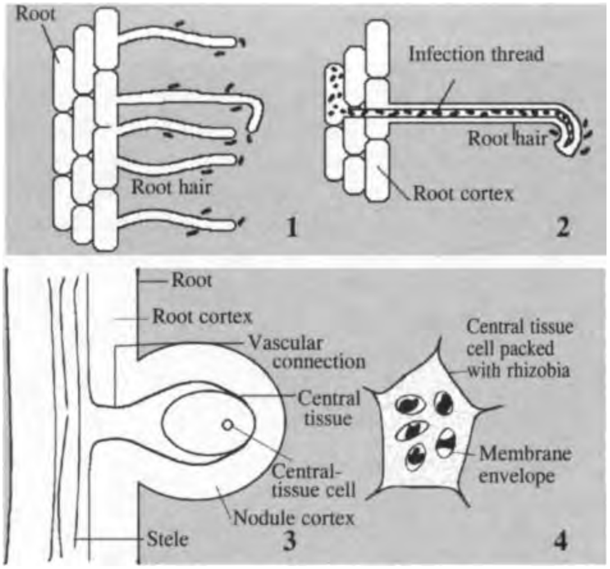


Fig.N.16: Diagrammatic representation of the process of nodule formation. 1-4: Rhizobia colonizing the rhizosphere infect the root hairs and further, cortical cells forming infection thread. Nodule develops on roots from the infected cortex; also shown are details of central tissue cell.

condition necessary for nitrogen fixation. The nodule function is influenced by such variables as the pH, salts, temperature, light intensity, mineral nutrients, antagonistic micro-organisms and the presence of combined soil nitrogen.

Bacteria living symbiotically with the root tissue convert atmospheric nitrogen into nitrogenous compounds (nitrogen fixation) using the energy derived from carbohydrates supplied by the roots. The compounds, used for protein synthesis, are released to the soil and converted to nitrates which may be used by other plants such as grass in a mixed clover-grass-Ley system. The stored nitrogen in leguminous crops is released to the soil on the death or plowing-in of the plants and degraded to nitrates. Legumes, such as beans or clover, are thus often grown prior to cereal crops to enrich the soil with nitrogen. Various strains of nodule-forming bacteria are present in the soil, but to achieve rapid nodulation, legume seeds are coated or inoculated with bacterial culture before sowing.

Ineffective strains of rhizobia form well-developed nodules with plenty of bacteroids. Initially, the nodules look white and turn pink as they grow, owing to the leghemoglobin pigment. When plants die, the nodules turn brown and split, and the nitrogen gets released in the soil.

Ineffective strains of rhizobia form small nodules with poorly developed bacteroid tissue.

Leguminous plant species possessing root nodules increase soil fertility by augmenting the soil nitrate content and hence are used in crop rotation practice.

Aggregates of ferromanganese occurring in huge quantities on the ocean floors are also known as nodules. Their composition is about 55% manganese, 35% iron and the balance being cobalt, copper and nickel. The size of the nodules averages about 4 cm.

Non-artesian water: See Phreatic water

Non-associated gas

The naturally occurring mixture of gaseous hydrocarbons found in porous sedimentary rocks in the earth's crust is natural gas. It is usually associated with petroleum deposits.

Natural gas is about 85% methane, the rest being hydrogen sulphide and sometimes, helium. Natural gas is classified as 'associated' or 'non- associated'; the gas from the 'non-associated' deposits may be nearly pure methane. This gas does not have any association with petroleum deposits such as crude.

Non-calcareous soil

A soil free from calcium carbonate is known as non-calcareous soil.

Non-competitive inhibitor

An inhibitor is a substance that considerably reduces or stops an undesired reaction. For example, nitrapyrin acts as an inhibitor in ammonia nitrification and reduces the fertilizer loss. In competitive inhibition, the inhibitor molecules are attached to the active site of the enzyme which is otherwise occupied by the substrate. Increasing the concentration of the substrate reverses the inhibition process. A non-competitive inhibitor changes the inhibiting activity without blocking the active site.

Non-edible oil cakes

The residual mass of the oil seed extraction process is known as the oil cake. Some oil cakes are edible and hence are fed to cattle, while others are non-edible. For example, caster seed oil cake is a non-edible oil cake. Both types of oil cakes are used as concentrated organic manures.

Non-essential amino acids

Amino acids that are produced in the body are not required to be included in the diet and are called non-essential amino acids. Amino acids such as alanine, proline, serine, glycine, etc. are non-essential amino acids.

An essential **amino acid** is the one that is necessary for survival but cannot be synthesized by the body. Isoleucine, phenylalanine, leucine, lysine, methionine, threonine, tryptophane and valine are some of the essential amino acids. Some amino acids (e.g., arginine and histidine) are essential during periods of intensive growth.

All essential and most non-essential amino acids are optically active due to one or more asymmetric carbon atoms. Some amino acids (such as ornithine and citrulline), which never occur in proteins, are nevertheless important intermediates in the urea cycle.

Non-essential nutrient

A few elements, which are beneficial but not essential for plant growth, are referred to as non-essential nutrients. They include cobalt, nickel, lanthanum, cerium, sodium, silicon, vanadium and aluminum. Their role was recognized when some advanced research methodologies and analytical techniques became known. Some of these elements are present in concentrations of less than a few parts per billion (ppb).

Non-exchangeable ions

The ions that are not available for reaction are termed non-exchangeable ions. They are fixed tightly to inaccessible sites (like mineral lattices) and become non-exchangeable, for example, fixed ammonium ions (NH_4^+) or potassium ions (K^+).

Compared to mineral potassium, non-exchangeable potassium is not bonded covalently within the crystal structure of the soil mineral particles but held between the adjacent tetrahedral layers of micas, vermiculites and inter-grade minerals.

Micas have potassium fixed in the interlayer spaces. Weathering releases the potassium in soils. Due to the variation in the binding strength, the rate of potassium (K) released from different micas differs. Because micas have their entire negative charge satisfied by potassium, the K-release results in the formation of secondary clay minerals such as illite (hydrous mica) and vermiculite, with the accompanying gain of water (or H_3O^+) and swelling of the lattice. Once this happens, potassium changes to an exchangeable form. Depletion of potassium from the soil solution by the plant or by leaching lowers the potassium concentration in the solution and induces the liberation of interlayer fixed potassium.

Usually more than 99% of the total soil potassium is in the non-exchangeable form, also known as the **mineral** or **reserved potassium**. It can contribute to the labile pool of potassium in soil. Depletion of potassium from the soil solution by the plant or by leaching induces the liberation of interlayer fixed potassium.

The amount of non-exchangeable potassium in clays is determined by extraction with boiling 1N nitric acid. It is called the nitric acid-extractable potassium, which varies from 7.5 mg to 50 mg/kg soil, depending on the nature and the amount of clay minerals. The release of non-exchangeable potassium helps to explain the extent of the crop response to fertilizer potassium.

Non-granular fertilizer

Non-granular fertilizer exists in a powder form. Commonly, such a fertilizer contains fine particles that are less than 3 mm in diameter.

Non-granular MAP production process: See Monoammonium and diammonium production processes

Non-humic substances

Humic is a general term for materials that contain **humus** which is a dark colored product of the soil organic matter.

Non-humic substances do not contain any soil organic matter or its altered product. They include compounds such as fats, waxes, resins, pigments, proteins, carbohydrates and low molecular weight substances, which also occur in plants and micro-organisms. Soil microbes attack most non-humic substances.

Non-ionic surfactant

Adjuvant is a substance added to the main composition (substance) in order to improve its function. There are four types of adjuvants, one of which is a surfactant. The surfactant adjuvant molecules have a lyophilic (a hydrophilic) phase. From the structure of the hydrophilic phase three classes of surfactants are recognized – anionic, cationic or non-ionic. The example of non-ionic surfactant is poly (ethylene oxide) laurylalcohol $C_{12}H_{25}O$ $(CH_2{\cdot}CH_2O)_{23}H$. The structure of a silicon type non-ionic surfactant is shown in Fig.N.17.

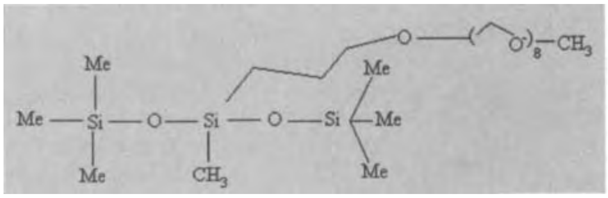


Fig.N.17: A new form of silicone type non-ionic surfactants.

Non-polar solvent

There are two types of solvents or molecules - polar and non-polar. A polar solvent describes a molecule in which the positive and negative electrical charges are permanently separated, as opposed to non-polar molecules in which the charges coincide. Polar molecules ionize in solution and make it electrically conductive. Most hydrocarbon liquids are non-polar whereas water, alcohol and sulphuric acid are polar in nature. Carboxyl and hydroxyl groups often exhibit an electrical charge. The formation of emulsions and the action of detergents is based on this behavior.

Non-protein nitrogen

Non-protein nitrogen is not a part of the protein structure. Hence, it is safe to be added to cattle feed. For example, urea nitrogen can be added to cattle feed.

Non-selective catalytic reduction process: See Environmental impact of nitric acid industry

Non-selective herbicides

Chemicals used for controlling or destroying weeds or herbs are called **herbicides**. There are two types of herbicides - selective and non-selective. The selective herbicide eliminates weeds without injuring the crop; the non-selective one is used as a soil sterilant and as a silvicide.

Non-specific adsorption

Adsorption is the attraction of a liquid, solid or gas to the surface of a solid or liquid. Non-specific adsorption refers to the adsorption irrespective of, or non-selective to, the electronic charge of an ion or a surface.

Specific adsorption, which is usually chemical, is selective for a particular ion or substance. Whereas a diffused ion association and an outer-sphere surface complexation are the molecular bases of non-specific adsorption, wherein the prefix 'non-specific' implies a near non-dependence on the electron configuration of the surface group and the adsorbed ion.

Non-sugars

Carbohydrates are produced in plants by photosynthesis and are classified into monosaccharides, oligosaccharides and polysaccharides. Starch, dextrin and cellulose are non-sugars which, on hydrolysis, yield a large number of monosaccharide molecules. They are amorphous, tasteless, non-reducing and mostly insoluble in water. Their molecular weight is usually very high and many of them, like starch or glycogen, have molecular weights of several million. (See also Carbohydrates.)

Non-symbiotic bacteria

Non-symbiotism represents a situation where two different organisms may not live together, yet either of the two is benefited; or if they do live together, they may not necessarily be advantageous to each other. Non-symbiotic nitrogen fixation is a case of non-symbiotism.

Unlike symbiotic bacteria, the non-symbiotic, nitrogen-fixing bacteria do not need a host plant or an organism as a symbiont for nitrogen fixation. Species of *Azotobacter* and *Clostridium* can fix nitrogen to the extent of 10 to 15 kg/ha/year in a non-symbiotic manner. Such an activity is called **non-symbiotic nitrogen fixation**.

Non-symbiotic nitrogen fixation: See Non-symbiotic bacteria

Non-systematic root scanning method for root colonization analysis

Quantification of root colonization by mycorrhizae is done by three methods. These are the **slide method**, the **grid line intersect method** and the non-systematic root scanning method. In the non-systematic root scanning method, the scanning is done under a dissecting microscope which rapidly shows the broad categories of root colonization and the intensity of their infection.

Non-systemic fungicides

Non-systemic fungicides (also called **contact fungicides** or **residual protective fungicides**) do not penetrate into the plant tissues but form a protective barrier on the plant surface, and thus prevent the fungus from entering the host. Most non-systemic fungicides react with the thiol groups present in the enzymes of the fungus and inhibit many metabolic processes; these are considered as multisite or multisided inhibitors. They include inorganic sulphur or copper and organic mercury compounds, the latter being slowly phased out.

Nontronite

Nontronite is one kind of smectite clay. It is a 2:1 clay mineral which undergoes reversible expansion on absorbing water.

Non-vital stains

In order to observe a substrate, the normally transparent cells or thin sections of a biological tissue are immersed in one or more colored dyes (stains). This makes them more clearly visible through a microscope. The stains are usually organic salts with positive and negative ions; those used to color the constituents of the living cells without harming them are called **vital stains**. The stains used for dead tissues are called non-vital stains.

Non-woody perennials

Non-woody perennials, also called **herbaceous perennials**, have aerial shoots that die down each autumn, only to be replaced each spring by new shoots emerging from an underground structure. Lupin and rhubarb are examples of non-woody perennials.

Norfolk rotation

Crop rotation is beneficial to crops. A four-course rotation was practiced even in the earliest agriculture systems.

The Norfolk rotation, which follows a root crop-cereal-ley-cereal sequence, was modified at the beginning of the 20th century to meet changing agricultural needs. In Norfolk, sugar beet replaced other root crops and in some cases, potato was introduced in a still widely used five-course rotation, comprising the sugar beet-barley-ley-potato-wheat sequence.

Normal albedo

Photosynthesis by plants depends on the light absorbing property of the surface of leaves. Albedo, a term describing the reflecting properties of a surface, is the ratio of the radiant flux reflected by the surface to the incident flux.

The **bond albedo** and normal albedo are two types of albedos. Normal albedo, more properly called the **normal reflectance**, is a measure of the relative brightness of the surface when viewed and illuminated vertically.

Normality

The term equivalent weight is used in many volumetric analyses and normality is the corresponding unit of concentration. Normality of a solution represents the number of gram equivalents of the solute in one liter of the solution.

$$\text{Normality (N)} = \frac{\text{Number of gram equivalents of solute}}{\text{Number of liters of solution}}$$

To prepare a 1N solution of hydrochloric acid (HCl), dissolve 36.5 g of HCl (1 mole = 1 equivalent) in 1 liter of water. (This solution is also 1 molar in HCl. However, normality and molarity are not equal for barium hydroxide, $Ba(OH)_2$, where 1 mole = 2 equivalents). The relation between normality and molarity concentration is:

$$\text{Normality (N)} = \frac{1}{n} \times \text{Molarity (M)}$$

where n is the number of moles of hydrogen ions (H^+) per mole of compound that a solute is capable of releasing, or the number of moles that can react with a base.

If the volumes of solutions of two different substances A and B which react with each other, are V_A ml and V_B ml respectively, then these volumes contain the same number of equivalents or milliequivalents of A and B. Thus:

$$V_A \times \text{Normality of A} = V_B \times \text{Normality of B}$$

Normal reflectance: See Albedo; Normal albedo

Normal salt

A normal salt is obtained by completely neutralizing an acid with an alkali. For example, the following reactions give NaCl, Na_2SO_4 and $NaHSO_4$ as normal salts:

$$HCl + NaOH \longrightarrow NaCl + H_2O$$
$$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$$
$$H_2SO_4 + NaOH \longrightarrow NaHSO_4 + H_2O$$

A compound belonging to the category of both the salt and the base is a **basic salt** because it contains hydroxide (OH) or oxide (O) as well as the usual positive and negative radicals of normal salts. Bismuth subnitrate ($BiONO_3$) and basic copper carbonate [$Cu_2(OH)_2CO_3$] are examples of basic salt.

Most basic salts are insoluble in water and are of variable composition.

Normal soils

Normal soils are the ones that have an excess of neither salinity nor sodicity. Their electrical conductivity of saturation extract is less than 4dS/m and the **sodium adsorption ratio** is less than 13.

Normal superphosphate

Normal superphosphate is made by treating ground rock phosphate with sulphuric acid.

$$Ca_{10}(PO_4)_6F_2 + 7H_2SO_4 \longrightarrow 3Ca(H_2PO_4)_2 + 7CaSO_4 + 2HF$$

The above reaction yields monocalcium phosphate and gypsum.

For the manufacture of normal superphosphates, a continuous process rather than a batch process is in vogue. Some of these processes are named after their inventors, for example, the Tennessee Valley Authority process, the **Maxitz-Standard Den process**, the Broadfield Den process and the Kuhlman Den process.

The treated mass is sent to a curing shed and stored for 3 to 4 weeks for curing and final drying. The dried product is excavated, milled, screened, and either bagged for marketing or sent for granulation.

Granulation is done in a granulator in the presence of steam and the finished product is then bagged. It contains 16 to 21% phosphorus pentoxide (P_2O_5) in a water-soluble form. In addition, it contains 11 to 12% sulphur as calcium sulphate. (See also Single superphosphate production processes.)

Normal superphosphate production processes: See Single superphosphate production processes

Norsk hydro process for MAP-DAP production: See Monoammonium and diammonium phosphate production processes

Norwegian saltpeter

Norwegian saltpeter is another name for **calcium nitrate**.

No tillage

No tillage, also called **zero tillage**, involves no pre-plant tillage operations such as seedbed preparation. In this method, the field is not plowed and the plant residues are left standing. In such a field, sowing is carried out by opening a small slit or punching a hole into the soil for placing the seed at the required depth.

NP complex

The NP complex is a complex fertilizer with only nitrogen and phosphorus. Urea-phosphate (17:44:0) and ammonium phosphate (28:28:0) are examples of NP complex fertilizers.

N:P:K

N:P:K is the generic name given to a fertilizer that has nitrogen (N), phosphorus (P) and potassium (K) as the ingredients. The NPK fertilizer is denoted by the proportion or weights of these nutrients. For example, a fertilizer designated as 12-12-18 contains 12% nitrogen, 12% phosphorus (as P_2O_5) and 18% potassium (as K_2O). The proportion of the three primary nutrients N, P and K is indicated on the bag, as shown in Fig.N.18.

The **NPK ratio** is the ratio of the nutrient contents in a fertilizer. For example, a fertilizer with a nutrient proportion of 12-12-18 is said to have the NPK ratio of 1:1:1.5. It is expressed in terms of N, P (or P_2O_5) and K (or K_2O), depending on the local legislation.

NPK ratio: See N:P:K

Fig.N.18: Fertilizer with NPK grade 5:10:5.

NR: See Nitrate reductase

NSCR

NSCR is short for **non-selective catalytic reduction** process.

N serve

N serve is the trade name of **nitrapyrin**, a nitrification inhibitor. Its chemical composition is 2-chloro-6 (trichloro-methyl) pyridine. It is mixed with an ammoniacal fertilizer in the proportion of 1 to 2% by weight of the fertilizer nitrogen.

N:S ratio

The ratio of the organic nitrogen and sulphur in plants or soils is the N:S ratio. The N:S ratio is as important as the content of sulphur or sulphate alone. The preferred N:S ratio in plants is 10 to 15, and in soil organic matter, 7 to 10. The immobilization of sulphur depends on the sulphur content of the soil decomposing material, and is the highest for a high N:S ratio. In contrast, sulphur mineralization is favored in soils with low N:S or C:S ratios.

There is a close relationship among soil organic carbon, nitrogen and sulphur. The C:N:S ratio of most well-drained, non-calcareous soils is around 120:10:1.4, and is dependent on the parent material, the climate, vegetation, the leaching intensity and drainage.

Nurse crop

A crop that protects soil or another crop (sown beneath it) or provides cover for game birds is called a nurse crop or **cover crop**.

Nutrient: See Plant nutrients

Nutrient availability

A commercial fertilizer contains at least one of the plant nutrients in a form available to the plant in a known amount. Generally, plant roots or foliage take up nutrients in the form of a solution in water. Thus, water solubility provides a conclusive measure of the nutrient availability to the plant. Many sparingly soluble materials available to plants are often more effective in the long run than are the readily water-soluble materials. In most countries, nutrient solubility in water or other reagents is specified on the package of the fertilizer; alternatively, identification and approval of the source of material is required to be stated on the package of the fertilizer.

Most common nitrogen and phosphorus fertilizers are readily water-soluble and the water solubility is accepted as an evidence of nutrient availability. Special methods are applied to evaluate nutrient availability of less soluble materials when low solubility of the fertilizer nutrient is considered advantageous.

Water solubility varies widely among phosphate fertilizers and several methods are used to evaluate it. One such method is based on the solubility of phosphate in neutral or alkaline ammonium citrate solutions or in a solution of citric or formic acid. In Germany, phosphate is expressed as the sum of two solubilities – that of P_2O_5 in water and in alkaline ammonium citrate. For superphosphate, at least 90% P_2O_5 must be water-soluble. For compound fertilizers, at least 30% of the total content must be water-soluble. In Belgium, 38% P_2O_5 must be neutral ammonium citrate-soluble; 93% of the indicated content must be water-soluble. In the USA, the available phosphate content in the fertilizer is determined by the solubility of P_2O_5 in neutral ammonium citrate.

The European Union specifies the following solvents for evaluating phosphate fertilizers: (a) water, wherever suitable, (b) 2% formic acid for soft neutral phosphates, (c) 2% citric acid for basic slag, (d) **Petermann's solution** at 65°C for precipitated dicalcium phosphate dihydrate, (e) Petermann's solution at ambient temperature for disintegrated phosphates, (f) **Joulie's solution** for all straight and compound fertilizers containing alumino-calcic form, and (g) neutral ammonium citrate for all fertilizers. Joulie's and Petermann's solutions are alkaline ammonium citrates containing free ammonia.

Nutrient balance

In order to maintain a certain level of available plant nutrients in the soil, some of the nutrients lost upon plant uptake, leaching, volatilization, immobilization, etc., must be replenished. The process of replenishment can result from fertilizer application, soil weathering, rainfall and microbial nitrogen fixation. In most soils, weathering provides nutrients such as Fe, Mn, Cu, Zn, Mo and B, required in minor amounts. In this process of replenishment, there could sometimes be a net nutrient gain. The difference between the gain and the loss of plant nutrients is the nutrient balance.

Nitrogen forms a part of chlorophyll and is essential for photosynthesis. Nitrogen is required for the functioning of DNA and RNA - for storing and processing genetic information. It is also present in amino acids for protein synthesis and in enzymes that control all transformations. Similarly, phosphorus is required for a wide range of plant processes from cell division to the development of a good root system to ensure a timely and uniform ripening of the crop. Phosphorus is a constituent of adenosine diammonium phosphate (**ADP**) and adenosine tri-ammonium phosphate (**ATP**), the two most important substances in life processes.

The gains and losses of nutrients in a natural ecosystem roughly balance each other. Continued biological growth (or the net fixation of carbon) depends upon the cycling of the nutrients between the biomass and the organic-inorganic stores. In this situation, removing a portion of the biomass from the ecosystem and not replacing the lost nutrients in the harvested biomass fraction, ultimately reduces the overall nutrient content of the system and hence, the biological yield. These depletions, unless corrected, lead to environmental degradation. The correction comes by applying fertilizers at the correct time, in the correct mix and in a proper ratio of biomass to mineral fertilizer to protect the soil from depletion and improve the environment.

Many countries are concerned with issues relating to **nutrient removal** and nutrient balance. In India, for instance, agricultural crops annually remove from the soil, about 4.27 million tons (MT) of nitrogen, 2.13 MT of phosphoric acid, 7.42 MT of potash and 4.88 MT of lime. This depletion is not made up by the current per hectare usage of organic and inorganic fertilizers.

The nutrient depletion is also aggravated by intensive cultivation, large production of yields through improved crop varieties, erosion and leaching. Whenever nutrient removal exceeds nutrient addition, the soil suffers a net depletion of nutrient reserves. With increasing human population, the production pressure on agricultural land increases and causes widespread and acute nutrient deficiencies. However, whenever the gap is so large that it becomes too expensive to bridge it with the help of mineral fertilizers alone, the use of all available organic manures, rural and urban wastes, crop residues, leaf litter and biofertilizers can become beneficial if employed in an integrated package with fertilizers.

Nutrient balance in plants

Balanced nutrition is one of the important aspects of sustainable agriculture. Crops need all nutrients in sufficient amounts in order to develop rapidly and to produce high yields in a sustained manner.

Sometimes, the application of a particular nutrient leads to an increased yield. But this may not guarantee a proper nutrient balance in plants. For example, in rice, application of 174 kg/ha nitrogen increases yields, but leads to the depletion of P, K and S from the soil. If such induced deficiencies are not made up, some characteristic symptoms appear and yields get affected.

The uptake of one nutrient depends on its ratio with other nutrients in the soil solution. For example, the excess of potassium in the soil solution can reduce the uptake of magnesium. Nitrogen loss from the soil increases the deficiency of other nutrients, and affects crop development and nitrogen utilization.

Nutrient balance data recorded over long periods provide information on the level of fertilizers applied and on whether this conforms to the sustainability aspect. Nutrients are removed from the fields after harvest, the depletion being dependent on the crop type, the yield and the part of crop removed. The nutrients left behind in the crop residues become partly available to the subsequent crops after mineralization, but they are rarely sufficient.

In summary, the amounts of nutrients removed from the soil depend on many factors. The recommended ratio of N: P: K to be added to the soil has, therefore, to depend on the (a) type of crop and the expected yield, (b) nutrient availability in the soil, and (c) other nutrient sources.

Nutrient budget

Nutrient budget deals with the quantitative estimation of major nutrients provided to the soil, retained by the soil after the harvest and taken away by the plant. It helps in the economic analysis of the crop system.

Nutrient concentration

Nutrient concentration in green or dry plant matter, or in the soil, is the extractable fraction of the nutrient from a particular part of the crop or soil at a certain time or stage of the morphological development.

Nutrient concentration, which is obtained by plant or soil analysis, is expressed as a percentage of dry weight for major nutrients or as parts per million (ppm) for micronutrients. It is classified as deficient, marginal, adequate, excess or toxic.

When nutrients are in a deficiency range, the plant growth and the yield are significantly reduced and foliar deficiency symptoms appear. In the deficiency range, application of a nutrient results in a sharp increase in the growth with very little change in the plant nutrient concentration. The graph of crop yield against nutrient concentration (Fig.N.19) shows that the critical concentration, which lies within the marginal or transition range, is that concentration from which the growth or yield begins to decline significantly.

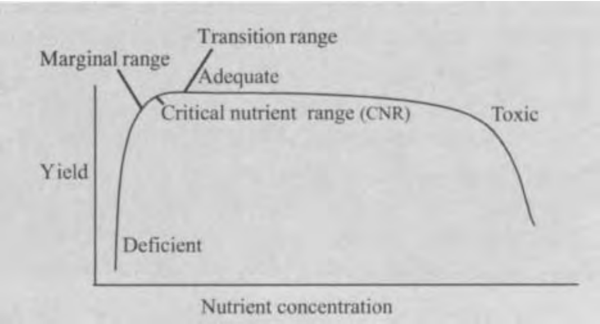


Fig.N.19: Crop yield against nutrient concentration.

The nutrient concentration in a plant depends on the species, plant age, cultivar, interaction with other nutrients and environmental factors such as light, humidity and moisture supply (Table-N.5).

Table-N.5: Micronutrient concentrations (mg/kg) in mature plant tissues of crop plants.

Micronutrient	Deficient	Sufficient	Excessive or toxic
Zn	<20	25-150	>400
Cu	<4	5-20	>20
Fe	<50	50-120	Unknown
Mn	<20	20-50	>500
B	<1.5	20-100	>200
Mo	<0.1	0.2-0.5	Unknown

Source: "Trace Elements in Soils and Plants" 2000, 3rd Edition, by Alina Kabata-Pendias. CRC Press, Boca Raton, FL. With permission.

Nutrient concept of Nicholas: See Functional nutrient concept of Nicholas

Nutrient cycle

Nutrient cycle is the movement of a nutrient in the biosphere (soil, plant, animals, man and environment) before returning to its original form or state. It is the pathway or movement of a nutrient from its occurrence to incorporation into the living organism, and its subsequent return to the eco-system.

One of the major cycles of chemical elements in the environment is the **nitrogen cycle**. The plant roots take up nitrates from the soil and pass these along the food chains to animals. Decomposing bacteria convert the nitrogen containing compounds (especially ammonia) in plant and animal wastes, into the nitrate form and this residue (retained in the soil as nitrate) is released for plant uptake (nitrification). Though nitrogen is indispensable to all life forms, the huge amount of nitrogen in the atmosphere is not directly available, but can be assimilated by some specialized bacteria and made available to other organisms by nitrogen fixation. With lightning flashes, atmospheric nitrogen combines with oxygen to form nitrogen oxides which enter the soil and become available to plants. Some nitrogen is returned from the soil to the atmosphere by the denitrification process brought about by another set of bacteria.

The phosphorus cycle and the carbon cycle are among the special cases of nutrient cycling. Although all agricultural sectors aim to increase the nutrient use efficiency, substantial nutrient losses become inevitable in nutrient cycle.

Nutrient deficiency symptoms

A growing plant with a nutrient deficiency shows some characteristic visual symptoms. For understanding and classifying the details of the types of deficiencies, certain diagnostic techniques are used (Fig.N.20).

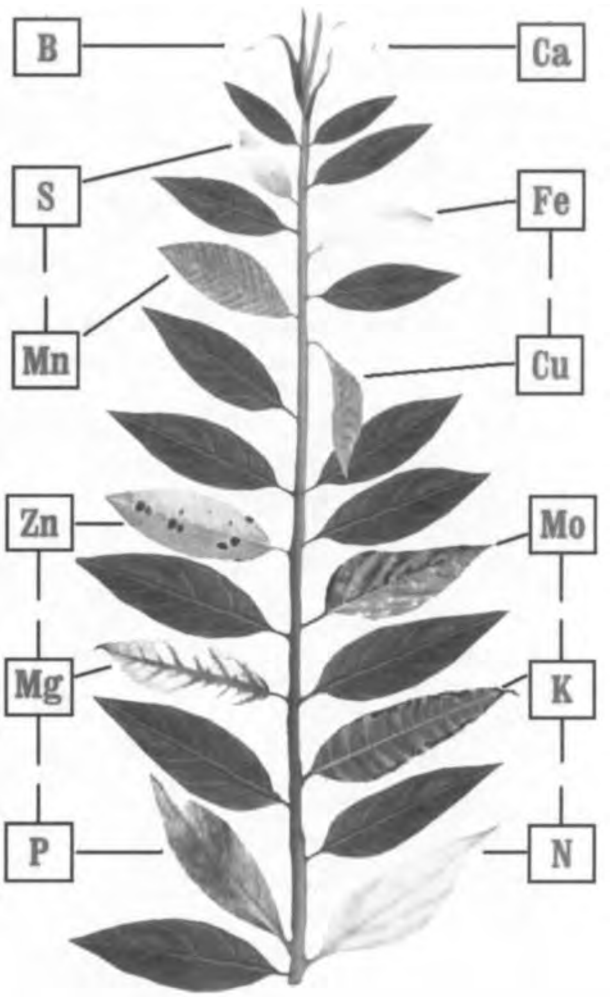


Fig.N.20: Picture of nutrient deficiency symptoms produced by various nutrient elements. (Picture courtesy: Institute of Micronutrient Technology, Pune, India).

The symptoms of nutrient deficiencies are (a) complete crop failure at the seedling stage, (b) severe stunting of plants, (c) specific leaf symptoms appearing at varying times during the season, (d) internal abnormalities, such as clogged conductive tissues, (e) delayed or abnormal maturity, (f) tangible decline in yields, (g) poor quality of crops, with respect to the content of oil, starch or proteins, and (h) poor storability. These symptoms appear only after the nutrient supply is so low that the plants can no longer function normally. The deficiency symptoms are helpful guides in determining the kind of fertilizer required. (See also Deficiency symptoms).

Nutrient efficiency

Nutrient efficiency is represented by the amount of dry matter produced per unit of the nutrient applied or absorbed. The highest efficiency is obtained with the first instalment of fertilizer; additional increments generally give returns in smaller measures. The efficiency of nutrient utilization is obtained by dividing the whole plant biomass by the total nutrient content in the biomass.

Nutrient efficiency has been classified by some, into three types - agronomic, physiological and apparent recovery efficiency. The **agronomic efficiency** is the economic production per unit of nutrient applied and is thus also called economic nutrient efficiency. Agronomic efficiency is the best way to express nutrient efficiency under field conditions.

$$\text{Agronomic efficiency (kg/kg)} = \frac{\text{Grain yield of fertilized crop (kg)} - \text{Grain yield of unfertilized crop (kg)}}{\text{Quantity of fertilizer applied in kg}}$$

Under greenhouse conditions, this may be expressed as gram/gram or mg/mg. The best criteria to determine agronomic efficiency is the economic parts of the plant.

The **physiological efficiency** is the biological production per unit of nutrient absorbed, known sometimes as **biological efficiency** or efficiency ratio, and is calculated as:

$$\text{Physiological efficiency (kg/kg)} = \frac{\left[\begin{array}{c}\text{Total dry matter}\\ \text{yield of fertilized}\\ \text{crop in kg}\end{array}\right] - \left[\begin{array}{c}\text{Total dry matter}\\ \text{yield of unfertilized}\\ \text{crop in kg}\end{array}\right]}{\left[\begin{array}{c}\text{Nutrient uptake}\\ \text{by fertilized}\\ \text{crop in kg}\end{array}\right] - \left[\begin{array}{c}\text{Nutrient uptake}\\ \text{by unfertilized}\\ \text{crop in kg}\end{array}\right]}$$

The efficiency is calculated as gram/gram or mg/mg under greenhouse conditions.

The apparent recovery efficiency is defined as the quantity of nutrient absorbed per unit of nutrient applied, and is given by the equation:

$$\text{Apparent recovery efficiency in \%} = \frac{\left[\begin{array}{c}\text{Nutrient uptake by}\\ \text{fertilized crop}\end{array}\right] - \left[\begin{array}{c}\text{Nutrient uptake by}\\ \text{unfertilized crop}\end{array}\right]}{\text{Quantity of fertilizer applied}} \times 100$$

wherein nutrient uptake is the product of concentration and dry matter.

The **nutrient use efficiency** is the product of the physiological efficiency and the apparent recovery efficiency:

$$\text{Nutrient use efficiency} = \text{Physiological efficiency} \times \text{Recovery efficiency}$$

Nutrient use efficiency is at its maximum at the critical nutrient concentration level.

Plants are exposed to many environmental factors that affect the nutrient uptake and utilization. A high nutrient efficiency may be due to the greater nutrient absorption or greater yield per unit of nutrient absorbed. Here, it is important to know the role of each factor in the uptake and utilization process to manipulate conditions to favor higher uptake or higher utilization.

Nutrient elements of a plant

If a mineral element is essential to plant growth and development and if that element is involved in the metabolic functions of the plant life cycle, it is called the nutrient element of the plant. There are 16 elements recognized as essential plant nutrients. (See also Plant nutrients.)

Nutrient immobilization: See Immobilization of nutrients

Nutrient index value

The nutrient index value, based on the proportion of soil samples from any locality, is expressed in three categories: low, medium and high. The percentage of the number of samples (out of the total analyzed) for a district or locality, falling into the low category with respect to any nutrient is multiplied by an arbitrary factor 1; that falling into the medium category is multiplied by 2, and that falling into the high category is multiplied by 3. The total of these divided by 100 and the percent value obtained is the nutrient index for the particular area and particular nutrient. Thus:

$$\text{Nutrient index value} = \frac{(L \times 1) + (M \times 2) + (H \times 3)}{100}$$

where L, M and H represent the percent number of the samples falling into the low, medium and high categories respectively. The nutrient index value ranges from 1 to 3.

Nutrient level

The nutrient level is the nutrient concentration available in a usable form in the soil. When the concentration of an essential nutrient element is so low as to severely affect the yield, the plant is said to be deficient in that element.

When the nutrient concentration reaches a critical level, the plant yield is generally maximized. Nutrient sufficiency can occur over a wide concentration range, so as not to affect the yield. The term, **critical nutrient concentration** (**CNC**), is used to interpret and diagnose any nutritional problem of a plant. CNC is often difficult to determine precisely, and so it is common to use a term called **critical nutrient range** (**CNR**). CNR represents a range of nutrient concentrations at a specified stage of growth above which the crop can be considered as adequately supplied with the nutrient, and below which the nutrient is deficient. CNR has been developed for many crops, for most of the essential nutrients. CNC in corn is about 3% nitrogen, 0.3% phosphorus and 2% potassium in the leaf opposite and below the uppermost ear at silking time.

Nutrient losses by erosion

The soil eroded by wind or water, loses its nutrients. Leaching takes away the nutrients from organic matter which is the natural reservoir of plant nutrients in the soil. Leaching also depletes the nutrients fed to the soil by fertilizer. The extent of all such losses depends on the high solubility and the total content of the nutrients in the soil in different forms.

The loss of soil nutrients (by leaching) is the highest for Ca, followed by Mg, S, K, N and P (in that order). The soil phosphorus leaches very little because of low solubility. Though both the nitrate and the ammonium ions are water-soluble, the nitrated form is more readily leached than the ammonium ions that are held by the cation exchange sites.

Phosphorus is lost mainly by surface run-off. Its total loss is the sum of that dissolved in the run-off water and that adsorbed on the eroded particles. This lost soil phosphorus meets the water reservoir and causes **eutrophication** and contamination.

Generally, any management practice aimed at reducing erosion also reduces nutrient loss.

Nutrient mobility

The ease with which a nutrient can meet the plant's demand reflects the nutrient mobility. It also indicates the nutrient availability (considered synonymous to mobility), which, in turn, depends on the ionic charge, its tendency to precipitate as insoluble compounds, the soil texture, water movement, and other ion concentrations. If the nutrient ion moves with the mass flow (sulphates and nitrates) it is mobile. Ions like phosphates, however, move through a diffusion process which is very slow - almost to the point of being called immobile.

Nutrients like P, Fe, Zn and Mo move by diffusion even under normal, non-deficient conditions. Plants require phosphate and iron in amounts similar to those of magnesium and sulphur but soil solutions normally have one hundredth to one thousandth times less phosphate and iron than magnesium or sulphate.

The German scientist E. A. Mitscherlich developed a relationship between the growth of plants and the supply of plant nutrients, which was further modified by R. H. Bray, *et al.* According to Bray, as soil nutrient mobility decreases, the amount of that nutrient needed in the soil to produce the maximum yield increases to reach a constant value. The magnitude of the constant value is independent of the crop yield, provided that the pattern of planting as well as the fertility rate is constant and soil and seasonal conditions are similar. The Mitscherlich equation is:

$$\frac{dy}{dx} = (A-y)\,C$$

where dy is the yield increase from an increment dx of the growth factor x, A is the maximum possible yield, y is the yield obtained for a given amount of x and C is the proportionality constant or efficiency factor. Bray modified the Mitscherlich equation to

$$\log (A-Y) = \log A - C_1 b - C(x)$$

where A is the maximum possible yield obtained after supplying all growth factors, Y is the actual yield and x is the growth factor, C_1 is a constant, b is the amount of immobile but available form of nutrients such as phosphorus and potassium and C is the efficiency factor for x which is the added fertilizer in the form of the nutrient b. Bray showed that the values of C_1 and C are specific and fairly constant over a wide area regardless of the yield and the season.

Understanding the interactions among crop growth factors is essential to identify the soil and crop management practices needed for profitable crop production. When the response of two inputs used in combination is equal to the sum of their individual responses, a positive or negative interaction takes place. Phosphates, which are the least mobile anions, either precipitate or are adsorbed to soil solids. The other slow ions, which move very little because of their attraction to the cation exchange sites, are potassium ions (K^+) and ammonium ions (NH_4^+).

Phosphate ions can move only a couple of centimeters in the soil, whereas the K^+ and NH_4^+ ions move many centimeters in the soil. These are still reckoned immobile or slightly mobile. Phosphates or potassium must, therefore, be placed in the root zone. In contrast, the nitrate and the sulphate ions are mobile and move with water. The soluble soil nitrogen is finally oxidized to the mobile ion nitrate, which leaches into the root when added at the soil surface. When NH_4^+ is applied at the surface, it oxidizes and acidifies the soil before the nitrate moves in.

Soils with a low cation exchange capacity have a lower ability to retain the NH_4^+ or K^+. Sandy soils, oxisols and ultisols fall in this category.

Nutrient piracy

When nutrients flow down with rain, the plants that grow on other trees (**epiphytes** or parasitic plants) absorb them, before they reach the ground or the host tree. This phenomenon is referred to as nutrient piracy.

Nutrient ratio

Soil provides at least 13 essential nutrients to plants, partly from its own resources and partly by channelling those added by fertilizers, manures and other sources. These nutrients are needed in specific proportions to meet the requirement of different plants. The proportion of nutrients in a given soil is more important than their actual amount.

The nutrient balance in crops is based on the nutrient ratios, such as N/S, K/Mg, K/Ca, Ca+Mg/K, N/P which are commonly used. At an optimal nutrient ratio, an optimal yield is obtained, unless some other limiting factor reduces it. When the ratio is too low, a response to the limiting nutrient in the numerator will be obtained. When the nutrient in the denominator is in excess (that is, the ratio is small), the yield response may or may not occur, depending on the level of the other yield factors. When the ratio is too high, the reverse is true. Consideration of more than one ratio at a time improves the chance of correct diagnosis. This is an integral part of the diagnosis and recommendation integrated system (DRIS).

Nitrogen is the most widely deficient nutrient and its application often results in an increased yield. However, its application does not build up soil fertility because an imbalanced nitrogen supply (relative to other nutrients) can be a major cause of soil nutrient depletion as experienced in many countries. It is known that application of 174 kg/ha of nitrogen increases the rice yield by a factor of 2.9 but also leads to increased removal of P, K and S by a factor of 2.6, 3.7 and 4.6, respectively.

A phosphorus deficient soil can reduce nitrogen efficiency. Similarly, inadequate supplies of phosphorus may lead to higher amounts of nitrate carryover in the soil and increase nitrate leaching into groundwater. In a large number of trials on the soil, no response was found to potassium in the absence of a phosphate application. A negative interaction between phosphorus and zinc is observed – high levels of phosphorus application reduced the concentration of the available zinc. A good soil management must, therefore, ensure a balance of all nutrients.

Nutrient recovery

Nutrient recovery is the proportion of the applied fertilizer that is absorbed by the crop. Nutrient recovery is usually expressed as percentage. Nutrient recovery is also called **apparent nutrient recovery** or **apparent recovery efficiency**.

Nutrient removal

Harvesting, leaching and volatilization remove nutrients from the soil. Similarly nutrients, transformed into their non-available forms, are as good as removed. Whenever nutrient removal exceeds its addition, the soil suffers a net depletion of nutrient reserves.

Nutrient toxicity

Nutrient toxicity is caused by excessive nutrient concentration which affects plants and the organisms that feed on these plants. For example, excessive molybdenum in grasses creates an imbalance of molybdenum and copper in the body of cattle and causes the disease **molybdenosis**. An excess supply of nitrogen tends to favor diseases because it produces luxuriant growth leading to shaded and humid conditions in the crop, which benefits some fungi and insects. Excess nitrogen also promotes succulent growth, makes the cell walls weaker and enhances protein content. These weakened cell walls are more prone to parasitic attack, and the enhanced protein content attracts insects.

Boron toxicity is most likely on acidic sandy soils or soils with a pH of 7 or more. The yields of cucumber and beans are affected by boron toxicity. The concentration range between nutritionally deficient and toxic levels is narrow and hence the problem of boron levels in plants is accentuated. Excess of chlorides and bicarbonates affect avocado, tobacco and berries. Nitrates are toxic to mammals, if present in more than 15 ppm of nitrate nitrogen.

Nutrient uptake

Nutrient uptake is the absorption of nutrients by plants. For growth and reproduction, plants need at least 16 nutrient elements, which they absorb through roots and leaves. From air and water, plants utilize H, O and C (as carbon dioxide). For absorption, nutrients should be close to the root surface. The nutrients reach the root surface by mass flow, diffusion or root interception.

Mass flow is the movement of nutrient ions with water from rainfall or irrigation. It is a passive movement of the fluid along with the solutes in response to pressure. The amount of nutrients reaching the roots by this process depends on their concentration in the soil solution and the rate at which water travels to the roots. The nutrient supply by mass flow is affected by the soil properties, climate, nutrient solubility and plant species. The level of a particular nutrient in the soil solution depends on the balance between its rate of supply to the root (by mass flow) and that of absorption. The mass flow supplies plenty of calcium (Ca^{2+}), magnesium (Mg^{2+}) and mobile nutrients such as sulphates and nitrates. A major portion of nitrogen reaches the root surface by mass flow.

Reduced soil moisture slows down water movement, and in turn, the mass flow. Mass flow also reduces with low temperatures because of the low transpirational requirement of plants. Mass flow to the roots, greatly restricted at night, is calculated from the product of the soil solution concentration and the volume of water transpired through the leaves. Transpiration is not a constant process; it varies with plant species, climate, soil conditions, location of water sources in the soil, age of plants and time of the day. Younger plants have a high nutrient concentration, the mass flow contributing a small fraction of the demand.

Diffusion is the movement of a substance from a region of high concentration to a region of low concentration. It occurs most readily in gases, less so in liquids and the least in solids. When nutrient supply in the root vicinity is not sufficient to satisfy the plant's demand, a concentration gradient develops and the nutrients move by diffusion. Most of the potassium and phosphorus move from the soil to the root surface by diffusion.

The uptake of nutrients by diffusion is a slow process. It is a dominant process for immobile elements like phosphorus and copper, at low concentrations. The nutrients nitrate (NO_3^-), sulphate (SO_4^{2-}), and borate ($H_2BO_3^-$) have long diffusion periods (of the day) and readily enter plants. The time scale for dihydrogen phosphate ($H_2PO_4^-$) ions is large due to their affinity for the soil solid phase. For nutrients which need many days to become available to the plant, deficiencies occur particularly in the absence of a significant convective uptake or a direct uptake by the plant root itself.

Fick's first law describes diffusion as:

$$\frac{dc}{dt} = D_e A \cdot \frac{dc}{dx}$$

where dc/dt is the rate of diffusion (change in concentration with time), dc/dx is the concentration gradient (change in concentration with distance), D_e is the diffusion coefficient which describes diffusivity of a homogeneous medium and A is the cross sectional area. The diffusion rate concept presents difficulties for the non-homogeneous soil medium. The diffusion coefficient for the medium is given by:

$$D_e = D_W \, \theta \left(\frac{1}{T}\right) \cdot \left(\frac{1}{b}\right)$$

where D_e is the diffusion coefficient in the whole soil medium, D_w is the diffusion coefficient in free water, θ is the volume of the soil water content, T is the tortuosity factor and b is the soil buffering capacity. The relationship shows that as the soil moisture content (θ) increases, the diffusion coefficient increases, causing an increased diffusion rate. As the moisture content is lowered, the moisture film around the soil particles becomes thinner and the diffusion of ions through these films reduces.

The distance of the diffusive nutrient movement through the soil to the root is usually in the range of 0.1 to 15 mm; it is the soil nutrients within this zone that contribute to the supply of nutrient diffusion to the roots. For most ions, the diffusion coefficients are in the region of 10^{-6} to 10^{-7} cm^2 s^{-1}. Phosphorus has the slowest diffusion coefficient (10^{-11} cm^2 s^{-1}). The plant requirement of phosphorus is mostly met during the diffusion process.

Fertilizer applications can improve mass flow and diffusion of ions to the roots by increasing the nutrient concentrations in the soil solution. An increased clay content and a low temperature of the soil moisture reduce the diffusion. These retarding effects are offset by the addition of phosphorus and potassium which help to increase the diffusion gradient.

The process of nutrient uptake includes the diffusion of carbon dioxide and oxygen into the plant tissue through the stomata. This is also called **foliar uptake**. Leaves absorb carbon dioxide, rainwater, dew (moisture) and release oxygen. Other nutrients are also absorbed through stomata as soluble ions from the sprinkled or sprayed fertilizer-enriched water. Foliar sprays are important for aquatic plants. Foliar uptake of the fertilizer is comparable to the uptake by roots.

Plant nutrients in the soil solution, which are present mainly in ionic form, diffuse into the root tissues. The outer plasma membrane of the cells (plasmalemma) is a great diffusion barrier. The nutrient transport across this barrier is the ion uptake process. The transport is not by mere diffusion but is related to specific membrane components and to metabolic processes that allow a selective uptake of the plant nutrients and is often associated with that of nutrients in the cell. For example, the potassium ion (K^+) concentration in the cell (cytoplasm) may be higher by a factor of 10^2 to 10^3 than that in the soil solution.

Root interception is one of the mechanisms of nutrient absorption by plant roots. The growing roots push through the soil and come in direct contact with the nutrients. Root interception depends on the soil volume occupied by the roots, the root morphology and the nutrient concentration in the root-occupied soil volume. Root interception can be enhanced by the introduction of mycorrhizae in infertile soil.

The root surface available for ion absorption depends on the surface area. The root density varies with soil properties, the plant species and management practices. On average, the soil volume occupied by the roots of important food crops is 0.7 to 9%. The only nutrient, which might be supplied completely by interception, is calcium although the process may provide a significant part of the requirements of magnesium, zinc and manganese.

The amount of a nutrient taken up by a growing crop is referred to as its maximum nutrient content, and this amount varies with each stage of its growth. Cereals have a rapid nutrient uptake in the early growth stages when 60 to 80% of the total need is accumulated. Thereafter, the uptake rate either remains constant or declines until ripening. During maturation, nutrients are relocated from the plant to the grain, seed or tuber. The maximum nutrient uptake rate varies with the plant species, climate and soil conditions. Common values for cereals in the temperate region are 5 kg/ha/day for nitrogen and potash and one tenths of this rate for phosphorus. Crops like rice and maize grow more quickly in warm climates than in temperate regions and show even a higher maximum rate of nutrient uptake. The uptake of some nutrients depends on their ratio in the soil solution; for example, excess potassium reduces magnesium uptake.

ATPase (ATP hydrolase), an enzyme located in the plasma membrane, initiates nutrient uptake. ATP hydrolase brings about the splitting of H_2O into H^+ and OH^-, from which hydrogen ion (H^+) is extruded into the outer medium creating a potential difference between the two sides of the membrane; the proton motive force thus obtained, drives the ion uptake. The plasmalemma-bound ATPase also drives the uptake of anions (NO_3^- and $H_2PO_4^-$).

The process of nutrient uptake takes place in the rhizosphere or the local soil environment and is influenced by plant roots. A convective flow and diffusion are the principal mechanisms for the movement of elements. The distance over which the convective flow to the root occurs is very short (typically, 3 mm). The convective nutrient uptake takes place in a matter of hours. This time scale is consistent with the fact that water absorption takes place only during daylight. The convective uptake is important for mobile nutrients like NO_3^-, $H_2BO_3^-$ and Ca^{2+}.

Nutrient use efficiency: See Nutrient efficiency

Nutrient utilization

The amount of nutrient required by crops depends on the (a) variety of crop, (b) moisture or water availability, (c) temperature, (d) soil type, (e) nutrient levels and their balance in the soil, (f) plant population, (g) methods adopted for tilling, and (h) pest control methods. Harvesting a complete crop removes a major portion of the nutrients.

Nutrient utilization can be seen in the amount of dry matter produced per unit of the nutrient applied or absorbed. The highest efficiency is obtained with the first instalment of fertilizer; additional increments provide smaller increases. The efficiency of nutrient utilization is the ratio of biomass to the total amount of nutrient in the biomass, and termed as the **utilization quotient**, coefficient of utilization or efficiency ratio. The efficiency of nutrient utilization is obtained by dividing the whole plant biomass by its nutrient concentration. Since nutrient concentration is the inverse of utilization quotient, the formulation results in multiplication of the utilization quotient by the biomass production. Thus, nutrient utilization coefficient can be separated into two components, namely, the utilization quotient and the biomass production.

Corn, soybean and sorghum require maximum nutrients within 50 to 80 days of their growth. These crops take up a higher proportion of their total potassium requirement during this period than nitrogen or phosphorus, indicating the importance of an adequate supply of potassium in the growing stages. Toward the end of their growth period of 95 to 140 days, the need of nitrogen and phosphorus is more than that of potassium. Thus, it is essential to have a sufficient supply of nutrients during the growing season.

NV

NV is short for **neutralizing value**.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

O

Oasis

Oasis is an area in a desert where there is sufficient water for plants to grow. It can vary in size, from a small plot to a vast region covering thousands of square kilometers. The Nile valley is a large oasis flanked by deserts. Oases occur around springs where the porous rock comes to the surface or where water may be tapped through wells. Artificial oases are created in many deserts.

Obligate aerobe

Obligate aerobe is an organism that grows only in the presence of oxygen. Examples of obligate aerobes are ***Rhizobium***, ***Azotobacter*** and ***Azospirillum***.

Obligate anaerobes

Obligate anaerobes are micro-organisms which grow only in the absence of oxygen.

Obligate parasite

A **parasite** that survives and reproduces only in/on a live host is called an obligate parasite. For example, a stem parasite dodder (*Cuscuta europaea*) or a root parasite broomrape (*Orobanche* sp) are obligate parasites.

Obligate saprophyte

An organism that lives and feeds strictly on dead organic matter is called an obligate saprophyte. Many bacteria and fungi are obligate saprophytes.

OC

OC is short for **organochlorines** and also organic carbons. (See also Persistent organic pollutants.)

Ochric horizon

Ochric horizon is a thin layer surface horizon, containing earthy pigments of ferric oxide, typically with light yellow to brown or red colored clay. It has very low organic matter and is too thin to be either a mollic or an umbric epipedon.

Odda process for nitrophosphate production

Odda process is one of the two methods of manufacturing nitrophosphate fertilizers. In the Odda process, also called **Odda route**, rock phosphate is treated with nitric acid and the resulting solution containing calcium nitrate is precipitated and separated by refrigeration and centrifugation. (See also Nitrophosphate fertilizers.)

Odda route

Odda route is another term for **Odda process**.

ODR

ODR is short for **oxygen diffusion rate**.

Off-type plants: See Rogues

Ohm

Ohm is the derived SI unit of electrical resistance. It is defined as a resistance between two points on a conductor when a constant potential difference of 1 volt applied between the two points produces a current of 1 ampere in the conductor. The direct reading instrument for measuring resistance in ohms is called **ohmmeter**; the other instruments are called **multimeter** (Fig.O.1) or **AVO meter** which measures both the current and the voltage.

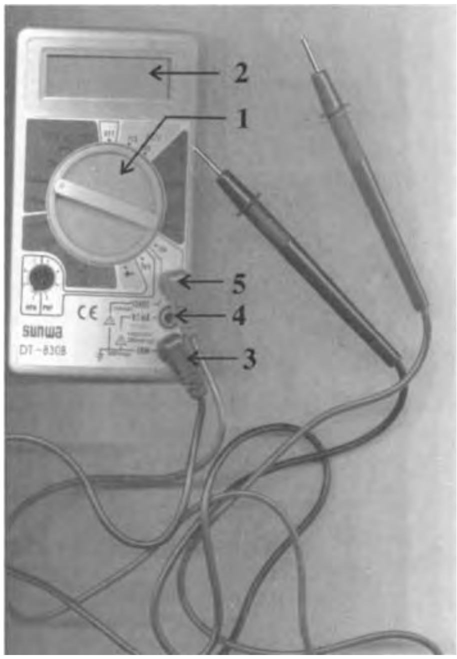


Fig.O.1: A mini digital multimeter. 1. Function and range switch. 2. Display. 3. Plug-in connection for negative test lead. 4. Plug-in connection for positive test lead, and 5. Plug-in connection for positive test lead for 10A measurement.

The international ohm, also called **mercury ohm** is defined in terms of the resistance of a column of mercury.

The water content of the soil is estimated using the resistance block technique which works on the principle of electrical conductivity. The decrease in the electrical conductivity corresponds to a decrease in the soil moisture. The estimation of sodium in the soil is also made based on the measurement of conductivity of the soil extracts.

Ohm's law states that the electric potential difference across a conductor is proportional to the current flowing through it, the constant of proportionality being known as **resistance of the conductor**. It holds well for most materials including solutions, provided that the passage of the current does not heat the conductor. However, semiconductor devices show a much more complicated behavior.

Ohmmeter: See Ohm

Ohm's law : See Ohm

O horizon

A soil is made up of several non-uniform horizontal layers and other sub-horizons at various depths. These horizons are identified by letter and number codes, the **master horizons** being identified with the letters **O**, **A**, **E**, **B**, **C** and **R**.

The O horizon, which is a surface horizon, is predominantly organic rather than mineral. A soil composed of several O horizons is an organic soil. Mineral soils, which may also have organic soil horizons, are differentiated by three degrees of decomposition of organic matter: slight (Oi), intermediate (Oe) and high (Oa). The slightly decomposed organic horizons have plant remains that can be easily distinguished, whereas in highly decomposed horizons they cannot be distinguished. In general, the capacity of organic soil to supply nitrogen, phosphorus and sulphur is high. (See also Soil horizons.)

Oil

Oil is a substance that is insoluble in water, soluble in ether, and greasy to touch. There are three main groups: mineral oils, fixed vegetable and animal oils, and volatile vegetable oils. Mineral oils include gasoline and other fuel oils, heating oils and lubricants. Fixed vegetable oils are divided into three subgroups– drying oils (linseed, tung), semidrying oils (cotton seed, soybean oil) and non-drying oils (castor oil and olive oil). Fixed animal oils include marine oils as cod-liver and whale oils. They usually have a high fatty acid content. Fixed animal and vegetable fats, such as butter fat and palm oil are classified as oils. Volatile vegetable oils have very distinct odor and flavor, and include oils of such seeds as bitter almond, peppermint and turpentine. When dissolved in alcohol, they are called essences. They contain terpenes and are used chiefly for perfumery and flavorings. Oils derived from fruits or seeds of plants are used chiefly in foodstuffs, and are known as **edible oils**; the most common ones are corn, coconut, soybean, olive, cotton seed, sunflower, safflower, etc. They have varying degrees of saturation.

Oil adjuvant

An **adjuvant** is a substance that is added to the main composition (substance) in order to improve the function of the main ingredient in terms of improved wetting, reduced evaporation, increased penetration and staggered release of nutrients.

Oil adjuvant is one of four types of adjuvants, which have been used in herbicide sprays for many years. There are three types of oil adjuvants: (1) **Phytotoxic, non-selective**: These are highly unsaturated (for example, diesel oil) and readily sulphonated, giving them a low unsulphonatable residue character. Oils of this category are added to knockdown-type herbicides for spraying on canals and ditch-banks or added to brush killers, to facilitate uptake through the bark. (2) **Phytotoxic, selective**: These are not actually adjuvants and may be sprayed directly, without mixing with water or in combination with herbicides. (3) **Phytobland oil-water emulsions**: These are nearly saturated light oils. They are not phytotoxic and are added to herbicides for better penetration in foliage. They are called by different names, such as **corn oils**, **superior spray oils**, **supreme spray oils**, etc.

Oil cake

The residue of oil-seed extraction is called an oil cake, the extraction being done either by expellers or by the solvent extraction process. When ground, it is called meal. Oil cakes are concentrated organic manures containing nitrogen, phosphorus and potassium. **Edible oil cakes** are used as cattle feed while **non-edible oil cakes** are not. The amount of nitrogen varies from 2.5% in mahua *(Madhuca indica)* cake to 7.9% in decorticated safflower cake. All oil cakes contain around 0.8 to 2.9% of phosphorus and 1.2 to 2.2% potassium.

Oil cakes are water-insoluble quick-acting organic manures. Nitrogen in the cakes becomes available to the plant in about a week. Powdered oil cakes, when applied to soil, are decomposed by micro-organisms. They are applied by the broadcast method, drilled into or placed near the root zone, depending on the crop. **Groundnut oil cakes** are used in the top dressing of sugar cane. Oil cakes from country 'ghani' (village oil expellers) contain a little more oil than the hydraulic or expeller-pressed cakes or solvent-extracted cakes, and hence are slow in converting the organic nitrogen into a useful form.

The main purpose in processing oil seeds is to recover fats. However, the value of the residual oil cake is also important from an overall economic stand point.

Oil of vitriol

Oil of vitriol is another term for sulphuric acid.

Oil seeds

Seeds with high oil content are called oil seeds. Groundnut, rapeseed, mustard, sesame, safflower and soybean are edible oil seeds, whereas castor and linseed are non-edible oil seeds. (Fig.O.2).

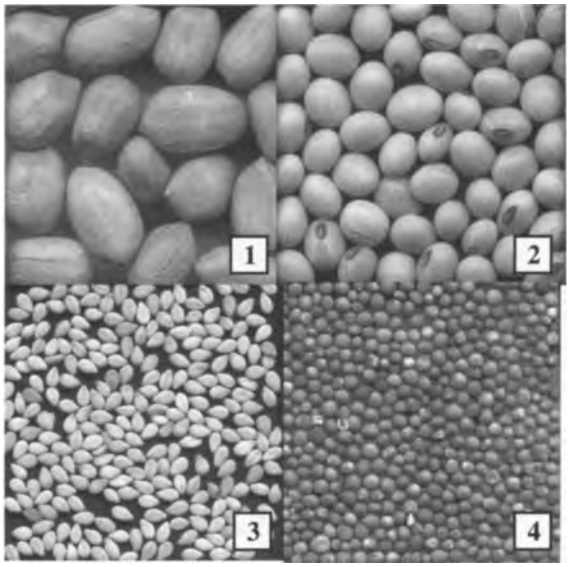


Fig.O.2: Oil seeds: 1. Groundnut, 2. Soybean, 3. Sesame, and 4. Mustard are important oil seeds.

The seed is enclosed in a shell or husk. The husk is removed before extracting oil. Pre-treatment, purification, milling, mechanical pressing, oil and fat extraction, filtration and refining through processes like bleaching, hydrogenation, fractionation and deodorization are the various steps in oil extraction. Dry storage of seeds is of paramount importance. In damp haystacks, bacteria and moulds can lead to 'spontaneous combustion' and 'spontaneous heating', which affect the oil yield.

Olericulture

Horticulture, of which Olericulture is a subdivision, refers to the scientific practice of gardening or cultivation of fruits, vegetables, flowers and shrubs. Olericulture deals specifically with the storage, processing and production of vegetables. The other subdivisions of horticulture are: **pomology**, dealing with the art and science of fruit crop production, and **floriculture**, dealing with the cultivation of ornamental and flowering plants for aesthetic purposes. (See also Horticulture.)

Oligosaccharides

Oligosaccharides are low-molecular-weight condensation polymers of **monosaccharides**. An oligosaccharide is a carbohydrate containing between two to ten simple monosaccharides linked together. Beyond ten, it is called a polysaccharide. They may be further classified into **disaccharides** (two monosaccharide units) and **trisaccharides** (three monosaccharide units). For example, sucrose and maltose are disaccharides. (See also Carbohydrates.)

Olive oil

Olive oil is a clear, edible substance obtained from the fruits of olive trees, the evergreen trees grown in Mediterranean climates. The fruit is pulped, pressed and finally extracted for oil. The best quality comes from the *first* pressing of just ripened fruits. The unripe fruits are pickled, treated with a lye solution to remove the bitter taste, and stored in brine. When left in the open, they turn black and may be pressed thereafter for oil.

Olsen test for soil phosphorus

The Olsen test is used to estimate the available soil phosphorus in neutral and calcareous soils. The test uses 0.5N sodium bicarbonate ($NaHCO_3$) buffered at pH 8.5 to extract the phosphorus from the soils. In these soils, calcium-phosphorus [Ca-P] minerals control the phosphorus concentration in the solution. The bicarbonate ion (HCO_3^-) causes calcium carbonate ($CaCO_3$) to precipitate during extraction, thereby lowering the concentration of calcium ion (Ca^{2+}) in the solution. Consequently, calcium-phosphorus [Ca-P] minerals dissolve to buffer the calcium ion (Ca^{2+}) and release phosphorus into solution. Increased solution phosphorus provides a measure of the ability of the soil to supply the available phosphorus.

The extraction procedure consists of adding 2.5 g of an air-dried (< 10-mesh sieved) soil sample into a 250 ml flask containing 50 ml of 0.5N sodium bicarbonate ($NaHCO_3$) at pH 8.5, shaken for 30 minutes, and filtered. The filtered extract is analyzed for phosphorus.

Other tests for estimating soil phosphorus use extractants containing 0.025M hydrochloric acid (HCl) and 0.03M ammonium fluoride (NH_4F) (**Bray-1** extractant/test), and 0.015M ammonium fluoride (NH_4F), 0.2M acetic acid, 0.025M ammonium nitrate (NH_4NO_3) and 0.13M nitric acid (**Mehlich test**). In some cases, ammonium chloride (NH_4Cl) and hydrochloric acid (HCl) are used in place of nitric acid and ammonium fluoride (NH_4F). The other tests include (a) neutral salt solutions like 0.01M calcium chloride ($CaCl_2$), (b) anion and cation exchange resins, and (c) complexing agents - milder extractant.

Open ditches system

One of the three principal surface drainage systems is the open ditches system. This system consists of constructing open water collection ditches at the end of gently sloping lands. This enables collection of run-off, which may be diverted to a desirable area. Open ditches or an **open drainage** are designed according to the topography of the land and soil characteristics. The dimensions of the ditches as well as the spacing are designed based on the rainfall of the area and soil properties. In order to keep the ditches from getting filled with mud and thereby closed, grass may be grown on the bottom and sides of the ditches. Fast spreading grass like Bermuda grass can encroach on the fields, and hence such grass is not grown in this drainage system. (See also Surface drainage.)

Open drainage system

Open drainage system is another term for **open ditches system**.

Open-hearth basic slag

Blast furnace slag is called open-hearth basic slag, depending on the process adopted for steel manufacture.

Open market price

Open market price is a free price decided entirely by the market forces of supply and demand. Suppliers, however, can manipulate the prices by forming cartels.

Operations research

Operations research, also called operational research, involves mathematical analysis for providing a quantitative basis for management decisions.

Optimum returns in agriculture

Optimum returns are the best returns one can get in the given situation or in a given set of circumstances. Generally, it is neither excess nor deficient. The interpretation also depends on the desired end point.

Farmers work to achieve the best returns from their farming. But the optimum depends on many factors, such as (a) the expected yield, (b) local conditions (soil, climate, water, temperature and length of the growing season), (c) environmental considerations (loss of nutrients to air and water), (d) biological factors, such as choice of crop and variety, yield potential of crops, losses through weeds, insects and diseases, and (e) crop quality. Protein content of cereals, sugar content of sugar beet, aroma, taste and color of fruits, and the size, shape, color and shelf-life of flowers would be the optimum qualitative returns.

Maximum yield is obtained when all factors including nutrients, are balanced to give the maximum crop growth under given climatic conditions. The economic optimum in crop production takes fertilizer costs into consideration and the optimum is reached when the extra yield (income) from applying a unit of fertilizer equals the cost of that additional unit. The economic optimum varies with the price of fertilizers and also with the value of the product, but is less than the maximum yield.

Some products demand a premium for their special quality, like the high protein content of cereals and the sugar content of sugar beet. A high nitrogen application enhances the protein content of wheat but reduces the sugar content of sugar beet and the oil content of rapeseed. Hence, the fertilizer optimum point can be higher for wheat and lower for sugar beet, the profitability depending on both the quality and the total yield.

Risk optimum is a special case of economic optimum. The true economic optimum is not known until after the harvest, while fertilizers must be applied at an early growth stage. The price obtained for the produce can vary greatly; an oversupply in a 'good' year can convert good yields to an economic disaster for farmers. To minimize the risk, the purchased inputs can be minimized or the estimated total nitrogen required can be split into several smaller applications adjusted to crop (and market) conditions.

Environmental optimum refers to environmental concerns. An example is the optimization of nitrogen application in relation to the risk of nitrate leaching. There are other optima from field experiments like energy optimum, which is the maximum recovery of energy in the form of crops compared to the energy consumed in the inputs (by way of using the machinery, tillage, fertilizers, pesticides, etc).

Optimum yield: See Targeted yield from soil

Orchid

Orchid is a plant of the large family Orchidaceae (15,000 to 30,000 species) which produces colorful and elaborate flowers. Some species are native to cold and temperate regions, but most occur in tropical, damp climates. Orchids have mostly aerial roots.

Ordinary superphosphate

Ordinary superphosphate is another term for **single superphosphate**, and is made by reacting rock phosphate with sulphuric acid. It contains 14 to 22% phosphorus (P_2O_5) and 12% sulphur.

Ore dressing: See Beneficiation

Organic agriculture

Organic agriculture or **organic farming** is a critical part of the management of eco-friendly sustainable agricultural systems. It includes the use of a vegetative cover as an effective soil and water conservation measure. The practices like no-till farming, mulch farming, and cover crops are carried out in this kind of agriculture. Nutrition is provided through organic manures, composts and legumes. Nutrient recycling mechanisms include the use of crop rotations, appropriate tree/crop combinations in agro-forestry and intercropping systems using legumes. Major strengths of organic agriculture include the avoidance of pesticide applications, adoption of an environmentally friendly approach and a larger concern for animal and human welfare. It is also believed that the produce from such type of agriculture is superior in terms of nutritional value, health benefits and taste, compared to the produce grown with chemical fertilizers.

Productivity of organic agriculture is lower than that of mainstream farms and the production costs are generally higher. But organic produce is a speciality product. However, it is also feared that organic farming alone will not be able to satisfy future needs of food on the existing cultivated land. (See also Organic farming.)

Organic amendment

Organic amendments, like other soil amendments, are additives used for improving the physical condition of the soil or to improve plant nutrition. Examples of organic amendments are crop residues, animal manures, wood manufacturing residues, industrial organic wastes, food processing wastes and fiber harvesting wastes. (See also Soil amendment.)

Organic biostimulants

Organic biostimulants are substances or non-fertilizer products that have some beneficial effect on plant growth. These are commonly non-fertilizer products and include **humic acid**, algal extracts and non-hormonal reductant metabolic substances of plants. For example, seaweeds like *Ascophyllum nodosum*, and *Facus serratus* contain cytokinins, **gibberellins**, **auxins**, etc. and are used as liquid organic biostimulants.

Organic carbon

Organic carbon is the carbon present in organic compounds of living organisms. It is also the carbon present in carbohydrates or organic acids.

The term 'organic' was originally confined to carbon compounds in organisms. Now the term also includes carbon compounds of artificial or synthetic origin.

Soil organic matter is approximately 50% carbon. A soil with more than 40% organic matter is usually termed **organic peat soil**.

Organic chemistry

Carbon, in combination with H, O, N, S and a few other elements, produces a vast variety of compounds. As a result, a separate branch of chemistry called organic chemistry has been developed around carbon compounds. Because carbon has the ability to form linked chains of atoms of any length and complexity, there are more organic compounds than inorganic compounds. Organic compounds form the basis of living tissue. Organic chemistry is also of fundamental importance in textile, petrochemical and pharmaceutical industries. (See also Carbon.)

Organic farming

Farming carried out with the help of naturally occurring animal and plant by-products is called organinc farming. Organic farming has to fulfil three major criteria, which are (a) meet the nutritional requirement of the crop, (b) encourage the growth of soil organisms, and (c) act as an aid to the soil. A farm product, to be labeled as an organic farm product has to be certified by specialized agencies. Some of the certified agencies include Oregon Tilth, California Certified Organic Farmers, INDOCERT (Indian Organic Certification agency), etc. An estimate of the market for organic food in the western world is $ 17 billion and growing.

Organic fertilizers

Fertilizers prepared by processing a combination of materials of biological origin, unprocessed mineral materials like lime, rock phosphate, etc, and organic wastes from industrial processing units homogenized by microbial decomposition are called organic fertilizers. Organic fertilizers should contain sufficient amount of plant nutrients to be valued as fertilizers. They may not be immediately available to the plants, but they enhance the fertility of the soil.

Organic fertilizers are referred to commonly, as **organic manures**, although processes carried out on organic fertilizers make them more standardized, which is not the same case with manures.

The advantages of organic fertilizers include the slow release of available water-insoluble nitrogen and phosphate. The slow-release minimizes the leaching of nutrients. Organic fertilizers (unlike inorganic fertilizers) contain no soluble salts and can be applied in large quantities without damaging the crops. There are some situations when organic fertilizers can even be better than inorganic fertilizers in supplying nitrogen and phosphorus to crops.

Organic fertilizers are products from wastes of animal husbandry (stable manure and slurry manure), plant decomposition products (compost, peat), or waste treatment plants (composted garbage, sewage sludge). They tend to be costlier than inorganic materials, when considered on the basis of gain per unit of nitrogen, phosphorus, potassium and sulphur.

In Germany, organic fertilizers are designated as secondary raw material fertilizers, subject to compliance with the German Waste Law and the German Fertilizer Law.

Organic fertilizers enriched with inorganic minerals or fertilizers are called **organic mineral fertilizers**. Organic mineral fertilizers are mixtures of inorganic fertilizers (N, P, K) with peat, composted bark, lignite dust or (occasionally) dried slurry. These are classified as (a) fertilizers capable of improving soil condition, having stable organic compounds and a slow effect on the nitrogen supply (biogenic composts, garden composts), and (b) fertilizers with short-term effects on nutrient supply, especially of nitrogen, having a high content of mineral nitrogen and/or readily available organic nitrogen compounds (sewage sludge, blood meal, potato starch waste water).

Organic fertilizers, with or without the added mineral fertilizer salts, are classified as those based on (a) **peat** (like composted bark and lignite), (b) waste materials of animal origin (like **horn meal**, **bone meal**, **blood meal**, hide meal, feather meal and **guano**), (c) waste materials of plant origin (like castor cake, cacao waste, brewers' grain, rapeseed, vinasse, spent mash, potato starch waste water and filtration diatomaceous earth), and (d) fertilizers based on municipal waste (like sewage sludge, biogenic and garden composts).

Organic fertilizers, animal wastes and agro-waste products are used in intensive horticulture. Some mixed fertilizers contain organic material with a varying nutrient content. To all these residues, potassium fertilizer is recommended as an additive.

In organic farming, plant nutrients are supplied through organic fertilizers, organic manure, composts and legumes.

Organic manures

Organic manures consist mainly of wastes and residues from plants, but sometimes also from animals. Organic manures are unprocessed organic wastes. They contain a high percentage of carbon, small percentage of plant nutrients and are used for fertilizing land (Fig.O.3).

As a source of plant nutrients, soil organic matter functions in three ways: (i) Nutrients contained in organic residues are released through mineralization. (ii) The solvent action of organic acids (or humic acids) helps to extract some plant nutrients from primary and secondary minerals. (iii) Soil organic matter is the main site of cation exchange in most mineral soils.

The waste from mixed arable farming and livestock farming is called **farmyard manure (FYM)**. FYM is partially decomposed straw, containing urine and feces. Other manures include decomposed plant remains and

Fig.O.3: Organic manures are commercially sold as potting mixtures.

unutilized materials like straw, organic wastes, town refuse, kitchen waste and sewage sludge.

Organic manures provide a limited amount of nutrients for plants and are a source of energy, carbon and nutrients for micro-organisms. Their salient role lies in their action on the physical structure of soil. Manures improve the soil structure either directly (as bulky diluents) or indirectly (by cementing the soil particles). They also improve drainage and aeration, and encourage good root growth and availability of water to crops. Organic manure also increases the cation exchange capacity and microbial activity. The components of organic manure include kitchen waste, crop residues, green manure, livestock, excreta, compost, stable manure and slurry manure. Specially treated organic manure includes fish meal, guano, bone meal, etc. which may also be categorized under **organic fertilizers**. Large amounts of organic manure are required for the desired nutrient supply. (See also Manure.)

Organic matter

Organic matter, present to an extent of 2 to 5% in the soil, is composed of different types of organic materials in different stages of decomposition. Soil organic matter usually contains 47% carbon, 44% oxygen, 7% hydrogen and 2% nitrogen and other elements. Its presence, per se, is more important than the details of its constituents. Organic matter is essential for soil structure, moisture retention, cation exchange capacity, nutrient supply and microbiological activity. (See also Soil organic matter.)

Organic mineral fertilizers

Organic mineral fertilizers are mixtures of fertilizer salts (N, P, K) with organic manure/composts, peat, composted bark, lignite dust or (occasionally) dried slurry. Mineral fertilizers are added to enrich the nutrient content of these low-level manures or materials.

Organic peat soil: See Organic carbon

Organic phosphorus

Phosphorus, present in the soil as a constituent of an organic compound (or a group of organic compounds) is known as organic phosphorus, most of which is in the form of esters of orthophosphoric acid (like glycerophosphoric acid, lecithin, nucleic acids, inositol phosphates and phospholipids). Organic phosphorus represents about 50% of the total phosphorus in soil and typically varies between 15 and 80% in most soils (ranging from a few milligrams to about 0.5 g/kg soil). Soil organic phosphorus decreases as depth increases, the depth varying among different soils. In general, organic phosphorus tends to accumulate in surface soil because it is a part of soil organic matter. Organic phosphorus content depends upon many factors such as climate, vegetation, soil texture, land use pattern, fertilizer application practices, drainage, irrigation, etc.

The quantity of organic phosphorus in soils generally increases with increasing organic carbon and/or nitrogen. However, the C/P and N/P ratios are more variable among soils than the C/N ratio. The average C/N/P/S ratio in the soil is approximately 140: 10: 1.3: 1.3.

Phosphorus mineralization, which is the conversion of organic phosphorus to an inorganic form, is very similar to nitrogen mineralization. In soils with high organic content, only a small amount of organic phosphorus needs to be mineralized to provide a substantial proportion of phosphorus to crops or natural vegetation. Enzyme phosphatase plays an important role in the mineralization of organic phosphorus in the soil.

Organic rice farming

Like any other organic farming system, rice is legitimately considered as being grown organically, if this fact is certified by an independent agency. Under this scheme, rice cultivation would have to be carried out using a set of standards like (a) synthetic fertilizers or pesticides to be avoided, (b) soil fertility to be maintained through natural processes, and (c) ecologically friendly methods of cropping to be carried out, like crop rotation, pest control through managing insects, weed management, etc.

It is to be noted that yields achieved through organic rice cultivation may not be high. However, the produce is priced higher than normal rice. This rice is also believed to be tastier and more nutritious.

The supply of nitrogen, phosphate, potassium and other nutrients is provided through naturally occurring sources in the following ways:

Potassium may be supplied through incorporation of rice straw. Potassium content is also generally high in irrigation water. Another source of potassium is *Azolla* which contains 0.3 to 0.6% of potassium on dry weight basis.

Rock phosphate is a good source of phosphorus, although it becomes available to the plant in a deferred manner. **Bone meal** is cheaply available and contains around 12% phosphorus. A flooded field is believed to have more phosphorus, available from the soil, than an upland field.

Nitrogen may be supplied to the crops by various plants. ***Azolla*** is a fern that contains 2.5% of nitrogen by dry weight (it fixes 40 to 80 kg of nitrogen per hectare in association with *Anabaena azollae*). Azolla may be used as **green manure** because of its large biomass. It may be incorporated both before and after transplanting. Inputs of azolla in a rice field have increased yields by 15 to 20%. Another source of nitrogen gaining popularity is the leguminous plant **Sesbania** (*Sesbania cannabina* and *Sesbania rostrata*). The organic matter and nitrogen derived from Sesbania supply proper economical nutrition. Simultaneously, these two components help improve the soil. Sesbania can produce about 100 kg of nitrogen per hectare (4 to 5 tons dry biomass of Sesbania per hectare) in a maximum of 60 days from growth. **Gliricidia**, another nitrogen supplier, serves as green manure because it enriches the soil and provides abundant nitrogen to plants.

Cyanobacteria or **blue green algae** are ideal for a flooded rice field. They fix 20 to 30 kg of N/kg and produce **auxin**, **indole acetic acid** and **gibberellic acid**. Incorporation of cyanobacteria has shown to increase yields by 15 to 20%.

Crop rotation maintains soil fertility and prevents weeds and pests. Mulches are also used to control weeds. Water management and good land levelling may be also practiced. Research has revealed that gliricidia is beneficial in the preparation of weedicides and rodenticides. Weeds can be controlled also by an innovative, time-tested method of introducing ducks in the fields. Ducks eat weeds as well as insects and snails which are a threat to the crop.

Another method of enriching the soil is the application of fish manure. Fish is allowed to grow in the water for a certain period. Then a plant called *Euphorbia neriifolia* containing poisonous ingenol-esters is added to the field, which kills the fish. This process releases nitrogen, phosphorus and calcium from the fish.

Organic soils

Organic soils are mostly composed of residues of vegetation and decomposed plant parts. The parent material of such soils can range from mosses to trees. Soil organisms (macro and micro) decompose the organic matter and produce humus that makes organic colloids. Humus helps the soil retain its moisture and nutrients. Organic soils are low in minerals and have at least 12 to 18% carbon by weight depending on the mineral content and the kind of organic material accumulating in the surface horizon. **Histosols** are organic soils.

Long stagnated water creates a low-oxygen environment. In such soils, the decomposition of plant residues is very slow. The Tundra soils and the Irish peat bogs are examples of such organic soils.

The distinction between organic and mineral soils is usually made by the criteria of (a) soil depth, and (b) carbon content. But such a distinction must be specified by a system of soil taxonomy. Histosols meet the specific depth requirement (in most cases 40 cm or more) of the organic soil material. Organic soils, in turn, must contain at least 12% organic carbon if no clay is present, and up to 18% when the clay content is 60%. Organic soils are far less extensive than mineral soils, but where present, they are of considerable importance because of their fertility and productivity. Many organic soils have to be artificially drained for agricultural purposes. Peat soils have more organic content than **muck** soils. High acidity and aluminum toxicity are common among organic soils.

Organic weathering

Weathering is a process by which objects on the earth's surface disintegrate and decompose, eventually producing soil particles, by their exposure to nature's forces like rain water, frost, wind and temperature changes. Organic weathering is caused by the action of plants and animals in combination with chemical and mechanical processes. For example, burrowing animals and plant roots may physically break up rocks; lichens, growing on bare rock surfaces cause decomposition through the removal of nutrients.

Organochlorines: See Persistent organic pollutants

Organomineral fertilizer

A mineral fertilizer mixed with **organic manure** or compost is called an organomineral fertilizer. To upgrade the low nutrient level of composts, they are enriched with mineral or inorganic fertilizers during the composting stage or even after the processing is complete. This enables the product to be made comprehensively beneficial to the plant.

Orographic rain

Precipitation refers to water in liquid or solid forms falling on the earth, either as rain, drizzle, fog, mist, snow, hail or sleet. The dominant factor in any type of precipitation is the uplift of moist air masses in which water condenses and falls as precipitation. This uplift is aided by several factors. But when mountains cause the moist air to rise, resulting in precipitation (rain), it is called orographic rain.

Orthoborate

Orthoborate is one of two types of borate, which is a salt of boric acid (H_3BO_3). Orthoborate, along with metaborate, is used as a fertilizer. (See also Borate.)

Orthophosphates

Phosphates derived out of **orthophosphoric acid** are called orthophosphates. The most common phosphates are calcium dihydrogen phosphate [$Ca(H_2PO_4)_2$], or single superphosphate and diammonium hydrogen phosphate $(NH_4)_2HPO_4$ or **DAP**. (See also Orthophosphoric acid.)

Orthophosphoric acid

Orthophosphoric acid is obtained by reacting phosphorus pentoxide with water or by reacting rock phosphate with concentrated sulphuric acid. Salts of ammonium, calcium or potassium with this acid are called **orthophosphates**, and these are used as fertilizers. Nearly 80% of the phosphorus pentoxide in fertilizers is derived from orthophosphoric acid. Commercial phosphates based on orthophosphoric acid, also known as phosphoric acid, are triple superphosphate, ammonium phosphate, ammonium polyphosphate, nitrophosphate, orthophosphate fertilizer and liquid fertilizers.

Ortstein

The hardpan layer of the B-horizon of podzols in which the cementation of the material is caused by sesquioxides (mostly iron) and illuviated organic matter is known as ortstein.

OSB

OSB is short for **overall salt balance**. (See also Salt balance.)

OSHA

OSHA is short for Occupational Safety and Health Administration (in the USA).

Oslo unit

Krystal unit is also known as Oslo unit.

Osmosis

Osmosis is the diffusion of a solvent through a semi-permeable membrane that separates two solutions of different concentrations. The membrane is said to be semi-permeable when the molecules of the solvent (and not those of the solute) can penetrate it. The movement is from the more dilute solution to the more concentrated solution, because of the thermodynamic tendency to equalize the concentrations. The liquid movement may be opposed by applying pressure to the more concentrated solution. The pressure required to stop the flow of the solvent from a dilute to concentrated solution is known as **osmotic pressure** of the solution. Osmotic pressure enables us to calculate the molecular weights and degrees of ionic dissociation to be determined. Osmosis is important in dialysis and in water transport in living tissue.

The pressure exerted by osmosis is substantial and accounts for the elevation of sap from root systems to the tops of trees. Osmosis is considered as an essential characteristic of growth. Reverse osmosis is utilized as a method of desalting sea water, recovering waste water from paper mill operations, pollution control, industrial water treatment, chemical separations and food processing.

Osmotic pressure: See Osmosis

Ostwald process of nitric acid manufacture: See Nitric acid production processes

Other process techniques for ammonia production: See Ammonia production processes

Outokumpu process for sulphuric acid production: See Sulphuric acid production processes

Out-wash plains: See Plains

Overall salt balance: See Salt balance

Overgrazing

Grazing is an important aspect in pasture land eco-systems and livestock husbandry. It determines the structure and composition of vegetation with which it interacts. It reduces the root growth and rhizome carbohydrate reserves. The decrease of carbon inputs leads to a reduced carbon to nitrogen ratio (C/N ratio) of the plant biomass below the ground, a lesser microbial growth, and a decreased potential for nitrogen immobilization.

When more animals are allowed to graze than can be sustained by the land's carrying capacity, it is called overgrazing. Overgrazing has resulted in denudation of vegetation and severe erosion by wind and water in both semi-arid and arid regions. In desert areas, a large number of animals have denuded the already scanty vegetation, causing soil to degrade further by wind erosion during dry periods.

The best management strategy for preventing overgrazing involves controlled grazing of pastures, adequate fertilization during rains to allow pasture species to recover, and protection from grazing animals at the recovery stage. A well-managed pasture supports good animal production.

Oversized fertilizer

The diameter of an ordinary commercial fertilizer granule is 0.5 to 6 mm and any granule bigger than this range is considered as oversized. For example, it may be coarser (6 to 12 mm diameter) as in the case of an aerially-sprayed fertilizer, applied to forest trees, or smaller than that, as in the case of ammonium sulphate.

The particle size distribution is normally measured by conducting a screen analysis (sieve analysis). The portion of a batch or sample that does not pass through a sieve of a specified aperture size is known as oversized material. The granule size distribution of a fertilizer should be uniform for its application through field equipment.

In the granulation loop of fertilizer production, the oversized or off-sized materials generated are recycled. Recycling is necessary to reduce the loss, once the product passes through the granulator. The quantity of oversized granules formed during granulation is measured by **granulation efficiency**. Recycling is also needed to generate nuclei for agglomeration and to stabilize the granulation conditions in the granulator.

Oxalic acid

Oxalic acid, $(COOH)_2$, also called ethanedioic acid, is a white, crystalline solid, slightly soluble in water. It is a naturally occurring highly oxidized organic compound with significant chelating activity. It is strongly acidic and poisonous, produced by many plants like sorrel (sourwood), the leaf blades of rhubarb, bark of eucalyptus and many plant roots. In plant cells and tissues, oxalic acid gets accumulated as either sodium, potassium or calcium oxalate, of which the latter occurs as crystals. In turn, salts of oxalic acids enter the bodies of animals and human beings, causing pathological disorders, depending upon the amount consumed. Many species of fungi like *Aspergillus*, *Penicillium*, *Mucor*, as well as some lichens and slime moulds produce calcium oxalate crystals. Upon the death of these micro-organisms, plants and animals, the salts get released into the soil, causing some amount of toxicity. However, oxalate-degrading microbes, called *Oxalobacter formigenes,* decrease oxalate absorption in animals and humans.

Oxalic acid is the first of a series of dicarboxylic acids. It is used (a) as a bleaching agent for stains like rust or ink, (b) in textile and leather production, and (c) as monoglyceryl oxalate in the production of allyl alcohol and formic acid.

Oxamide

Oxamide ($H_2NCOCONH_2$), a diamide of oxalic acid, is a white crystalline and non-hygroscopic fertilizer containing about 32% nitrogen, most of which is water-insoluble at 25°C. Oxamide is made from cyanogen hydrolysis in an acid medium. It releases nitrogen slowly and hence is used as a slow-release fertilizer. It is decomposed by soil micro-organisms in the soil.

Oxic horizon

Oxic horizon is commonly found in oxisols. This sub-surface horizon (endopedon) of sandy loam or of finer texture (more than 15% clay) has a low cation exchange capacity (CEC) and low weatherable minerals. The oxic horizon contains materials like kaolinite, hydrated iron oxides and hydrated aluminum oxides, insoluble primary minerals and a very small amount of water-dispersible clay.

Oxic horizons, which occur in old, weathered soils or soils derived from highly weathered parent materials have (a) a thickness of at least 30 cm, (b) a fine fraction that retains 10 meq or less of ammonium (NH_4^+) ions/100 g clay, (c) a CEC equal to or less than 16 meq/100 g clay, except when chlorites containing intercalated aluminum are present, (d) very little or no alumino-silicates such as mica and feldspars, and (e) less than 5% by volume of the original material preserved.

Oxidase

Oxidase is an enzyme that catalyzes an oxidation process by the removal of hydrogen ion which combines with molecular oxygen to form water or hydrogen peroxide.

Oxidation

Oxidation is any chemical or biochemical reaction in which an atom or ion loses electrons. Originally, oxidation was regarded as a chemical reaction with oxygen. Oxidation involves the removal of electrons and is also called **de-electronation**, whereas reduction involves the gain of electrons and is called **electronation reaction**. In the oxidation process, the oxidation number of some element increases and electrons appear on the right hand side of the equation.

$$\begin{aligned} 2Na &\longrightarrow 2Na^+ + 2e \\ Cl_2 + 2e &\longrightarrow 2Cl^- \end{aligned}$$

Here, the sodium atom has lost an electron to become sodium ion (Na^+) and the chlorine atom has gained an electron to become chloride ion (Cl^-).

Oxidation and reduction (**redox reactions**) always occur simultaneously and the substance that gains electrons is termed as **oxidizing agent**, whereas the one that loses electrons is called the **reducing agent**.

The number of electrons that must be added to or subtracted from an atom in a combined state to convert it to the elemental form is called the **oxidation number**. For example, in calcium chloride ($CaCl_2$), the oxidation number of calcium is +2 and that of chlorine is -1. Many elements can exist in more than one states of oxidation. For example,

$$\begin{aligned} &\underset{\text{(Ferrous)}}{Fe^{2+}} \longrightarrow \underset{\text{(Ferric)}}{Fe^{3+}} + e^- \\ &\underset{\text{(Stannous)}}{Sn^{2+}} \longrightarrow \underset{\text{(Stannic)}}{Sn^{4+}} + 2e^- \end{aligned}$$

Oxidation number is a measure of the electron control that an atom has in a compound compared to an atom in a pure element. An oxidation number consists of two parts: (a) its sign indicating whether the control has increased (negative) or decreased (positive), and (b) its value giving the number of elements over which control has changed. The oxidation number is used in naming inorganic compounds like ferrous or ferric.

The atmospheric oxygen and free oxygen in rainwater convert rock minerals to oxides which require more space, and thus help to break the rock. Stiff blue clay containing iron (II) oxide is converted to crumbling red earth, iron (III) oxide, by exposure to oxygen. The end products of oxidation are usually stable compounds such as hematite, goethite, gibbsite and manganese oxide. The red or brown color of many tropical soils is a diagnostic feature of oxidation.

Oxidation number: See Oxidation

Oxidation of ammonia

Ammonia gets oxidized by atmospheric air in the presence of a platinum or platinum-rhodium gauze catalyst, when electrically heated in the range 750 to 900°C as follows:

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$$

Ammonia is oxidized to produce nitric acid and all nitrate fertilizers. (See also Ammonia oxidation.)

Oxidation state of organic matter

The oxidation state of soil organic matter may be expressed by the formula,

$$W = \frac{2(Qo - Qh)}{Qc}$$

where W is the oxidation quotient, Qo is the number of oxygen atoms, Qh is the number of hydrogen atoms in the organic matter and Qc is the number of carbon atoms in the soil organic matter.

The following are the values of W for some of the compounds: 0 for glycosides, 4 for completely oxidized carbon compounds (CO_2) and minus 4 for completely reduced carbon compounds (CH_4).

In practice, one must determine the quantity of C, H and O in organic compounds of the general formula $C_xH_yO_z$. It is, therefore, necessary to analyze gravimetrically, the elements of the compound and to determine its molecular weight (MW). The elemental analysis and the MW give the molecular formula which defines the values of x, y and z.

Oxide

An oxide is a chemical compound of oxygen and another element. The formation of an oxide, called **oxidation**, may occur rapidly as in burning, or slowly, as in rusting. Metallic oxides, such as **quicklime** or calcium oxide (CaO), react with water to form alkalis and with acids to form salts. Non-metallic oxides, such as sulphur trioxide (SO_3), react with water to form acids and with bases to form salts. Sulphur dioxide and nitrogen oxides are common air pollutants that combine with water to form acid rain. Industrial uses of oxides include production of acids and glasses.

Some oxides such as those of aluminum, tin and zinc dissolve both in acids and bases making them amphoteric in nature.

Oxidizing agent

The substance that gains electrons in any redox reaction is termed an oxidizing agent. Many important chemical reactions involve oxidation and reduction. In fact, most reactions used for energy production are redox reactions. Combustion reactions provide most of the energy to power our civilization.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + \text{energy}$$

Here, oxygen is the oxidizing agent and methane is the reducing agent.

Any compound that spontaneously evolves oxygen either at room temperature or under slight heating is called an oxidizing agent. The term includes chemicals such as peroxides, chlorates, perchlorates, nitrates and permanganates. These can react vigorously at ambient materials such as cellulosic and other organic compounds. (See also Oxidation.)

Oxisols

Oxisols is one of twelve soil orders (US). These soils are fertile and rich in iron, aluminum oxides and kaolinitic clays. The mineral soils that have an **oxic horizon** within 2 cm of the surface or plinthite as a continuous phase within 30 cm of the surface, are oxisols; they do not possess a spodic or argillic horizon above the oxic horizon. Oxisols occur in humid tropical climates and need to be fertilized and limed for good crop yields. Oxisols may be highly productive for grain, tuber and oil crops.

Oxisols have low activity clays and are nutrient-poor. They have a weakly buffered system that has little or no horizon differentiation. This reflects their (a) high weathering intensities in low altitude humid environments, (b) geomorphic stability and age, associated with pre-Cambrian platforms, and (c) development from polycycled pre-weathered parent material derived from highly weathered terrestrial source areas.

Oxygen

Oxygen (O) is an odorless, colorless, gaseous element that belongs to group 16 (formerly group VI) of the Periodic Table (Fig.O.4). It is the most abundant element in the earth's crust (49.2% by weight), is present in the atmosphere (20% by volume) and is a constituent of water. It exists in three isotopes 16, 17 and 18. Oxygen is essential for respiration of most living organisms and for combustion. It is used in metallurgical processes, in high temperature flames (welding) and in medical treatment.

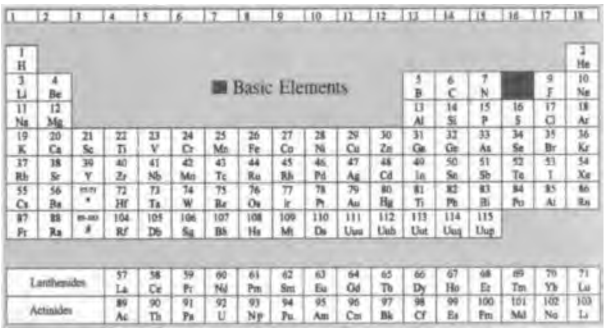


Fig.O.4: Position of oxygen in the Periodic Table.

The common form of oxygen is di-atomic oxygen (O_2). There is also another form - reactive allotrope ozone (O_3). Chemically, oxygen reacts with most other elements forming oxides. For industrial use, it is obtained by fractional distillation of liquid air. This has been replaced by a process which utilizes ambient temperature separation by means of a pressure cycle in which molecular sieves of synthetic zeolite preferentially absorb nitrogen from air, giving 95% oxygen and 5% argon.

The most popular industrial use of oxygen is in oxygen enrichment of steel blast furnaces. Large quantities of oxygen are used in the synthesis of nitric acid from ammonia, methanol and ethylene oxide, as also in oxy-acetylene welding.

Almost all life depends on chemical reactions with oxygen to produce energy. Animals receive oxygen from air, as do fish from water. The amount of oxygen in the air remains constant because of photosynthesis in plants and the decomposition of water vapor by the sun's ultraviolet rays in the upper atmosphere. This phenomenon is known as **oxygen cycle**.

Oxygen cycle: See Oxygen

Oxygen diffusion rate

Oxygen diffusion rate (**ODR**) is the rate at which oxygen in the soil-air diffuses and equilibrates with atmospheric air. Large soil pores facilitate the ODR, while small pores and water-filled pores restrict it. The ODR declines as soil depth increases. Oxygen diffusion at the rate of more than 0.004 $g/m^2/sec$ is good enough for the growth of most plant roots and micro-organisms. In deep clayey sub-soil, the pores are small, and hence, the ODR is low which results in slow root growth. When pores are filled with water, oxygen diffusion is further reduced.

Ozone

Ozone (O_3), which is triatomic oxygen and measured in Dobson units, is a blue gas with pungent odor. Ozone is made by subjecting oxygen to a high-voltage electric discharge. It is used for killing germs, bleaching, removing unpleasant odors from food and sterilizing water. It is a powerful oxidizing agent and decomposes rapidly above 373° K.

The upper atmosphere contains a layer of ozone, formed when ultraviolet radiation acts on oxygen. It protects the earth from the sun's ultraviolet rays. In recent years there has been significant reduction in the amount of atmospheric ozone. This is due to the discharge of chlorofluorocarbons (CFC) into the atmosphere (both the troposphere and the stratosphere), which are widely used in refrigeration, insulating foam, solvents, aerosol propellants, and chlorine and bromine gases. These remain in the atmosphere for long periods and destroy the ozone layer.

Scientists predict that as the ozone shield thins and allows more ultraviolet radiation to reach the earth, there could be an increased incidence of skin cancer and eye disease among humans, and could cause damage to marine life, crops and forests.

The Montreal Protocol, ratified by 183 countries (by 2002), called for freezing the use of chlorofluorocarbons at the 1986 level, and then rolling back the production in a phased manner. Developed countries have been responsible for the overwhelming contribution toward use of ozone depleting chemicals. With stronger political will, many countries have phased out use of most of the CFCs, halons, methyl bromide and other substances. Developing countries are committed to reducing their CFC production and consumption by 85% in 2007. Regular reviews by United Nations Environmental Program (UNEP) and other world bodies consider that implementation of the Montreal Protocol's provisions are on the right track. Data emerging out of such reviews suggests that atmospheric concentrations of CFCs have declined paving the way for a possible corresponding decrease in global warming. But on the other hand, use of other ozone-depleting substances such as HFC (hydrofluorocarbons) and HCFC (hydrochlorofluorocarbons) have been on the rise, causing concern on the future of the ozone layer.

More recent evidence reveals that the Antarctic ozone hole has increased in size and measures 10.6 million square miles. And although some scientists believe that this rate is not as rapid as during the 1980s and that a future Arctic polar ozone hole seems unlikely, many experts consider this as an issue that demands serious attention.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

P

Paddy

Paddy is the rice grain along with the husk. The origin of the word is in the Malaysian language where it is called *Padi*.

Paddy is principally a tropical crop, grown extensively in South and East Asia. It requires high temperature and humidity for growth. About 93% of the rice area lies on both the sides of the equator up to 40° latitude and between 80°E and 140°E longitudes. The distribution of paddy crop depends more upon climatic than soil conditions. For optimum growth of rice, the ideal temperature is in the range of 20 to 37°C. Considering the requirement of climatic conditions for paddy cultivation, it is grown in four different seasons as given in Table-P.1.

Table-P.1: Main cropping seasons of rice

No.	Season	Sowing period	Harvesting period	Duration in days
1	Aus or Autumn Paddy	May/June	September/ October	100–110
2	Aman or Winter Paddy	June/July	November/ December	140–180
3	Boro, Dalua or Spring Paddy	December/ January	March/ April	100–110
4	Summer Paddy	February/ March	June/July	110–120

The extent of water availability largely determines the method to be adopted for rice cultivation. The methods are classified under (a) dry cultivation, (b) semi-dry cultivation, (c) wet cultivation, and (d) intensive cultivation, popularly known as the **Japanese method of paddy cultivation**.

The right stage for harvesting paddy is when the ears are nearly ripe and the straw is still slightly green. If the harvesting is delayed till the crop is completely ripe, grains may shed and the milling quality could be affected.

The rice grain is made up of three main layers namely the hull or husk (which contains the lemma and palea), the bran layer, the germ layer, and the endosperm or the kernel. After removing the hull (say, by milling) rice becomes edible. Dehulled rice looks brown and is called **brown rice**. It retains the nutrition of the cereal.

Milling of brown rice removes the entire bran and most of the germ layer. This creates unpolished **white rice**. Further processing involves polishing this rice. Polished white rice (Fig.P.1) removes the essential fat component (aleurone layer).

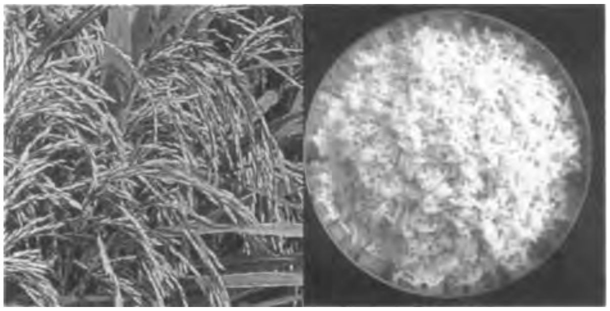


Fig.P.1: Paddy in field (left) and polished rice.

Rice is classified into various categories depending on the size, variety and processing methods.

Rice is stored as dried paddy or rough rice and milled only when needed for immediate use or sale. Stored as paddy, rice is protected by pesticide sprays or powders. The storage of up to 3 to 4 months improves the cooking quality. During that period, rice absorbs moisture, expands and becomes flakier than freshly harvested rice.

PAHs

PAHs is short for polycyclic aromatic hydrocarbons. (See also Persistent organic pollutants.)

Palmer index for determining drought

In the 1960s, Wayne Palmer developed a model to determine drought. It has come to be called the Palmer drought index or Palmer drought severity index.

The Palmer index uses past information on temperature and rainfall to determine long term drought, spanning over several months, to further arrive at some parameters of precipitation and dryness. The value 0 represents normal for both rain and dryness. Drought is indicated by minus numbers, for example, –2 is moderate drought and –4 is extreme drought. Similarly, rains are indicated by positive numbers, for example, 2 is moderate rainfall, etc.

Palmer index has been used by government agencies as a basis for analyzing drought conditions. The advantage of the index is in its standardization and local adaptability. It is useful in determining long-term droughts. However, it cannot give short-term forecasts and does not take into account water locked up in snow. (See also Drought.)

Pan

Pan, also called **hardpan** or **sole**, is a hard stratum of strongly compacted soil caused by continual plowing to the same depth of hardened soil which has high clay content. The precipitated iron and silicates cement the soil particles and form pans. Pans often impede drainage and root growth. Pans can be broken up using a sub-soiler.

Pan granulation of fertilizer

The granulation of fertilizers is one of the most significant advances in fertilizer technology. Granulation improves the storage quality and nutrient release quality of a fertilizer. It is advantageous to both the manufacturer and the user.

Granulation processes can be classified by the nature of the feed material to be granulated (solids, slurries, melts) and by the types of granulation equipment used. The most important devices used are the (a) pugmill, (b) rotary drum, (c) TVA ammoniator-granulator drum, (d) spherodizer, (e) SAI-R drum granulator, (f) inclined pan granulator, (g) fluidized-bed granulator, and (h) air-cooled prilling tower.

Pan granulation is fertilizer granulation using a rotating shallow inclined pan which carries powdered or pre-melted material. During granulation, the rotation of the pan and the force of gravity push the fertilizer powder into a spiral path. The particles grow and eventually reach the bed surface. Concentrated salt-melts of urea, ammonium nitrate or calcium nitrate can be processed in the pan granulator.

For producing granular superphosphate, phosphoric acid is added to digest finely-milled crude phosphate in a granulator. The relationship between the critical rotation speed, pan diameter and inclination is the same as for the drum granulator.

The throughput (m) of a pan granulator (tons/hour) is calculated as:

$$m = R \times 1.5d^3$$

where R is a constant varying from 0.95 to 1.11 for a mixed fertilizer and d is the pan diameter in meters.

Panicle blast of rice

Panicle blast is another name for **leaf blast in rice**.

Panicle initiation

The cereal growth stage at which inflorescence or visible panicle emergence occurs is known as panicle initiation (Fig.P.2). It indicates the beginning of the reproductive stage of the plant. Knowledge of these growth stages is useful in deciding the proper time for such agricultural operations as top dressing of nitrogen, application of herbicides, insecticides and fungicides. Knowledge of the growth stage is also useful in many physiological studies, such as yield pattern, plant sensitivity to environmental factors, etc. In cereals, the reproductive and the ripening stages are more sensitive to water deficiency than the vegetative stage. In wheat, the embryo ear has its full complement of spikelets well before the ear emerges from the flag leaf sheath, which must be a consideration for increasing the spikelet number.

Fig.P.2: Panicle initiation or cob emergence in cereals is seen at the flag leaf stage and is the beginning of the plant's reproductive stage.

The most common method for identifying growth stages in cereals is the **Feekes scale**, based on the external appearance of the plant or plant organs. The growth cycle of cereals is divided into 10 stages, each being subdivided into secondary growth stages.

Pansukh

Pansukh (meaning drying of leaves) is an Indian word for a disease-like condition in the rice crop, the main cause being multinutrient imbalance It is caused by an imbalanced ratio of potassium to nitrogen (K/N) and of iron to manganese (Fe/Mn), or by a low potassium content.

The disease is visible in the form of a reddish yellow coloration of the leaves, starting from the tip. In severe conditions the affected plants dry up. The development of roots and tillering is poor. Flowers are mostly sterile, and the head, if produced, is light.

To prevent the disease or to minimize its intensity, excess water in the field is drained away. Light irrigation at short intervals is given as required. Application of ammonium sulphate at 13.5 to 22.5 kg/ha helps minimize the disease.

PAPR

PAPR is short for **partially acidulated phosphate rock**.

Parachute technique of rice transplantation: See Japanese method of paddy cultivation

Paragonite

Paragonite [$NaAl_2(AlSi_3)O_{10}(OH)_2$] is one of the most common types of micas. (See also Micas.)

Parapeaty horizons

Peat with low organic matter creates parapeaty horizons.

Parasite

Parasite is an organism that lives on the food ingested by its host. Parasites lodging on the exterior of their host are **ectoparasites** and those lodging in the internal organs or tissues of the host are **endoparasites**. **Obligate parasites** survive and reproduce only in or on a living host (Fig.P.3).

Fig.P.3: Cuscuta sp., a plant parasite.

Parasites usually adopt a very specialized way of life, involving one or several hosts; those on the human body include lice, various bacteria, protozoa and fungi, which cause many characteristic diseases. **Facultative parasite** is an organism which can live entirely on organic matter from the dead or decaying tissue of plants or animals (as **saprophyte**) but can also live as a parasite on a live host.

Destruction of the host reproductive organs by parasites is known as **parasitic castration**. The action of smut fungi in the grain of wheat or the conversion of stamens and carpels into petals in plants infested by nematodes are instances of parasitic castration.

Parasitic castration: See Parasite

Parenchyma

Parenchyma is a living plant tissue consisting of spherical or elongated, unspecialized, undifferentiated cells (Fig.P.4) which may vary in structure and function. Parenchyma tissue walls are made of cellulose, pectin and hemicellulose. These tissues are located in several parts of the plant. In herbaceous plants they are located in the central pith and the outer cortex of the stem.

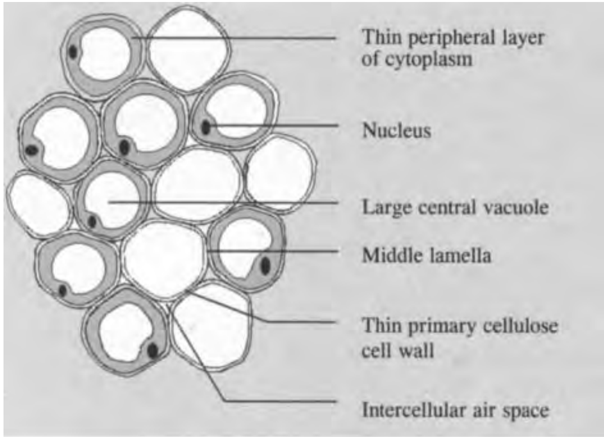


Fig.P.4: A schematic of parenchyma tissue.

Parenchyma has intercellular air spaces to facilitate a gaseous exchange between the living cells and the external environment. Its cells often store food. For example, the parenchyma cortex stores starch in potato tubers and its walls act as pathways for water and mineral salts to be transported through the plant.

Although unspecialized, parenchyma cells get modified and specialized in certain plants. Epidermis, mesophyll and endodermis are some modified parenchyma.

Parent material

A hard or loose rock from which a **solum** (or the layer above it) is formed directly or through an intermediate laterite is known as **parent rock**, or parent material. The term was coined by Belgian pedologists. Unconsolidated weathered mineral and organic matter are the parent materials of A and B soil horizons.

The changes undergone by the parent material are due to weathering or leaching and translocation. Any material that has not moved from its original location is called the **in-place parent material**; for example, bedrock (Fig.P.5).

The material from which a particular soil develops by weathering is the parent material of that soil. Soil development depends on the nutrient content and particle size of the parent material. While well-developed soils retain some properties of the parent rock, insufficiently developed soils retain most properties of the parent rock.

Fig.P.5: Parent material or bed rock (shown by an arrow), from which soil develops.

The parent material has a bearing on soil formation; for example, quartzose sandstone yields only quartz on disintegration. The resultant soil does not permit plant growth to any significant degree and thus limits the role of organic matter in soil formation. In contrast, weathering of basalt leads to the production of clays which support luxuriant vegetation and help accelerate soil formation. Soils generated from limestones tend to be alkaline, but the acidity produced by the decaying organic matter neutralizes it partially.

Rocks, minerals and deposits carried by flowing water, wind and ice combine to form different parent materials. The parent material mass has a distinct shape and characteristic particle sizes. Its minerals or organic masses are known as landforms. Familiar **landforms** are **mesas, butters**, **plateaus**, **plains**, **glacial moraines** and **terraces**. The sediments carried by the flowing water form floodplains and river terraces. Materials carried by wind (**eolian deposits**) form **loess**. Glacial deposits make glacial moraines. The downward movement of weathered rock particles under the force of gravity is called **mass wasting**. This causes the formation of **colluvium**.

Parent rock: See Parent material

Parnas apparatus

Parnas apparatus is a distillation apparatus used in the **Kjeldahl method** for determining the nitrogen content of the soil. During the first phase, nitrogen is transformed into ammonium sulphate [$(NH_4)_2SO_4$]. During the second phase of distillation, the sodium ion (Na^+) substitutes for the ammonium ion (NH_4^+). Ammonia (NH_3) is then collected and titrated in the third and final phase and the quantity of nitrogen is calculated as:

$$\text{Nitrogen (percent)} = \frac{\text{Ammonia content} \times 14}{17} \times 100$$

Partial drought: See Drought

Partially acidulated phosphate rock

Igneous phosphate rocks are sometimes unsuitable for direct plant uptake because of their poor solubility, requiring the addition of a more soluble phosphate form. Alternatively, a partial acidulation can be resorted to for rendering its phosphorus (P_2O_5) more available to plants. Crops respond to partially acidulated phosphate rocks (**PAPR**) in a manner similar to that of fully acidulated products, such as single superphosphate or triple superphosphate. Partially acidulated rock phosphate requires less acid; promoting an increase in its production.

The amount of water-soluble phosphate in PAPR varies based on the degree of acidulation. Approximately 10 to 20% acidulation has been suggested for upland crops and for soils with a pH of around 5.5 and a high phosphorus-fixing capacity. For soils with a low phosphorus-fixing capacity, 50% acidulation has been proposed, commonly using sulphuric and phosphoric acids. Three processes are known in the manufacture of PAPR, namely, (a) the conventional **run-off pile (RoP)** process followed by granulation, (b) a single-step acidulation and granulation process, and (c) a slurry granulation triple superphosphate-type process.

For economic reasons, sulphuric acid is used for acidulation and a run-off pile process of manufacture. Ground rock phosphate, sulphuric acid and water (if required) are fed continuously to a pugmill-type mixer. The retention time in the mixer is 30 to 60 seconds. Depending on the rock and the degree of acidulation, the product can be transferred directly from the mixer to a storage tank without curing or denning, stored for two weeks before reclaiming, and crushed to pass through a 4 mm screen before use.

Partial oxidation process for hydrogen production: See Ammonia production processes

Particle density

The density of the oven-dry soil particles (excluding air) is called particle density. It is also known as real density.

Particle size distribution of fertilizer

Until about 1950, fertilizers were available as fine, dusty powders or small crystals susceptible to hard caking during storage. They tended to create lumps which had to be broken before being applied. The successful development of granular fertilizers has helped improve their storage, handling and application through appropriate equipment.

The particle size distribution of fertilizer products or fertilizer raw materials is defined as the range of particle sizes (diameters) of the material in a given sample of fertilizer. The particle size is typically analyzed by **sieving (screen analysis)** which involves separation of particles according to their size fraction.

First, sieves with their apertures increasing in size from bottom to top are stacked. The sample is placed in the uppermost sieve of the stack. It is then shaken in a controlled manner, during which each particle of the sample gravitates downward through the screen apertures until it reaches a screen with apertures too small to let it pass further. At the end of the specified shaking period, the material on each screen is weighed individually and compared with the original weight to ascertain the particle size distribution of the sample. When a **sieve analysis** of micron-sized raw material particles is required, a **wet sieve analysis** using a **wet sieve shaker** may be necessary.

The fertilizer particle size distribution affects agronomic response, granulation, process performance, application properties, storage, handling, blending properties and aggregate analysis, as described below.

(i) Effects on agronomic response: Fertilizers of very low water solubility are ground to ensure their rapid dissolution in the soil solution and utilization by plants. For example, the effectiveness of raw phosphate rock generally increases, as the material is ground to a particle diameter of about 150 μm. Micronutrients or secondary nutrient sources of low solubility (such as sulphur, metallic oxides and frits) also require fine grinding; the smaller the particle, the higher the nutrient availability and the release. However, excessively fine grinding often leads to handling difficulties. To overcome such difficulties, measures for dust control may be taken, such as spraying pulverized materials lightly with oil, water or amine formulations.

(ii) Effects on granulation and process performance: For granular NPK products, two methods are employed: the **agglomeration process** and the **slurry-based nitrophosphate-type process**. In the agglomeration process, the initial and final mechanical strengths of the agglomerated granules are obtained by mechanical interlocking or by fitting individual particles. The particle size of the solid raw material and its distribution is very important. Normally, if the final product is in the range of 2 to 5 mm, the raw materials should be widely distributed within a range of about 0.2 to 3.0 mm. A dry granulation process in which mixed raw materials are agglomerated by pressure gives compacted fertilizers.

(iii) Effects on storage, handling and application properties: Control on the particle size of fertilizers is important to ensure their satisfactory storage, handling and use.

The size of an average granular fertilizer product is around 1 to 3.5 mm. The Association of American Plant Food Control (AAPFC) defines a **granular fertilizer** as follows: 95% or more of the product is retained on a series of sieves with sieve openings in the range of 4.75 to 0.850 mm; in this range, the largest particle passes through the sieve having an opening of not larger than four times the sieve opening which retain 95% or more of the product. According to the European and Japanese definition of granular fertilizer, the granules are generally in the range of 2.0 to 4.0 mm.

(iv) Effects on blending properties: With the advent of bulk blending as an important system of mixing and distributing fertilizers, the particle size has assumed importance as a method for reducing the segregation tendency of the blends. Mismatched particle sizes in raw materials used for blending can result in segregation, mainly by vibration, coning and ballistic action.

Fertilizers get vibrated during transport. Normally, vibration does not segregate fertilizer blends, unless the blended ingredients are so diverse in size that the particles of one ingredient shift downward through the void spaces among the larger particles. Smaller particles in the fertilizer, which are retarded by frictional resistance of the pile surface, tend to remain behind and come to rest, whereas larger particles continue to travel further down the pile surface before coming to rest.

When a fertilizer is propelled through the air, by a fan-type fertilizer spreader, particles of different physical properties follow different paths, because of the varying effects of gravity and air drag. The result is segregation due to ballistic action. The particle sizes of the blended ingredients must match, if the segregation by ballistic action is to be minimized.

The fertilizer particle has a much greater effect on ballistic segregation than on particle density. This is because of the relative effects on the weight (and thus on inertia) of the moving granules. Increasing the granule diameter from 1.18 mm to 3.35 mm increases the granule weight more than twenty-fold, whereas the usual range of granule density changes from 1.3 to 2.7 g/cm^3 which is only a two-fold increase. Air drag is less on a small particle, and is reduced only in direct proportion to reduction in the particle diameter.

(v) Aggregate analysis: Primary particles, like clay, tend to adhere under natural conditions to form secondary units called **aggregates**. The ability of wet aggregates to resist breakdown should be high to let air and water quickly permeate to the plant roots. The size distribution of soil aggregates is important because it determines their susceptibility to movement (erosion) by wind and water. The stability is significantly correlated with crop yields, when other conditions are equal.

Particle transport

Soil particles detaching or separating from soil mass is the first step in soil erosion. The detached soil particles get physically carried from their original place by wind or water. This phenomenon is called particle transport.

Parts per million: See ppm

Pascal

Pascal (Pa) is a unit of pressure in the SI system, and is defined as the pressure exercised by a force of one **Newton** over an area of one square meter (1m^2). The kilopascal (kPa), or 1000 Pa is 1/100th of a bar. One atmosphere is equal to 1,01,325 pascals.

Passive absorption

Passive absorption refers to the movement of water resulting from the pulling forces on the water column into the roots of the plants. It compensates for the water lost by transpiration. It is the absorption of water by plant roots without any carrier or energy.

Passive ion uptake

Plants take up nutrients only in the ionic form (they absorb ions from the soil). The ions move with water to the plant roots passively, from a higher to a lower concentration, or down the chemical gradient of the potential energy.

The sodium ion uptake by roots is an example of passive ion uptake.

pC

pC is the negative logarithm of electrical conductivity of a solution. It allows calculation of the assimilability of nutrient salts. By measuring the electrical conductivity, we can characterize certain groups of soils (especially saline soils) on the basis of salt content and salt movement in the profile.

Pdff

Pdff is an acronym for **phosphorus derived from fertilizer**.

PE

PE is short for **potential evapotranspiration**.

Pea rhizobia

Bacteria belonging to the genus *Rhizobium*, have many strains. In the symbiotic association with leguminous plants, rhizobia enter the root hairs, multiply at the roots and form nodules on the roots in which they fix nitrogen. The fast-growing and acid-producing species mainly form nodules on the roots of the pea group of legumes. These strains are commonly known by different names; one of them being pea rhizobia.

Pearls of plant food

Ammonium nitrate is among the most common of nitrogenous fertilizers. It contains 32 to 35% nitrogen by weight and is usually available as white granules or prills of 1.2 to 3 mm size. These prills or granules are sometimes called pearls of plant food.

Peat

Peat is a mass of dark-brown or black fibrous debris, produced by partial disintegration of vegetation in wet places. It varies from a light spongy to a dense brown humified mass. When buried under pressure and heat, it forms coal over a geological time period. Peat is used to improve aeration and water retention of the soil. The raw materials for peat fertilizers are highly decomposed **upland moor peat (black peat)** or **acidic low moor peat** (pH <7).

Acid peat is a decomposed plant material containing 54% carbon. It can develop in water bodies that are calcium deficient. The carbon to nitrogen (C/N) ratio in peat is about 40. Such peat has a high sorption capacity. Depending on the kind of application, the crop being grown, and the nutrient status of soil, several mixtures of peat and mineral fertilizers are available. Land with a high level of peat is called **peat land**; it is generally found at the base of valleys. Similar mixtures of organic and mineral fertilizers are available, based on **composted bark** or lignite (which is a partial substitute for peat) and other organic materials such as a **dried slurry** or **spent mushroom substrate**.

The following minimum requirements of nutrient content in peat are specified as 1% nitrogen, 0.5% phosphorus, 0.8% potassium and 15% organic substance. The organic substance of composted bark is highly stable against biological degradation, and resembles peat. Threshold values for heavy metal concentrations are also specified for peat mixtures.

Types of peat are distinguished according to the degree of decomposition and transformation of the plant debris. They are (a) fibrous peat (**fibrist**), (b) **altered peat (saprist)**, and (c) **semi-fibrous peat (lenist)**. The identified categories of peat, depending on the environment, are (a) **calcic peat** (mesotrophic and eutrophic), and (b) **acid peat** (oligotrophic).

When organic matter is low in peat, it results in **pseudo peat**, **parapeaty horizons** and humiferous pseudopeats. The unconsolidated soil material containing non-decomposed organic matter is the **peat mass**.

Peat based inoculant

Peat based inoculant is a type of inoculant. Microbial cultures are mixed with peat and the mixture is used as an inoculant for seed or soil inoculation.

Peat, coco

Coco peat, also known as coir fiber pith or coir dust, is a by-product produced by the coconut industry in Sri Lanka, India and Indonesia. It is a natural and reusable resource produced when coconut husks are processed for the extraction of their long fibers (Fig.P.6). Coco peat is the fiber fraction of the coconut husk.

The coir dust is washed, heat treated, screened and graded before being processed into various coco peat products for horticultural and agricultural applications (Fig.P.7).

Coco peat was first introduced to English horticulture as a growing medium, more than 135 years ago. It is becoming increasingly more popular the world over because of its ecological benefits.

Coco peat is a multi-purpose soil conditioner and a growth medium. It is consistent, uniform in texture, and is a completely homogeneous material composed of millions of capillary micro-sponges that absorb and hold water up to eight times their own weight. Its natural pH of 5.7 to 6.5, unusually high cation exchange capacity and good water holding capacity (27% of the readily available water) facilitate the release of nutrients in solution over extended periods (especially in conditions of water scarcity).

Coco peat is a totally organic and reusable product. It does not pose a threat to, other ecological systems. Using coco peat helps save precious water resources.

Coco peat is a proven natural alternative to mined peat moss. Its use can help to slow down peat extraction from environmentally sensitive swamps worldwide. Used as a growing medium, coco peat outperforms peat and sphagnum peat.

Fig.P.6: Coco peat is a reusable and natural product of the coconut industry.

Fig.P.7: Coco peat comes in various grades depending on application.

Peat land

Land with a high level of peat is called peat land. It is generally found at the base of valleys.

Peat mass

Unconsolidated soil material containing non-decomposed organic matter is **peat** mass.

Peat scours

Molybdenum, if present in excess of the prescribed limits, causes toxicity. It can result in stunted growth and bone deformation in animals. This disease is known as peat scours in New Zealand.

Peat soil

Like all organic soils, peat soil is designated as histosols. It is never saturated with water for more than a few days and has more than 20% carbon from undecomposed or slightly decomposed organic matter.

Peat soils are usually calcium deficient and difficult to manage. Fertilization, liming and drainage are necessary for cultivating peat soil. Fertilizers make up for the deficient nutrients, while liming enhances the breakdown of organic matter and has a beneficial effect on the soil structure. This is because calcium ions (Ca^{2+}) help the individual particles to aggregate and improve the soil porosity, enhancing the infiltration of air and water.

Dal soil is the local name for peat soil in The Netherlands and consists of sandy subsoil covered with young peat layers.

Pechiney-Saint-Gobain process for ammonium phosphate nitrate

In the Pechiney-Saint-Gobain process, a slurry of concentrated (97%) ammonium nitrate solution and ammonium phosphate is used to produce ammonium phosphate nitrate in a rotary-drum granulator. The grade of the principal product is 17-17-0.

PEC process for nitrophosphate fertilizers

The PEC process, also known as the **carbonitric process**, has been used commercially for making **nitrophosphate fertilizers**. The process is of historical importance but is not used anymore because of, among other things, the absence of water-soluble phosphorus in the end product.

The PEC is a four-step process, and uses carbon dioxide to precipitate calcium. The following are the four steps: (i) Dissolve phosphate rock in nitric acid. (ii) Ammoniate the solution from the first step to precipitate all phosphorus as dicalcium phosphate, leaving the excess calcium in the solution as calcium nitrate. (iii) Add ammonia and carbon dioxide to convert calcium nitrate into ammonium nitrate and calcium carbonate. (iv) Granulate and dry the product. The final product consists of a mixture of dicalcium phosphate, ammonium nitrate and calcium carbonate. The grade is about 16-14-0. Phosphorus (as P_2O_5) is not water-soluble, but is almost completely citrate-soluble.

The main step of calcium precipitation using ammonia and carbon dioxide is:

$$Ca(NO_3)_2 + 2NH_3 + CO_2 + H_2O \longrightarrow CaCO_3 + 2NH_4NO_3$$

Pectin

Pectin is a high molecular weight polyuronide. It is related to the carbohydrate family and is present in fruits and berries.

Pectin occurs in varying amounts in fruits and plants. It contains carbon, hydrogen and oxygen, and on hydrolysis, yields glycosides and galacturonic acid. It can form a gel when it absorbs water.

Commercially, the primary source of the commonly used pectin is lemon and lime peel; other citrus fruits like orange and grapefruit may also be used. Pectin is widely used in the food industry, principally in gel preparation.

Pectin is also used in making drugs, protective colloids, emulsifying agents, etc.

Ped

Several substances cement soil particles together. The cemented particles forming different shapes are called **aggregates**. The natural aggregate of soil is called ped.

The extent of ped development relates to the strength of the failure zones. Failure of soil aggregates to remain cemented creates failure zones in the soil. Failure zones separate the peds and make them visible. They are soil structural units. For a granular soil structure, the term aggregate may be used interchangeably with ped. Peds of different shapes (prism, block or granule) indicate the type of soil structure. The soil class is determined by the ped size. The degree of cohesion of peds shows the grade.

Pedogenesis: See Pedology

Pedology

Pedology is the study of such aspects of the soil as its composition, distribution, formation process and utilization. It helps to extrapolate and scale up spatial variability from soil components to the population of soils.

Pedology is an integrative and extrapolative science. Several branches of fundamental sciences have made valuable contributions to this study, though the largest share of contribution comes from the applied sciences of agriculture and forestry. It provides an organizational framework to catalogue modes, mechanisms and magnitudes of spatial variability, and to generalize this knowledge base for the development of models.

Pedogenesis or genesis of soil refers to the phenomena and processes involved in soil formation, starting off with the initial material stage in the presence of organic matter and leading up to the final stage of the development of soil horizons.

Pedon

To classify and study the individual soil, a three dimensional body of soil is cut out, which is called a pedon and is the fundamental unit of soil. It has a minimum volume of the earth necessary to contain all the properties of that soil. Its depth goes up to the extension of the plant roots. Its lateral cross-section (which commonly ranges from 1 to 10 m^2 in area) varies according to the horizons contained in that soil. It permits the complete study of horizon shapes and relations. A **polypedon** is a group of similar pedons next to one another, which can be identified on a map and is used as a field classification or soil mapping unit.

Pedoturbation

Pedoturbation is the local cyclic movement of soil materials under the influence of fauna, flora, frost or thaw, swelling of clays and weathering of soil minerals. It also refers to the mixing of all soil components not caused by illuviation.

Peeler

Peeler refers to a plant which demands high value nutrients and which impoverishes the soil in the absence of fertilizers.

Pelletants: See Pelleted seeds

Pelleted seeds

The process of coating seeds is called **pelleting**. Rhizobia-inoculated seeds can get damaged if the soil is hot, dry and very acidic. Seeds are, therefore, coated with powdered lime or phosphate for protection from damage brought about by soil property, insects, etc.

While inoculating seeds, several materials like adhesives and neutralizing agents are required to be mixed with the inoculants. The neutralizing agents are known as **pelletants**; these agents can be calcium carbonate, ground rock phosphate, bentonite clay, milk powder, gypsum, etc.

Seeds inoculated with a biofertilizer are treated with powdered calcium carbonate or rock phosphate, shaken for a while, and dried in shade. Large quantities are processed in a mechanical mixer, and after removing the lumps, synthetic or Arabic gum is used for holding the layer of coating materials on the seed surface. Pelleted seeds can be stored for 2 to 3 weeks at about 4°C. Powdered gypsum, dolomite, superphosphate, basic slag and bentonite have been used as pelleting materials.

Pelleting: See Pelleted seeds

Pelletization of fertilizers

Pelletization of fertilizers refers to conversion of a powdered fertilizer into pellets for ease of application and handling. It also reduces the moisture absorption property of the fertilizer, and helps in its better utilization.

Pelletization is a significant advance in fertilizer technology and provides considerable advantage to both the manufacturer and the user.

Pellet application refers to a localized placement method in which pellets of a nitrogenous fertilizer are placed between two rows of paddy crop, at the depth of 2.5 to 5 cm. In another method, pelleted fertilizers and manures mixed with clay or cow dung are placed near the root zone. (See also Fertilizer granulation.)

Pellet placement: See Localized placement

Pelophos

Pelophos, which is equivalent to sintered **rhenania phosphate**, is a commercial phosphatic fertilizer produced by fusing basic slag (obtained from steel manufacture) with rock phosphate and sulphuric acid. It contains 17% total phosphorus of which 16% is citrate-soluble and 5%, water-soluble.

Pencil point disease of coconut: See Molybdenum

Peneplains: See Plains

Penetrometer

Penetrometer is a rod-shaped instrument for measuring the resistance to penetration of a needle or a rod in the soil. The penetrometer has a tip of known cross-section. This rod is driven manually into the soil with the tip being angled frequently at 30 degrees (to simulate root properties). A graphic recording system displays the depth attained by the rod and the resistance experienced by the rod in Newton/cm^2 (Fig.P.8).

Depending on the resistance, rods of different cross sections can be used. Penetration resistance is correlated with root growth, earthworm activity and tillage effects. When penetration resistance exceeds 2 MPa (Mega Pascals), the root growth is often reduced to half, while values higher than 3.0 MPa often simply prevent root growth. Since the penetrometer needle is not as flexible as the root, the readings quantify resistance in the vertical direction, integrate the impending effects and identify the causes. Penetrometer readings can be used to create maps of derived properties. The penetrometer is used to determine the degree of looseness and cohesion of the soil, compactness of the B_2 horizon, and that of plow pan, etc.

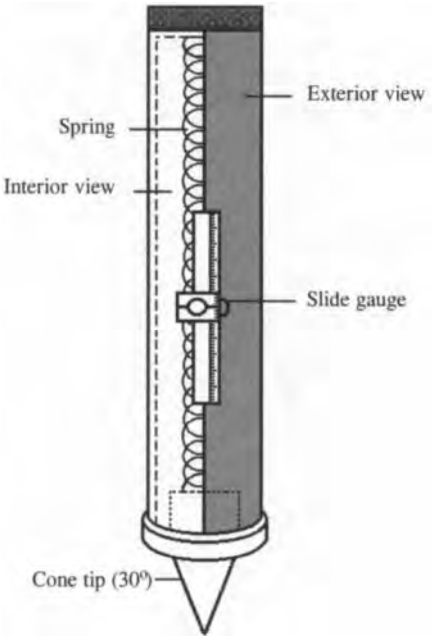


Fig. P. 8: Diagrammatic representation of a penetrometer

Penman method for evapotranspiration

The Penman method for roughly calculating the potential evapotranspiration (expressed in mm/day) is based on the evaluation of energy balance of the evaporating surface, and the heat exchange between the evaporating surface and its immediate environment by radiation, convection and conduction.

Penman proposed the following equation for evaporation from an open water surface (Eo) in mm/day:

$$Eo = \frac{\Delta Qn + YEa}{\Delta + Y}$$

where Δ is the slope of the curve of saturation vapor pressure versus temperature, Y is the psychometric constant or the ratio of specific heat of air to latent heat of evaporation of water, Ea is the aerodynamic component and Qn is the soil heat flux.

Pentoses

Pentoses are the ketoses which are a kind of sugar containing five carbon atoms.

Peptisation

Peptisation is another name for deflocculation, the process of dispersing a gel or a flocculated solid to a sol form.

Peraquic: See Hemist

Percentage yield concept

The concept of percentage yield is a way of evaluating the effect of inputs. In agriculture, it is the crop yield expressed as a percentage of the maximum possible yields. The yield potential is determined by calculating the effect of photosynthesis during the grain-filling period, after considering the respiratory losses and the material relocation assimilated before grain-filling.

The percentage yield is thus not the absolute yield produced at a given level of input, but a percentage of the maximum possible yield. It is useful in the soil test-crop response correlation work and is less sensitive than absolute yield. For rice, considering the growth in an environment where the daily amount of solar radiation received is 16.7 MJ/m^2 (assuming photosynthesis efficiency of 26%), and the net carbohydrate production in a 40-day grain filling period, the maximum possible yield would be 16.4 t/hectare. The actual yield in the same environmental conditions would be little more than 10 t/hectare. The percentage yield of rice would hence be

$$\frac{10}{16.4} \times 100 = 61\%$$

Percolation

Percolation is the downward movement of water through the soil profile. It is influenced by the soil texture and the presence or absence of hard pans.

Perennating organs: See Perennial crop

Perennial crop

Any plant that lives for three or more years is known as a perennial crop. **Woody perennials** (trees and shrubs) have a permanent aerial form which continues to grow year after year. **Herbaceous (non-woody) perennials** have aerial shoots that die down each autumn and are replaced each spring by new shoots from underground organs, such as bulbs, corms, etc. Lupin and rhubarb are examples of herbaceous perennials.

The survival of perennial plants from one year to the next is by vegetative means. This process is called **perennation**. In herbaceous perennials, the aerial parts of the plant die down and the plant survives by means of underground storage roots (carrot), rhizomes (couch grass), tubers (dahlia), bulbs (daffodils) or corms (crocus, gladiolus) (Fig.P.9). These **perennating organs**

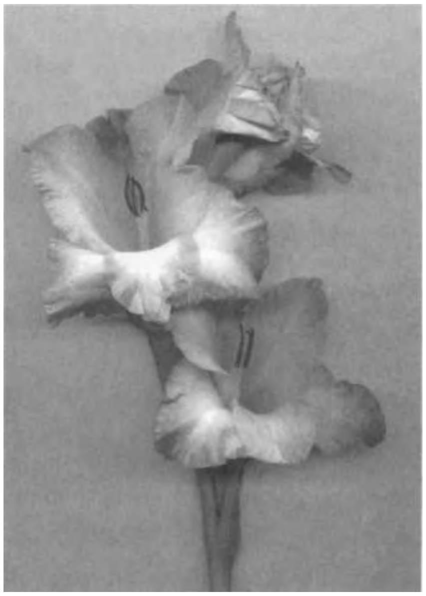


Fig. P. 9: Gladiolus, a perennial crop.

are also responsible for vegetative propagation. Woody perennials survive the winter by reducing their metabolic activity, like leaf loss in deciduous trees and shrubs.

Perfectly white Lambert surface

Albedo, a term describing the reflecting properties of surfaces, is the ratio of the radiant flux reflected by a surface to the incident flux. Normal reflectance, which strongly depends on the wavelength, is referred to as "a perfectly white Lambert surface," the latter being a surface that absorbs no light and scatters the incident energy isotropically. Magnesium oxide, magnesium carbonate and some other bright powders approximate this phenomenon.

Performance efficiency of machines

Performance efficiency refers to the quality of work done by a machine. For a harvesting machine, performance efficiency is a measure of the actual performance compared to the ideal or desired performance. For example, if a harvesting machine is to perform more than one operation (combine), the quantity (for example bushels) of grain harvested could be measured compared to the total baskets of grain in the field. The combines could also be evaluated according to the amount of the damaged grain or the number of cracked shells.

Periderm: See Cork cambium

Periodic Table

Periodic Table is a table of the chemical elements arranged in the order of atomic number, generally in rows, such that elements with similar atomic structure (meaning, similar chemical properties) appear in vertical columns. It is an arrangement of the chemical elements by symbols in a geometric pattern designed to represent the Periodic law by aligning the elements in Periods and Groups.

Twenty one elements of the Periodic Table fall in the categories of primary, secondary and micronutrients of plants. In addition, six or seven of them are essential elements but not nutrients.

The chief function of the Periodic Table is to serve as a fundamental framework for the systematic organization of chemistry.

Periodic tillage

Conservation tillage may result in low fertility in the root zone. Phosphorus and potassium accumulate in the upper layer of the soil (top 5 to 10 cm) in conservation tillage. Periodic tillage implies tilling of land occasionally like, for instance, plowing once in 4 or 5 years. Periodic tillage is desirable because it allows proper mixing of soil for distribution of nutrients throughout the plow zone.

Permafrost

When the mean annual soil temperature is below 0°C, the depth of soil that freezes in winter may exceed the portion of soil that can thaw or melt in summer. As a consequence, a layer of permanently frozen soil, called permafrost, may develop.

Permafrost ranges from material that is essentially all ice, to frozen soil which appears ordinary except that it is frozen and hard. The surface layer that thaws in summer and freezes in winter is the active layer where some vegetation can grow.

Permafrost is widespread in tundra regions and is generally characterized by the absence of trees. Low-growing shrubs, herbs and grasses grow on the soil with permafrost, if the temperature is above freezing point in the summer.

The base of the active layer is the upper surface of the permafrost or the permafrost table. The melting of frozen soil ice in summer results in wet soil conditions, even if there is little or no rainfall, because permafrost inhibits the downward movement of water from the soil. Alternate freezing and thawing of wet soil above the permafrost produces cryoturbation (movement and mixing of soil due to freezing and thawing).

Soil wetness from melting of ice and the irregular soil surface due to cryoturbation necessitates the distribution of utilities to buildings above ground level. Permafrost eliminates most groundwater movement, preserves organic remains, restricts or inhibits plant growth and aids frost action.

Permafrost is one of the primary factors in engineering and transportation in the polar regions.

Permanent hardness of water: See Hardness

Permanent soil solution

Permanent soil solution refers to capillary water moving through the soil pores from wet to dry areas under a hydrostatic gradient. It contains dissolved solutes, such as plant nutrients.

Permanent staining

Staining is a technique in which normally transparent cells or thin sections of a biological tissue are immersed in one or more colored dyes to make them more clearly visible through a microscope. Permanent staining is used for a tissue that is to be preserved for a considerable period of time; it does not distort the cells.

Permanent wilting

Permanent wilting is the percentage of soil water held at a pressure less than minus 15 bars. The water potential at this point is minus 1500 kPa or minus 15 bars and this can vary among plant species. The soil particles sometimes hold water so tightly that the plants cannot absorb it. As a result, plants wilt irreversibly and die. Permanent wilting can also lead to the death of the plant if it does not get water for a long period of time. It is also the state of a plant when it is unable to recover from moisture stress even in an atmosphere saturated with water vapor. Permanent wilting is also known as **permanent wilting**

point or the **permanent wilting percentage**.

The soil water content depends primarily on the ability of soil to transmit water. Although the wilting point water pressure is commonly taken as minus 15 bars, there is substantial variation among different plant species in their ability to resist soil drought. For instance, some plants survive well below the standard wilting point index.

Permanent wilting is obviously different from **transient wilting**. Transient wilting is observed commonly during mid-day, when evaporative water loss is maximal. Plants often regain their turgor at night after transient wilting. However, in some plants, wilting is a defense mechanism to avoid overheating, in which the leaves droop and move away from the sunrays. With sunset, the plant begins to transpire at the normal rate, and leaf cells regain their turgidity. A practical use of the wilting point and field capacity concept is the determination of the plant-available water range in the soil.

Permanent wilting percentage: See Permanent wilting

Permanent wilting point: See Permanent wilting

Permeability of soil

Permeability of soil is a property that allows movement of water through saturated soil, actuated by hydrostatic pressure encountered normally in natural subsurface water. Permeability depends on the size of the pores and their tortuosity. More nutrients are lost from highly permeable soil.

H. **Darcy** gave a simple **law for the flow of water through sand columns**. For the rate of flow of a fluid through a unit cross-section of a porous mass under unit hydraulic gradient at 15°C, Darcy's expression is

$$V = \frac{K+H}{L}$$

where V is the rate of flow in cm/h, H is the height of water column in cm, L is the height of the sand column in cm and K is the permeability coefficient with the dimensions of velocity. K is, therefore, called **filtration velocity**.

Freezing temperature changes the ease of this movement. Saturated soils do not allow water movement. The addition of organic matter to the soil makes permeability easy. A high sodium content in irrigation water can cause a severe permeability problem. Similar to the salinity problem, a low permeability results in a decreased water supply to the crop.

Persistence: See Hardness

Persistent leaf

There are many types of leaves, of which a persistent leaf is one that remains on the stem for more than one season.

Persistent organic pollutants

Persistent organic pollutants (**POPs**) are major environmental contaminants. They are of two major types - **organochlorines (OC)** and **polycyclic aromatic hydrocarbons (PAHs)**. Organochlorines are a class of chemicals which are compounds of chlorine and organic matter. Since chlorine, a poisonous gas, is extremely reactive in nature, its compounds also produce many by-products.

Most organochlorines are man-made and are constituents of synthetic fertilizers, pesticides and industrial waste products. Examples of OC are DDT, chlordane, dioxin (a by-product of P.V.C.), etc. OC type pollutants pose a major problem because they persist and continuously remain in circulation.

PAHs are the result of incomplete combustion of fossil fuels producing asphalt, coal tar, etc. They pollute water. Although they are POP, they are not as mobile and persistent as the OC type pollutants.

Pesticide

Pesticide is a substance which is used to kill pests as these are responsible for damage to crops or the well-being of humans and animals. Pesticides (Fig.P.10) are subdivided into categories such as **insecticides** (which kill insects), **herbicides** (which kill plants), **fungicides** (which kill fungi), and rodenticides (which kill rats and mice). A major question with all pesticides relates to the possibility of unfortunate environmental side effects. (See also Integrated pest management.)

Fig.P.10: A range of pesticides available commercially.

Petermann's solution: See Nutrient availability

Petrocalcic horizon

A horizon enriched with secondary carbonates, but indurated or hardened, is called petrocalcic horizon.

pF

pF is the logarithm to the base 10 of the water column height (expressed in cm), called **water potential**. It measures the suction or tension with which water is held by the soil. The force equivalent to a column is indicated thus: (a) 10 cm height of water in the column corresponds to pF=1, (b) 100 cm of water to pF=2, (c) 1000 cm to pF=3, and so on. The types of water based on water potential (pF) are as follows: (a) maximum water holding capacity (pF 1.0), (b) field capacity (pF 1.8), (c) normal water holding capacity (pF 2.5), (d) wilting point (pF 4.2), and (e) hydroscopic water (pF 4.7).

The normal water holding capacity range of pF in soils is 2.5 (field capacity) to 4.2 (permanent wilting point).

In the UK and some other countries, water retention is measured in pF units. The numbers of the pF scale are based on the force of a height (in cm) of a column of water equal to the forces with which the water is held.

PFR

PFR is short for **plant food ratio**.

pH

The pH or **potential hydrogen** is the negative logarithm or logarithm of the reciprocal of the hydrogen ion activity. pH is also called hydrogen ion concentration or **proton concentration**, and is given as:

$$pH = \log \frac{1}{a_{H^+}} \text{ or } -\log a_{H^+}$$

where a_{H^+} is the activity of the hydrogen ion and pH is the hydrogen ion concentration, indicating the degree of the soil acidity or alkalinity.

Specific processes that influence the pH of the soil solution are those relating to (a) dissociation of carbonic acid, (b) interaction between soil humus and aluminum hydroxy polymers, and (c) mineral weathering. An instrument called **pH meter** with a 0 to14 scale, measures the pH value. A value below 7 represents acidic, above 7 represents alkaline and 7 represents the neutral point.

Proton concentration is vital for all living organisms. It also has an impact on soils and soil constituents. A high **hydrogen ion** (H^+) **concentration** ($pH<4$) of soil constituents attack soil minerals, dissolve the metal cations out of the crystal lattice, and eventually lead to mineral degradation. Low soil pH affects root growth, and also affects the decomposition of organic matter.

High pH conditions (>5) suppress bacterial life, and favor fungal life. In many cases, high pH conditions lead to higher solubility of Al^{3+} and Mn^{2+} ions, causing toxicity in the soil. Such a situation leads to hampered plant growth as also the inhibited formation of ammonia and nitrate.

Aluminum reduces phosphate availability and is toxic to most crops, but some plantation crops (for example, tea and rubber trees) tolerate acidic conditions down to pH 4. Under alkaline conditions above 7.5, nutrients such as Fe, Mn, Zn, Cu and B are strongly bound to the soil and their availability is consequently reduced, causing deficiencies. The soil pH should be adjusted to the range appropriate for the soil and the crop.

There are two kinds of acidity – the **actual acidity** and **potential acidity**. The actual or active acidity is determined by the hydrogen ion (H^+) concentration in the soil solution, as measured by hydrogen ion electrodes. Actually, many more hydrogen ions are stored than those determined by hydrogen electrodes. This stored acidity is known as potential acidity. The solution and adsorbed hydrogen ions (H^+) are determined by titration with a base. Low pH levels can be easily overcome by liming with calcium-magnesium (Ca/Mg) oxides, carbonates and silicates.

The soil acidity is problematic in humid zones. Here, the hydrogen ion (H^+) formed in the upper soil layer replaces the adsorbed metal cations (Ca^{2+}, Mg^{2+}, K^+) which are then leached. The soil pH is determined in slurries with the soil to water ratio of 1:1 or 1:2.5. For example, 10 g of soil is added to 10 ml of distilled water in a beaker and stirred. The pH is recorded using glass and calomel electrodes before the suspension settles. There are variations in the pH values due to changes in the soil to water ratio; but the discrepancy is overcome by measuring pH in 1M potassium chloride (KCl) or 0.01M calcium chloride ($CaCl_2$).

Phase contacts in fertilizer caking

Fertilizer caking is caused by the formation of contact points among the particles. There are different types of contact points. Phase contacts are crystal bridges formed at the contact points between particles. In a stored fertilizer, there are continuous internal chemical reactions, dissolution or re-crystallization due to thermal effects. As a result, the most troublesome type of caking may take place.

pHc

The pHc is the pH of water when in equilibrium with calcium carbonate ($CaCO_3$), and is expressed as:

$$pHc = (pK_2 - pKc) + p(Ca + Mg) + pAlk$$

where pK_2 is the negative logarithm of the second dissociation constant of carbonic acid (H_2CO_3), pKc is the negative logarithm of a solubility product of calcium carbonate, p(Ca+Mg) is the negative logarithm of molar concentration of calcium (Ca) and magnesium (Mg), and pAlk is the negative logarithm of the equivalent concentration of carbonate plus bicarbonate (CO_3^{2-} + HCO_3^-). The pHc is determined at the same time as the pH of water to predict whether calcium carbonate ($CaCO_3$) precipitates in water, or if water can dissolve calcium carbonate ($CaCO_3$) when it passes through a calcareous soil. The **saturation index** (**SI**), originally developed for carbonate deposition in boilers, is related to pHc as follows:

$$SI = 8.4\ pHc$$

With pHc increasing, calcium carbonate precipitation decreases; no precipitation occurs at 8.3 to 8.4.

Phenolic foam as soil conditioner

Phenolic foams are synthetic **soil conditioners**. They are used by florists as a mounting medium or plant growth medium. Foamed polystyrene and foamed urea-formaldehyde resins are also used as soil conditioners. (See also Soil conditioners.)

Phenotype

Phenotype is a set of observable characteristics of an individual or group resulting from the interaction of its genotype with the environment. The physical characteristics can be structural, biological or behavioral in nature. The constitution of a trait and its manifestation differs from one individual to another. The individual variations among the same species is the result of the **genotype**, the environment and random variation. Examples of phenotypic expressions are size and color that vary between two individuals.

Phenyl phosphorodiamidate

Phenyl phosphorodiamidate (**PPD**) and **N-(n-butyl) thiophosphoric triamide (NBPT)** are urease inhibitors. When added to urea or an ammonia-containing fertilizer, they retard nitrification and urea hydrolysis, and prevent nitrogen loss. Both inhibitors lower ammonia concentration in flood water, resulting in lesser ammonia volatilization.

Philosopher's wool

An archaic name of zinc oxide is philosopher's wool.

Phlobaphene

Phlobaphene is a product of tannin oxidation. There are certain tissues with cells arranged parallel to each other, with their lumens containing phlobaphene. These tissues form older cortex and bark.

Phloem

The tissue that conducts food material in vascular plants from the site of production (notably leaves) to regions where it is needed (such as growing points) is called phloem. Phloem tissues support the plant parts in which they occur. Phloem may also include companion cells, parenchyma cells, fibers, sclereids, rays and certain other cells. As a vascular tissue, phloem is spatially associated with xylem, and together they form the vascular system (Fig.P.11).

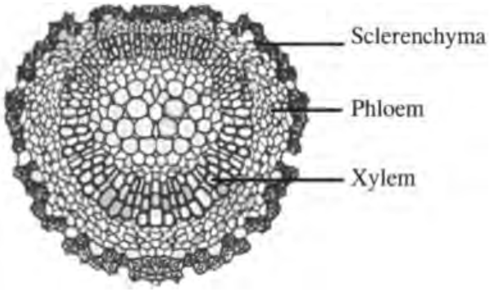


Fig.P.11: Cross-sectional schematic showing conductive tissues of the mid-rib of a leaf.

Phloem consists of hollow sieve tubes running parallel to the long axis of the plant organ and formed by end to end joining of the elongated cells (sieve elements). The end walls of phloem are adequately broken down to allow passage for materials. In young plants and newly formed tissues of mature plants, phloem is formed by the apical meristem. In most plants, **secondary phloem** is later differentiated from the vascular cambium which replaces the earlier, older one. (See also Translocation.)

Phlogopite

Phlogopite is one of the most commonly present micas and is denoted as $K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$. **Mica** is commonly found as small flakes or lamellar plates without a crystal outline. Thin cleavage sheets of mica, particularly **muscovite** and phlogopite, are elastic, flexible and tough. They range from translucent to transparent. They have low electrical and thermal conductivity and high dielectric strength, and hence are used as electrical insulators.

pH meter

A pH meter measures the concentration of the hydrogen ion (H^+) or acidity in an aqueous solution, suspension or paste, on a 0 to 14 scale. It consists of two electrodes, namely, glass electrode and calomel (reference) electrode. A **glass electrode** consists of a thin-walled bulb of pH sensitive glass, sealed to a stem of high resistance glass. The chemical reaction at the electrodes creates an electromotive force which can be measured as per Walther Nernst's equation. The pH meters are calibrated using a standard buffer before measuring the pH of the unknown solution (Fig.P.12).

The useful life of a glass electrode can be extended if it is kept moist when not in use.

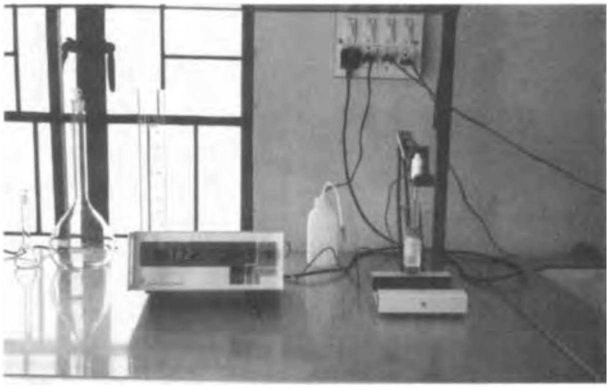


Fig.P.12: pH meter.

Phorophyte

Phorophyte or **epiphyte** is a plant that grows on another plant, without obtaining nourishment from it. Mosses, ferns, various types of lichens and orchids are epiphytes. They thrive in warm and wet climates.

PhoSAI for non-granular diammonium phosphate production: See Monoammonium and diammonium production processes

Phosphal

Phosphal is the trade name of a phosphate fertilizer extracted from an ore of aluminum phosphate. This ore was first found in Senegal.

Phosphal is a dark brown, finely-ground, calcined calcium phosphate fertilizer material. It has 34% phosphorus (as P_2O_5) which is 80% citrate-soluble. (See also Calcined phosphate.)

Phosphate buffering capacity

Phosphate buffering capacity is an index of the soil's ability to re-supply the phosphate ion to the soil solution. The availability of nutrients to plants depends not only on the concentration of nutrients in the solution but also (and more importantly) on the capacity of the soil to maintain the concentration. The buffering capacity involves all solid components in the soil system; thus, ions must also exist in soils as solid compounds, or be adsorbed to the cation or anion exchange sites. For example, with $H_2PO_4^-$, solid phosphate minerals dissolve to re-supply or buffer the solution.

Soil buffer capacity is the ratio of the concentration of the adsorbed ions to the solution ions; the ratio increases with the increasing **cation exchange capacity** (**CEC**) and is, therefore, related to the amounts and types of clay, minerals and organic matter in the soil. The addition of fertilizer phosphorus increases the anion-exchangeable dihydrogen phosphate ions ($H_2PO_4^-$) but more importantly, some $H_2PO_4^-$ precipitates as solid phosphorus compounds, contributing to the buffering capacity of the soil phosphorus.

Buffering capacity is a very important soil property which strongly influences nutrient availability and fertilizer management. The steeper the slope of the relationship between the quantity of the adsorbed nutrient and the concentration of the nutrient in solution, the greater the buffering capacity.

Phosphate excess

Generally, the phosphate or phosphorus concentration of 60 μmol/g dry matter and 30 to 50 ppm in nutrient solution is adequate for plant growth. Soil with a high oxide percentage of aluminum and iron has a high capacity for absorbing soluble phosphates; leading to phosphate or phosphorus excess in such soils. The phosphorus excess may not show any direct effect on the plant but may interfere with its metabolism. Excessive phosphorus causes deficiency in micronutrients such as zinc, iron and manganese, and affects normal calcium nutrition, making calcium deficiency visible. In a plant leaf, more than 1% phosphorus is considered high, even toxic.

Phosphate fertilizer: See Available forms

Phosphate fixation

The process of soluble ion $H_2PO_4^-$ rapidly reacting in soil to form insoluble phosphate is called phosphate fixation. (See also Phosphorus; Precipitated phosphate.)

Phosphate industry, an environmental perspective

The immediate and very substantial benefits accruing from increased chemical fertilization led to setting up of fertilizer plants all around the world. Geographical locations where natural deposits of minerals are located, have thus become major production hubs. Florida, Garrison and Montana are major centers of the phosphate industry. However, massive industrial production of phosphate has proved to be hazardous to the environment.

Raw phosphate ore contains high concentrations of fluoride (around 3% of the ore). Additionally, toxic gaseous compounds, such as hydrogen fluoride and silicon tetrafluoride are released in the process of extracting phosphate out of the ore.

Emission of gaseous fluorine compounds in the form of gas, smoke or dust from the phosphate industry (especially superphosphate) causes fluorosis, a disease that affects livestock in and around the production site. Such emissions cause drastic reduction in grain production, and damage to crops and natural vegetation around the site.

In 1970, a United States Department of Agriculture (USDA) report indicated that airborne fluorides have caused more damage to domestic animals than any other air pollutant.

To curtail problems caused by fluoride gases, air pollution control devices aimed at preventing the gas from escaping have been in use. These are called "**wet scrubbers**". However, although the escape of fluoride gas is thus prevented, silica combines with the fluoride, forming hydrofluorosilicic acid and sodium silicofluoride. These toxic silicofluoride complexes, considered a waste, are just dumped in piles into wastewater ponds around the plants, without recovering the fluorine from them which is in great demand.

Much of this toxic waste is used as a water fluoridation agent in drinking water. One study estimates that 200,000 tons of silicofluorides are used every year in water treatment facilities. Such a use of known toxins in drinking water is reported to have elevated the level of lead in children's blood. There are contrasting views on the status of the silicofluorides when they are diluted with water. Some scientists believe that silicofluorides dissociate into free fluoride ions, leaving behind no residue. Others refute this view and insist that the complex acts even as an inhibitor of vital enzymes that control the functioning of the central nervous system.

The scrubbers contain, besides silicofluorides, toxic impurities, such as arsenic, lead, etc. Arsenic in the silicofluorides can be as high as 1.6 ppb whereas the U.S. Environmental Protection Agency's goal is to reduce the arsenic level to 0 ppb.

In the process of manufacturing commercial phosphatic fertilizers, phosphogypsum slurry is created. It is disposed of in piles or stacks into acidic wastewater ponds around these plants. This gypsum is radioactive in nature because of the presence of uranium (and radium) in the phosphate ore. The concentration of uranium in the phosphate gypsum waste is much higher than in phosphate rock. Additionally, radon gas (from the breakdown of radium-226) is formed, which spreads to large areas and is a threat to life. Lung cancer and leukaemia rates have reportedly increased in areas around the plants.

Phosphogypsum, therefore, cannot be used in the construction industry. Its piles keep getting higher and higher, occupying large land areas and posing a big threat to the soil, water, animals and people in the area.

A possible use of phosphogypsum could be for land fills, road building and as a soil conditioner. Such uses would need to be legalized. The earlier the disposal avenues are finalized, the faster would be the reduction of pollution levels.

Aware and wealthy economies have some built-in checks and balances in their system for pollution control; yet many aspects of the environment remain unaddressed as detailed above. In the developing world, the situation is generally worse as it takes great political will and stupendous economic might to focus on the supposedly "softer issues" like pollution and environment. Thus, the extent of damage caused to the environment in the developing world is unfortunately quite significant.

Phosphorus fertilizers may contain some heavy metal impurities like cadmium (~ 50 mg cadmium/kg of phosphorus). WHO has limited the daily intake of cadmium to 1 microgram/kg of body weight/day. Cadmium contributed from NPK is 80 microgram/kg of fertilizer on dry weight basis compared to around 225 microgram/kg from farmyard manure.

Phosphorus also significantly contributes to the eutrophication process of surface waters and the threshold is considered to be in the range of 0.020 to 0.050 ppmw of phosphorus. The high phosphorus content in the sewage water is due to detergents, animal wastes and plant residues. Phosphorus from fertilizers reaches surface waters mostly by erosion and hence, to prevent losses, soil erosion control measures should be undertaken.

Phosphate ore beneficiation: See Floatation of phosphate rock

Phosphate potential

Phosphate potential is the chemical potential of soil that indicates the availability of phosphorus in the soil. The potential is that of monocalcium phosphate given by (1/2 pCa + $pH_2PO_4^-$) and is measured from the pH and phosphorus concentration in a solution of 0.01M calcium chloride ($CaCl_2$) equilibrated with the soil. According to Schofield, who developed this method, it is not the amount of the available phosphorus in the soil that controls its uptake by the plants, but the work which is required to get it from the soil pool. The major advantage of this method is that the evaluation is not dependent on any arbitrary method or procedure.

Phosphate reaction product

When a water-soluble phosphate fertilizer is applied to soil, it reacts with Ca, Fe or Al ions in the soil solution and precipitates as insoluble phosphate, or gets adsorbed on the surface of clay particles. This process is known as **phosphate fixation** or **reversion of phosphate**, and the compounds formed are known as the phosphate reaction products. The ionic forms of inorganic phosphorus are pH dependent.

Phosphate rock

Phosphate rock is a source of phosphorus, its most naturally occurring raw material being apatite. It is the starting material for all phosphorus fertilizers and contains 27 to 41% phosphorus as P_2O_5. (See also Rock phosphate.)

Phosphate rock floatation

Phosphate rock floatation is a technique used for the removal of impurities from rock phosphate and also for upgrading low grade ores. (See also Floatation of phosphate rock.)

Phosphate rock selection: See Phosphoric acid production processes

Phosphates

Salts based on phosphorus (V) oxyacids with alkali or metal oxide, and in particular, salts of phosphoric or orthophosphoric acid (H_3PO_4) are called phosphates. There also exist many polymeric phosphates containing P-O-P bridges formed by heating free acid and its salts under a variety of conditions. The fused and non-crystalline phosphate products are available for use in fertilizers, as are linear polyphosphates, cyclic polyphosphates and cross-linked polyphosphates or ultra phosphates.

Phosphates are applied to the soil as **phosphatic fertilizers** to supply phosphorus to crops. Certain organic phosphates are used as insecticides.

Phosphate slag: See Basic slag

Phosphate solubilizing micro-organisms

Soil bacteria, especially those belonging to the genera *Pseudomonas* and *Bacillus*, and fungi belonging to the genera *Penicillium* and *Aspergillus* are able to solubilize insoluble soil phosphates by secreting certain organic acids (namely, formic, acetic, propionic, lactic, glycolic, fumaric and succinic acids) which bring down the pH and solubilize the bound forms of phosphates. These micro-organisms are called phosphate solubilizing micro-organisms (**PSM**). Some of the hydroxyacids may chelate with Ca, Al, Fe and Mg, and provide better solubilization and usage of the soil phosphorus.

An endophytic fungal associate called arbuscular mycorrhiza (AM), is a common inhabitant of a number of plant roots and helps in phosphorus uptake. AM-infected plants increase nutrient uptake and utilize water more efficiently than non-infected ones. The other bacteria and fungi involved in phosphate solubilization are listed below.

(i) **Bacteria**: *Acromobacter* spp., *Bacillus* sp., *Bacillus polymyxa, Erwinia* spp., *Flavobacterium* spp., *Pseudomonas ratthonis, Pseudomonas* sp., *Pseudomonas striata, Thiobacillus thiooxidans* and *Xanthomonas* spp.

(ii) **Fungi**: Fungal isolates such as *Aspergillus awamori, Aspergillus niger, Aspergillus* sp., *Candida* sp., *Cladosporium* sp., *Curvularia lunata, Fusarium oxysporum, Penicillium digitatum, Penicillium* sp., *Pythium* sp., *Rhizoctonia* sp., *Schwanniomyces occidentalis* and *Sclerotium rolfsii* are known as the most efficient isolates.

The organisms listed above solubilize chemically-fixed soil and rock phosphates. Generally, phosphate-solubilizing micro-organisms can enzymatically mineralize organic phosphorus into its soluble form.

In 1950, in the erstwhile USSR, Menkina prepared phosphate fertilizers under the name of '**Phosphobacterin**', incorporating *Bacillus megatherium* var. *phosphoticum*, which was reported to give a 5 to 10% increased crop yield. Phosphobacterin was introduced in India where emphasis was on a higher utilization of the locally available, low-grade rock phosphate deposits. A significant increase in the yield was noted when wheat and rice were inoculated with *Penicillium striata* and *Bacillus polymyxa*, respectively, in the presence of rock phosphate at 100 kg phosphorus (as P_2O_5) / ha. For optimum results in agricultural yields, efficient phosphate-solubilizing organisms must be isolated and congenial conditions created, by devising better inoculation techniques and overcoming hostile soil environment.

Phosphatic fertilizers

Phosphatic fertilizers contain phosphorus. Many among them have phosphoric acid combined with calcium. Phosphate fertilizers are made from phosphate rock.

Different terms are used to describe the phosphorus content in fertilizers, such as the water-soluble, the citric acid-soluble and the citric acid-insoluble.

Water-soluble phosphoric acid is used in low and high content superphosphates and in ammonium phosphate (Fig.P.13). These fertilizers get absorbed quickly by plants and are effective only in alkaline or neutral soils. When water-soluble phosphoric acid is added to the soil, it changes to an insoluble form. In acidic soils, the fertilizer reacts with the soil iron and aluminum, and becomes unavailable to plants.

Phosphatic fertilizers are basically divided into two groups.

(i) **Straight phosphatic fertilizers**: These supply mainly phosphorus. Examples include single superphosphate, double or triple superphosphate, dicalcium phosphate, rock phosphate, **pelophos**, calcium metaphosphate (metaphos), **bone meal**, etc.

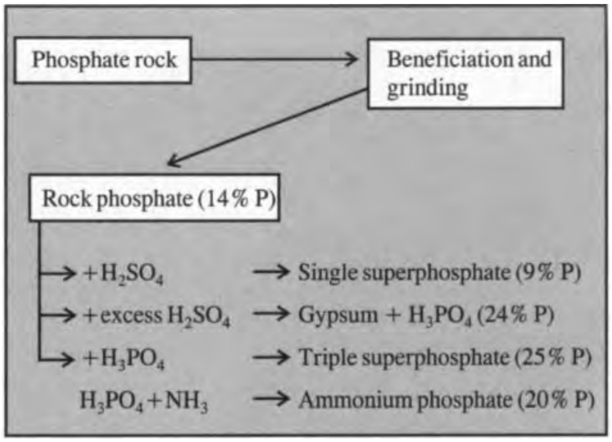


Fig.P.13: Synthesis of phosphate fertilizers.

(ii) **Compound phosphatic fertilizers**: These supply nitrogen, or nitrogen and potassium, along with phosphorus. Some of these are di-ammonium phosphate, ammonium phosphate sulphate, nitrophosphate, monoammonium phosphate and many other NP and NPK complexes.

Basic slag, dicalcium phosphate, **rhenania phosphate**, and raw and **steamed bone meal** are phosphatic fertilizers. These have a citric acid-soluble form of phosphoric acid. The calcium content and the basic reaction make these fertilizers suitable to acidic soils.

Rock phosphate, raw bone meal and steamed bone meal also contain an insoluble form of phosphoric acid or tricalcium phosphate. These are very effective in strongly acidic soils.

Phosphobacteria

Phosphobacteria, found in soils, can increase the plant-available phosphorus through solubilization of the insoluble forms of phosphorus and the decomposition of organic phosphorus compounds. They also produce growth-promoting substance like IAA and G.A. In controlled experiments, an average of 10% increase in the crop yield has been reported.

Several fungi (like *Penicillium* spp.) increase phosphorus uptake, especially in calcareous soils with high pH. Phosphate solubilizing micro-organisms release organic acids which may dissolve phosphorus minerals. These micro-organisms can reduce the requirement of commercial phosphate up to 50% and make phosphorus directly available from phosphate rocks.

Phosphobacterin: See Phosphate solubilizing micro-organisms

Phosphocomposts

Compost is used as a fertilizer. It is a mixture of decaying organic matter, such as vegetation and manure, consisting of about 1.6% nitrogen, 1.0% phosphorus and 0.2% potassium, on a dry-weight basis and has about 40% solids. When such composts are enriched with phosphatic minerals or fertilizers, they become phosphocomposts. The materials used for phosphorus enrichments are bone meal and phosphate rock. These supply soluble phosphate with a slow rate of release.

Phosphoglyceric acid

Phosphoglyceric acid is an example of a three-carbon compound found in C_3 plants. There exist two groups of plant species with distinct photosynthetic systems. In C_3 plants, the carbon location is a three-carbon carboxylic acid and phosphoglyceric acid. The carbon dioxide compensation point is high (~50 ppm). The net **photosynthesis** is inhibited by the atmosphere containing more than 1% oxygen. In C_4 plants, the stable product is a four carbon acid.

Phosphogypsum

Phosphogypsum, which is calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$), is a by-product in the manufacture of phosphoric acid by the wet process. It is high-grade gypsum containing 90 to 95% calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$), and has lower amounts of impurities than mineral gypsum. It is powdery and brownish white in color, as against mineral gypsum which is lumpy and often needs to be powdered before use. It is a very valuable material in agriculture as it contains two important nutrients - sulphur and calcium.

Phosphogypsum is produced by the reaction of rock phosphate with sulphuric acid:

$$\begin{aligned} Ca_{10}(PO_4)_6F_2 + 10H_2SO_4 + 20H_2O \longrightarrow {} & 10(CaSO_4 \cdot 2H_2O) \\ & + 6H_3PO_4 + 2HF \end{aligned}$$

When sulphuric acid is used to dissolve phosphate rock, about 11 to 14 tons of phosphogypsum waste is generated per ton of the fertilizer phosphorus produced.

Pure phosphogypsum is a harmless mineral found in nature. In the past, phosphogypsum was disposed of in the sea where it gradually dissolved. However, the waste from fertilizer production contains some heavy metals and radioactive elements from phosphate rock. For example, a part of cadmium present in rock phosphate is a part of the phosphogypsum waste. Because of this, restrictions are increasingly placed on the disposal of phosphogypsum waste in the sea. Phosphogypsum is separated from the phosphoric acid by filtration, washed with water to remove the adhering phosphoric acid, re-slurried and finally discharged to a phosphogypsum pond.

The impurities found in phosphogypsum are due to the nature of rock phosphate used. Phosphogypsum contains 16% sulphur (43% SO_3) and 21% calcium (30% CaO). The sodium monoxide and potassium monoxide ($Na_2O + K_2O$) content is only 0.4%, which is much less than the permissible limit for sodium alone (0.75%) in mineral gypsum.

Pure phosphogypsum is used to the extent of 90 to 95% for making (a) ammonium sulphate with ammonia and carbon dioxide, (b) cement and sulphuric acid by calcining gypsum with coke and clay, (c) plaster or building material for construction purposes, (d) a set retardant of cement, and (e) fertilizer fillers. It is also used as landfills, and for reclamation of sodic soils.

Phospholipids

Phospholipids are esters of glycerol and are similar in structure to fats. However, unlike fats, they contain only two fatty acids. The third ester linkage involves a phosphate group which gives phospholipids two distinct parts: a long non-polar tail and a polar substituted phosphate head. Because of this dual nature, phospholipids tend to form bi-layers in an aqueous solution, with the tails in the interior and the polar heads interfacing with the polar water molecules.

Phospholipids form a significant portion of cell membranes and perform two important functions. They protect the cell from extra cellular fluids, and allow nutrients and other chemicals to enter the cell, while letting the waste products leave the cell. Lecithin is an example of phospholipids. (See also Lipids.)

Phosphoric acid

Phosphoric acid (H_3PO_4), also known as **ortho-phosphoric acid**, is the most significant source of phosphate fertilizers. Phosphoric acid based fertilizers mainly include ammonium phosphate, diammonium phosphate and monoammonium phosphate.

Phosphoric acid is deliquescent and commercially the most important derivative of phosphorus, accounting for over 90% of the phosphate rock mined. The white rhombic solid is highly soluble in water and ethanol, and the concentrated aqueous solution is generally available for use.

Phosphoric acid is used in several industries other than the fertilizer industry. Most elemental phosphorus is converted into phosphoric acid for non-fertilizer use. There are two basic processes for the production of phosphoric acid.

Metaphosphoric acid is obtained by heating phosphoric acid until dense white fumes begin to appear. The product is highly deliquescent and glassy in appearance. Its salts are known as **metaphosphates. Orthophosphoric acid** is the most common and is used as an important phosphate ingredient in commercial fertilizers. (See also Phosphoric acid production processes.)

Phosphoric acid by wet process: See Phosphoric acid production processes

Phosphoric acid process efficiency: See Phosphoric acid production processes

Phosphoric acid production, Albright and Wilson process: See Phosphoric acid production processes

Phosphoric acid production by anhydrate process: See Phosphoric acid production processes

Phosphoric acid production by furnace process: See Furnace process for phosphoric acid

Phosphoric acid production processes

In the last three decades, phosphoric acid has become the most important source for production of fertilizers. It is produced by two basic types of processes, namely, the **furnace process** and the **wet process**.

The furnace process includes the blast furnace process and the electric furnace process. The blast furnace process is obsolete and the electric furnace process is used mainly for the production of elemental phosphorus, most of which is used to make phosphoric acid for non-fertilizer applications. The wet process is classified according to the acid (sulphuric-, nitric-, or hydrochloric acid) used to decompose phosphate rock (Fig.P.14).

The process using sulphuric acid is the most common among the processes for producing phosphoric acid for fertilizer use. The major chemical reaction in the wet process for making phosphoric acid from fluoroapatite phosphate rock is:

$$Ca_{10}F_2(PO_4)_6 + 10H_2SO_4 + 10nH_2O \longrightarrow 10\,CaSO_4 \cdot nH_2O + 6H_3PO_4 + 2HF$$

where n = ½, 0 or 2 depending on the hydrate formed by calcium sulphate. This reaction may take place in two stages, the first stage giving monocalcium phosphate and the second stage giving phosphoric acid by the reaction of monocalcium phosphate with sulphuric acid.

The production of the wet process phosphoric acid, sometimes called **green acid,** is classified based on the hydrate form in which calcium sulphate crystallizes. The hydrate form is controlled mainly by temperature and acid concentration. Currently, there is no commercial use of anhydrite (n=0) process, and this non-use is mainly due to high temperatures involved and the corrosion observed in those conditions.

The dihydrate process is by far the most popular the world over, in the view of its simplicity and ability to use a wide variety of phosphate rocks in the process. Hemi hydrate processes produce phosphoric acid of a relatively high concentration without the need of the concentration step. There is also some interest in the two-stage processes that involve crystallization in the hemi-hydrate form followed by recrystallization in the dihydrate form, with or without filtration or centrifugation.

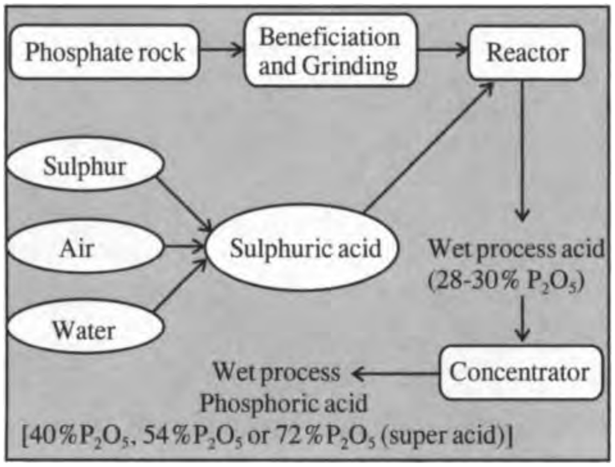


Fig.P.14: Flowsheet for manufacture of phosphoric acid by wet process.

The dihydrate process involves the following steps: (a) phosphate rock selection, (b) selection of sulphuric acid source, (c) receiving and storing of raw materials, (d) grinding of the rock, (e) reaction of phosphate rock and sulphuric acid, (f) filtration of gypsum from phosphoric acid, (g) concentration and purification of the acid, and (h) sludge disposal. These steps are described below.

(a) Phosphate rock selection: The plants are built to use a blend of rocks from different sources. The plants have always an inbuilt extra capacity for grinding, filtration and slurry handling systems to take care of variation in the rock composition. As phosphate rock is a complex raw material that affects plant operation in numerous ways, a thorough evaluation of the quality should be made before selecting a phosphate rock or changing the source to another. Chemical and mineralogical analysis of a phosphate rock is helpful in evaluating the rock's usefulness. However, a trial run in a pilot plant is needed for complete evaluation of the rock. The phosphate rock used in the process is of as high a grade as possible, usually ranging from 30 to 35% P_2O_5 and 1 to 4% iron and aluminum. It is ground, such that 60 to 70% of it passes through a 200 mesh sieve.

(b) Source of sulphuric acid: The sulphuric acid requirement is calculated assuming its amount required to combine with calcium present in the rock to form calcium sulphate. Assuming an overall recovery of 94% phosphorus to get 1 ton of phosphorus (as P_2O_5), we need 1064 kg of phosphate rock. Knowing the calcium oxide content in the rock, and considering that 15% of fluorine combines with calcium oxide to form calcium fluoride, the sulphuric acid requirement is calculated. For a high grade phosphate rock, H_2SO_4 required is 2.5 tons per ton of phosphorus; and for low grade rocks, it is 3.15 tons per ton of phosphorus. Most phosphoric acid plants have onsite facilities for producing sulphuric acid from sulphur or pyrites. Here sulphuric acid of 93 to 98% concentration is used. A by-product acid is not used because of the impurities present in the acid.

(c) Receiving and storing of raw materials: Modern plants require bulk handling and storage of phosphate rock. The raw materials are stored in dry conditions and protected against rain, wind and freezing weather. Relatively coarse rocks can be stored in piles. The storage capacity should ideally be 1.5 times the largest shipment, to ensure constant supplies.

(d) Grinding of rock materials: Phosphate rocks of less than 35 mesh require either wet or dry grinding depending on the raw materials. Fine grinding is required when there are multi-compartment digesters and the sulphate control is poor. Most of the old plants use dry grinding, and a majority of the new plants use wet grinding with a ball mill. Ring roller mills or ball mills are used with air classification. As a result, a slurry containing 62 to 70% solid is produced. Wet grinding requires about 30 to 40% less power and there is no atmospheric pollution by dust. The main disadvantages of this process are that the balls and the mill lining wear out faster, and the amount of recycled waste water that may be required in phosphoric acid production is reduced. Also, it is necessary to maintain the ratio of solids while grinding.

(e) Reaction of phosphate rock and sulphuric acid: The purpose of the reaction step is not only to extract maximum phosphate from the rock but also to ensure that the growth of gypsum crystals is slow for easy filtration of gypsum. The average retention time in the reactor system is about eight hours.

The systems are designed to prevent direct contact between phosphate rock and sulphuric acid. A high concentration of free sulphuric acid would result in the formation of a coating of calcium sulphate on the phosphate rock, thereby blocking further reaction. On the other hand, a high concentration of calcium ions in the slurry would increase the amount of phosphate co-crystallized with gypsum. In order to maintain a uniform composition of slurry, the incoming stream of sulphuric acid and phosphate rock is mixed and agitated as rapidly and as completely as possible to ensure homogeneity. Most of the modern plants use about 96% pure sulphuric acid. Its mixing with dilute phosphoric acid generates heat which is used to evaporate the water and volatilize fluorine compounds (mainly SiF_4 and HF).

Three methods of cooling are generally in use: (a) blowing air on to the slurry, (b) blowing air across the slurry, and (c) flash cooling under vacuum.

The various dihydrate processes differ essentially in the reaction step. The reactor design falls into multi-compartment reactors or single-tank reactors. Processes that use a multi-compartment reactor are **Prayon Mark IV dihydrate process** and the Norsk Hydro dihydrate process. The Prayon Mark IV dihydrate process produces phosphoric acid of about 28% phosphorus concentration (as P_2O_5). The multi-compartment cells are of concrete, lined with rubber and carbon bricks. Every tank is provided with an agitator of special design to carry out mixing of solid suspensions and foam breaking. Slurry from the tank overflows to the digestion system, where calcium sulphate crystallizes.

The processes using a single-tank reactor are both of conventional and isothermal types. The conventional type processes include Rhone-Poulenc dihydrate system, SIAPE process, and Tunisia and Jacob's dihydrate phosphoric acid process. Examples of isothermal processes are the Raytheon isothermal reactor process, Kellogg-Lopker process and Somerville process.

The **Rhone-Poulenc phosphoric acid reaction system** uses a reaction tank made either of steel lined with rubber, or of concrete lined with carbon bricks. Baffles are provided to prevent the slurry from rotating as a single mass. Phosphate rock is added to the tank through ducts, and concentrated sulphuric acid (98%) is added via one or several discs fixed to the drive shafts. There is no risk of any temperature peaks, caused by local sulphuric acid excess which can affect the crystallization adversely.

The Rhone-Poulenc's DIPLO process is a variation of the Rhone-Poulenc's conventional dihydrate process and is based on the same principles as the single-tank process but differs in that two attack tanks are employed in series with no circulation between them. The process uses low-grade, less-reactive or unground phosphates.

The **Societe Industrielle d'Acide Phosphorique et d'Engrais (SIAPE) process** involves a cylindrical tank, with an outer ring-shaped compartment, and divided into a central compartment into which phosphate rock, sulphuric acid and the returned acid are fed. The tank is made of concrete, and coated inside with rubber and then covered with carbon bricks. The process is developed for low-grade ores with a relatively high carbonate content. The agitation is improved by using an axial-radial double-impeller agitator. To address situations of poor quality of indigenous phosphate rock, the SIAPE modified the process by adding a digestion tank with two agitators and a temperature gradient between the recycled slurry and the slurry in the attack tank to achieve good crystal growth.

The **Jacob's dihydrate phosphoric acid process** uses an annular reactor with a separate cooler seal and filter feed compartments. The design allows phosphate rock and sulphuric acid to be added at several points. The equipment has multiple agitators and low-level flash coolers. The system allows easy sulphate control, good crystal growth and low nucleation rates.

Raytheon isothermal reactor process, as the name suggests, maintains a constant reactor temperature by keeping the contents in rapid circulation. This gives a number of advantages over conventional reactors, which are as follows: (i) The raw material use efficiency is enhanced. (ii) The sulphate and product compositions are easier to control. (iii) The slurry concentration in the reactor and thus the filtration rate, are more stable.

The reactor consists of one reaction compartment containing a draft tube and a circulating impeller. A controlled flow of 93 to 98% sulphuric acid is introduced into the reactor inside the draft tube, just above the propeller. The turbulent flow ensures maximum dispersion of acid at this point. The overflow nozzle located on the shell of the reactor above the top of the draft tube regulates the slurry level. The slurry containing 29% phosphorus (as P_2O_5) and 38 to 40% solids overflows through a self-venting pipe.

The circulation ratio of the isothermal reactor is about 10 times of that occurring in most conventional multi-compartment reactors. This high circulation rate gives uniform temperature, uniform sulphate concentration and larger gypsum crystals.

The **Kellogg-Lopker** isothermal process uses a reactor system comprising two vessels, namely, a dissolver and an evaporator. The phosphate rock and the recycled phosphoric acid are introduced into the dissolver working under ambient pressure. Sulphuric acid is introduced into the vacuum evaporator. Agitation is provided by pumping from the bottom of the dissolver and injecting the material tangentially into the evaporator just below the liquid level. It returns to the dissolver under gravity. The difference between the liquid levels in the two vessels corresponds to the difference in their operating pressures. The Kellogg-Lopker system accepts very coarsely ground phosphate rock and has low residence time (one and a half hours compared to eight hours for the Prayon process).

In the **Somerville process**, phosphate is introduced in an agitated digester containing a slurry under atmospheric pressure and is then drawn by vacuum into the cooler/evaporator. Sulphuric acid and recycled phosphoric acid are added and the slurry is then pumped back into the digester.

All the processes use a small excess of sulphuric acid. However, it is possible to operate with deficient sulphuric acid and excess sulphate, by replacing part of sulphuric acid by ammonium sulphate or any other soluble sulphate. About 10 to 15% of the sulphuric acid can be replaced by ammonium sulphate. The advantage is that the corrosion rate is lower with the use of a small amount of ammonium sulphate by-product. The disadvantage is that the reaction time is longer and the presence of ammonium phosphate in phosphoric acid limits the utility of the acid.

The retention times in the industrial plants range from 1.5 to 12 hours or more. When the retention time is short, it is difficult to control free sulphuric acid concentration in the liquid phase. The typical value for free acid is around 1.5%.

Foaming in the reactor is often a problem, especially when the rock has a relatively high content of organic matter or carbonate. Various anti-foaming agents are used to control foaming such as fatty acids, oleic acids and silicones, of which 2 kg/ton of P_2O_5 is adequate.

(f) Filtration of gypsum: The filtration step aims to separate gypsum (or any other insoluble material) formed during the reaction of phosphate rock with sulphuric acid, as completely, efficiently and economically as possible. All modern plants use continuous horizontal vacuum filters. The popular types of filters are tilting pans, rotary filters, rotary table filters and belt filters. Some of the product acid is recycled to the digestion step to control the percentage of solids in the slurry, which is normally 35 to 45%.

Filters are characterized by their surface area and the rate of rotation (in a rotary filter) or the rate of travel (in a belt filter). The filtration rate is also affected by the size and shape of gypsum crystals which, in turn, are decided by the type of phosphate rock, crystal shape modifiers, control of reaction conditions, sulphate concentration, slurry re-circulation, phosphoric acid concentration, etc. The filtration rate is also affected by temperature, concentration, viscosity of the acid, the desired recovery, the amount of vacuum, the design of the filter and insoluble impurities in the rock like clay. The normal filtration rates reported in the production are 2 to 18 tons/m^2/day.

(g) Concentration and purification of acid: Phosphoric acid produced by most dihydrate processes contains 26 to 32% phosphorus (as P_2O_5). This concentration is sufficient for making a few fertilizers like mono and dicalcium phosphates, mixed phosphates etc. The required concentrations of phosphoric acid for the manufacture of various fertilizers are: (a) triple superphosphate (**den process**) 50 to 54%, (b) triple superphosphate (slurry process) 38 to 40%, (c) DAP about 40%, (d) MAP 40 to 50%, (e) merchant grade (shipping) 50 to 60%, and (f) superphosphoric acid (liquid fertilizer production) 68 to 70%.

Precipitates, like calcium sulphate and fluorosilicates, can get formed in phosphoric acid before, during and after concentration. These compounds are called **sludge**, and they cause difficulties while handling the acid. They also form scales in evaporators. Hence, many manufacturers clarify the acid and use the sludge in making fertilizers where they are not harmful. Acids for shipment should be free from sludge. Hemihydrate processes yield acids which are relatively free from sludge. The major constituent of most sludges containing 52 to 54% P_2O_5 is a complex salt with a composition $[(FeAl)3KH_{14}(PO_4)_8.4H_2O]$. 70 to 80% of fluorine present in the acid is removed during concentration of the phosphoric acid from 30 to 54% phosphorus (as P_2O_5). The by-products produced are fluosilicic acid, fluosilicates, cryolite, aluminum fluoride, hydrofluoric acid and liquid hydrogen fluoride. These are to be recovered to prevent pollution.

Two types of phosphoric acid concentrators are known, those that are directly fired and indirectly fired. The directly fired evaporators are not in vogue because of the difficulty in cleaning the exhaust gases to recover acid. Most phosphoric acid concentration processes heat the acid with steam in a heat exchanger under vacuum. Commonly used evaporators are tubular evaporators with forced circulation. The tube can be made of graphite or stainless steel. The impregnated graphite tubes, though cheap, are fragile and crack during operation. The concentration from 30 to 54% phosphorus using steam are carried out in one, two or three stages with interpass crystallizers to decrease the scale formation in the heat exchangers. The concentration requires 1.9 tons of steam per ton of phosphorus (as P_2O_5) in the concentrated acid. Generally, this heat is available from sulphuric acid manufacture.

(h) **Sludge disposal**: Acids containing sludge can be used for fertilizer production provided the fertilizer production is carried out onsite. The sludges from filter acid usually are gypsum and fluosilicates. The sludge formed after concentration of acid contains a large proportion of iron and phosphate compounds. This sludge is separated before the acid is shipped and can be used for making triple superphosphate. Most of the phosphorus (as P_2O_5) in the sludge is citrate-soluble but not water-soluble.

The sludge may be used in the production of non-granular mono-ammonium phosphate which is used as an intermediate in the production of compound fertilizers. There is no economical method for using sludge solids where phosphate fertilizers are sold on the basis of water solubility.

Precipitation after concentration to 54% phosphorus (as P_2O_5) is slow and never so complete as more precipitate will form on standing.

The process efficiency is affected by P_2O_5 losses in reaction and filtration, by incomplete dissolution of the rock, by formation of soluble phosphate compounds and by insufficient washing of the cake. In a well-designed and well-operated plant, undissolved rock should not amount to more than 0.2 to 0.5% of the original P_2O_5. Normally, the loss of soluble phosphate from incomplete washing should not exceed 1.5%.

Corrosion is a serious problem in wet-process acid production. Fluoride in the rock is given out as hydrofluoric acid which reacts with silica to give fluosilicic acid. Reactor tanks have carbon brick lining over the rubber lining. Filters, pumps and agitators are made of stainless steel, usually 316, 317 ELC or alloy 20. The piping is made of rubber-lined steel or composite assemblies. Rubber hoses are used extensively.

Hemihydrate and two stage process: There are a number of hemihydrate and combined systems developed by various companies. The basic equipment for hemihydrates and combined processes differ only in technical parameters, such as material of construction, etc.

Hemihydrate process: As the hemihydrate reaction proceeds in two zones, the reaction section needs two separate compartments with a preferred volumetric ratio of 2:1. Phosphate rocks, sulphuric acid and dilute phosphoric acid are fed into a reactor where the rocks are exposed to sulphate ions under controlled chemical conditions. The slurry overflows to the next compartment and the heat is removed by vacuum cooling to maintain the slurry temperature at 98 to 100°C. The product acid (40% to 50% phosphorus as P_2O_5) and hemihydrate gypsum are separated by a horizontal vacuum filter with three counter-current wash stages. The product acid is used directly or stored as it requires no clarification.

The following are the advantages of the process. (i) Evaporation is less, leading to cost saving. (ii) The acid contains less sulphate and less suspended solids. (iii) In view of the high rate of reaction, much coarser rocks can be used, thereby reducing the cost of grinding equipment.

The major disadvantages of the hemihydrate process are as follows: (i) The small crystals of hemihydrates from the slurry of phosphoric acid make the filtration difficult. (ii) The water balance is more critical and hence there is a restriction on the amount of wash water. The amounts of both, soluble and co-crystallized P_2O_5 in the filter cake are greater because of higher P_2O_5 present in the slurry being filtered. (iii) Hemihydrate is not stable and reverts to gypsum ($CaSO_4\,2H_2O$) even before the acid is filtered. This can also happen more freely during washing. This reversal leads to scale formation in pipes and equipments. (iv) There is more wear and tear of equipment at higher temperatures and higher acid concentrations.

Three single stage hemihydrate processes are commercially in operation. They are (a) Norsk Hydro Licensing process, (b) Prayon process, and (c) Occidental process.

The hemihydrate-dihydrate processes without intermediate filtration, also called hemihydrate with re-crystallization (HRC), are widely used in East Asian countries. The plant layouts for these processes resemble those of multiple-reactor dihydrate processes. An exception is that the attack and digestion reactions operate under conditions which favor rehydration of hemihydrate to gypsum and which is encouraged by the seed dihydrate crystals recycled in slurry from the filter feed. The filtered gypsum is much purer and, therefore, of greater use as cement- setting retarder or as plaster. The process provides a very high recovery of phosphorus (as P_2O_5) from the rock since losses in the gypsum are very low. The disadvantage is that the process is highly complex and costly.

The commercial processes developed are by Mitsubishi Chemical Industries Ltd., Nippon Kokan KK and Nissan Chemical Industries Ltd.

Hemihydrate-dihydrate process with intermediate filtration: The first stage of the process is identical to the hemihydrate process. The hemihydrate cake is discharged from the filter into an agitated vessel where hemihydrate is transferred to dihydrate. A small feed of H_2SO_4 increases the rate of transformation. All the co-precipitated phosphate rock with hemihydrate is released into a liquid phase. The dihydrate gypsum is filtered.

An extra filtration step increases the cost and complexity of the plant. There is no need for concentration of acid as we get above 45% P_2O_5 containing phosphoric acid.

The dihydrate obtained is purer and can be used as a cement-setting retarder or as plaster. Plants available based on this technology have been developed by (a) Singmaster and Breyer, (b) Prayon, (c) Fisons Fertilizers, (d) Norsk Hydro Licensing, and (e) Nissan Chemical Industries Ltd.

Dihydrate-hemihydrate process: Although the attack and digestion sections are run under dihydrate conditions, it is not desirable to affect a very high degree of phosphorus recovery during the separation of the acid from the dihydrate. This is because the succeeding dehydration step requires about 20 to 30% phosphorus pentoxide and 10 to 20% H_2SO_4. A centrifuge is used, instead of a filter, to produce a thicker slurry of gypsum in phosphoric acid and it is not essential to produce filterable crystals of gypsum. Hence, it is possible to get 35% phosphorus (as P_2O_5) containing acid instead of a maximum of about 32% by the ordinary dihydrate process. The transformation of dihydrate to hemihydrates is not affected by impurities in the apatite.

The process has almost the same advantages and disadvantages as the hemihydrate-dihydrate process except that the hemihydrate by-product may be more useful. However, the acid concentration is somewhat lower. Japanese Central Glass Company, and Societe de Prayon of Belgium have developed commercial processes based on this technology.

The anhydrite process of making phosphoric acid involves high temperature and pressure. In the clinker process, rock phosphate is treated directly with 98% sulphuric acid and calcined to improve handling. The resulting clinker is leached with hot water to give acid containing 50% or more of P_2O_5. While the cost of calcining and the complexity of batch leaching are the handicaps, recently TVA has shown the use of fuming sulphuric acid to eliminate the calcining step and a rotary continuous device to simplify the leaching method.

Transport and storage: Most of the acid shipped has been of 54% P_2O_5 concentration although some superphosphoric acid of 69 to 72% P_2O_5 has also been shipped. Phosphoric acid for shipment should be relatively free of sludge-forming solids (preferably $<1\%$). This calls for clarification.

Two means of protection against corrosion of tank walls are the: (a) lining of the steel tank with chloroprene-based rubber, and (b) lining of steel tanks with molybdenum alloyed stainless steel (317L). The clarified acid is transported over long distances in special ocean-going ships.

Acid storage tanks are either rubber-lined steel or stainless steel. In some cases, ponds or lagoons are used for storage. The ponds are lined with heavy sheets of rubber or plastic underlaid with gravel with a sump drainage so that any leakage can be detected and returned to another pond. Most storage tanks have facilities for agitating the acid occasionally to prevent settling of solids. For small quantities, glass carboys can be used.

Purification of phosphoric acid: For most fertilizer production, purification of phosphoric acid from the wet-process is not necessary. However, two common fertilizer applications call for purification of the acid: (i) Merchant grade acid that is shipped by rail, barge or ocean vessels should be purified to minimize the formation of insoluble precipitates or sludge. These acids are used for manufacture of various fertilizers or chemicals. (ii) Phosphoric acid for use in liquid fertilizers needs partial purification to prevent formation of precipitates upon ammoniation or during storage of the ammoniated solution.

Excessive amounts of magnesium, titanium and organic matter cause precipitate formation. A major fraction of the sludge in merchant grade acid sludge is the compound $(Fe, Al)3KH_{14}(PO_4)_8{\cdot}4H_2O$. It precipitates slowly over a period of several months. Hence, long storage periods are required to ensure completion of precipitation.

When phosphoric acid is used in human food processing and animal feed supplement programs, toxic impurities (like fluorine, arsenic, heavy metals) and radio active metals must be reduced to an insignificant presence. The solvent extraction or ion-exchange with or without chemical treatment is resorted to, for purifying the acid. Usually, a solvent extraction treatment is used and when chemicals are used, they react with the impurity alone and do not chemically alter the phosphoric acid. The concerned methods are described below:

(i) Removal of organic matter: Organic compounds present in phosphate rock decompose to carbon during the oxidation and dehydration steps, thereby imparting a black color to the acid. Calcining of the rock completely destroys the organic matter before the process of phosphoric acid manufacture. Also, treating the acid with active carbon at 60 to 80°C with or without a flocculating agent decolorizes the acid.

(ii) Defluorination: The wet process phosphoric acid, after concentration as superphosphoric acid, contains fluorine that is not acceptable for use in animal feed preparation. The acceptable level of fluorine is 100P:1F. Several procedures have been proposed to remove fluorine from phosphoric acid based on volatilization or chemical precipitation. The procedure adopted by Occidental Chemical Company involves feeding silica and steam into 54% P_2O_5 containing phosphoric acid and removing the volatilized fluorine by scrubbing as fluosilicic acid.

(iii) Solvent processes: These are operationalized by the following methods.

(a) Precipitation: A large amount of a water miscible organic solvent is added to phosphoric acid which precipitates many dissolved impurities out of the solution. For example, when methanol is added, alkali metal or ammonium ions precipitate as insoluble salts. Other solvents used are acetone, methyl ethyl ketone, alcohols and dioxane.

A disadvantage of this process is that the phosphoric acid is to be separated from a large amount of the solvent, usually by stripping, which is expensive. The processes based on this principle are: Chemische Fabrik Budenheim, TVA (methanol/ammonia), Goulding (methanol/potassium dihydrogen phosphate) and Rupel (methanol/potassium chloride).

(b) Extraction: An alternative method of purifying phosphoric acid with organic solvents is by liquid-liquid extraction. Here phosphoric acid is brought in contact with a water-immiscible solvent in a series of mixer settlers. The crude acid is concentrated before subjecting it to solvent extraction in view of unfavorable partition coefficient of phosphoric acid between the aqueous solution and organic solvent. The solvent extract is washed with purified phosphoric acid and is then usually contacted with water, in which most of the acid passes. The end product is purer but much weaker. The depleted solvent phase is recycled.

The **Prayon process** uses a mixed solvent di-isopropyl ether (DIPE) and tri-n-butyl phosphate (TBP). Acid purification involves four operations: solvent extraction, re-extraction, separation of solvent from purified acid and color clarification. Four volumes of the mixed solvent (50 to 95% di-isopropyl ether and 5 to 50% tri-butyl phosphate) in a counter-current way is brought in contact with one volume of the acid at 5 to 25°C. This gives two phases - aqueous and organic. The aqueous phase is stripped in an evaporator to release ether, while the organic phase is washed with water. Re-extraction of the acid is favored by slight increase in temperature. The final steps in the process are stripping (to remove residual traces of the solvent), addition of a solid chemical absorbent, filtration to remove the organic matter, and concentration.

The **Albright and Wilson process** calls for the impure acid concentration to the level of 74 to 80% of total acidity (%H_3PO_4 + %H_2SO_4 - 54 to 57% P_2O_5) and then clarified. Next, it is contacted with 1.2 to 1.6 parts by weight of methyl isobutyl ketone (MIBK) in a reactor to give an organic extract of phosphoric acid and an aqueous phase (raffinate) containing impurities and a portion of P_2O_5. A multistage counter-current extraction is carried out in a vertical cylindrical column equipped with rotating-disc agitators and stator rings. The acid enters near the top and the solvent near the bottom. The acid containing the solvent leaves the top of the column and a dense aqueous phase is discharged at the bottom. The organic extract containing 50 to 60% of phosphoric acid is scrubbed with a pure aqueous solution of phosphoric acid in a multi-stage counter-current scrubbing system, using 0.3 to 0.5 units of P_2O_5 for each unit of P_2O_5 in the extract.

The used scrub liquor passes back to the first stage extraction column where it enters near the top and emerges with the aqueous impurity containing raffinate. The raffinate is then stripped to recover the methyl isobutyl ketone, and impure phosphoric acid is used in a phosphate fertilizer. About 0.4 ton of P_2O_5 is found in the raffinate for each ton of P_2O_5 in the impure feed acid. The solubility of MIBK in phosphoric acid is less than 2% and hence little steam is required for stripping. The scrubbed organic extract is re-extracted with water to give the required purified phosphoric acid after stripping the solvent. The MIBK solvent is recycled after the acid recovery. When the impurities accumulate beyond the limits to use raffinate in fertilizer production, it is strongly acidified with sulphuric acid before additional extraction. Impurities remain in acidified aqueous phase which is neutralized with lime before disposal as waste.

Phosphoric acid is also produced by several other processes, such as electric furnace process, blast furnace process, etc.

Phosphoric acid production using blast furnace process

A blast furnace is used commercially to produce phosphoric acid for industrial and chemical applications, but not for fertilizers, the latter use being uneconomical. As in the electric furnace process, a low grade siliceous phosphate rock with moderately high aluminum and iron content, is acceptable.

The blast furnace process was used in the production of phosphoric acid from 1928 to 1938.

The blast furnace process differs from the electric furnace process in the following aspects: (i) Coke is used both as a reducing agent as well as fuel. Its requirement is around 2.5 t/t of P_2O_5 recovered as phosphoric acid. About 0.6 ton of coke is consumed in the reduction of P_2O_5 to phosphorus and the remainder generates heat by combustion with preheated air. (ii) In the electric furnace, the charge consists of phosphate rock, silica and coke in lump or agglomerated form. It is not necessary to calcine or dry the charge in the process. (iii) The gas from the furnace contains about 37% carbon monoxide and 1 to 2% phosphorus by volume. The rest is nitrogen. The recovery of phosphorus is difficult in view of the low percentage in the gas. (iv) The gas after phosphorus recovery contains 34% CO, 1 to 2% oxygen and the rest nitrogen, and is used for preheating the air to the blast furnace.

By-product disposal and recovery: Disposal of by-products is a major problem in all phosphoric acid processes. Only one-third of the phosphate rock is a useful product (that is P_2O_5), the remainder is a large tonnage of material like dilute sulphuric acid, some of which is toxic and disposed of in different ways. For every ton of P_2O_5, about 5 tons of the by-product material is produced.

Fluorine compounds must be removed from effluent gases. The fluorides are let into streams or oceans either with or without neutralizing with lime. In some plants, fluorine recovery is practiced. The fluorine containing vapors leaving the evaporator are scrubbed with a dilute solution of fluorosilicic acid (H_2SiF_6). Under such conditions, fluorine compounds are absorbed but water vapor is not. Such an acid, containing up to 95% H_2SiF_6, is useful as fluoridation of public water supplies.

Gypsum disposal is a problem because of the large mass involved. The material is commonly sluiced into rivers and oceans. In good tidal conditions or open sea, gypsum is quickly dissolved in water without the calcium concentration being altered. In addition, all heavy metals present in phosphogypsum are already present in sea water. But the changes in the concentration of the metals and the pH will be significant. This causes pollution, which is costly to remedy.

In the USA, the general practice is to sluice the gypsum to a waste pond and gradually develop a pile by building dikes either of earth or gypsum around the pond.

Major uses of phosphogypsum are to make (a) ammonium sulphate by reacting gypsum with ammonia and carbon dioxide, (b) cement and sulphuric acid by calcining the gypsum with coke, clay or shale, and (c) plaster or plaster-board for building materials or make pressed or cast blocks for construction purposes. Phosphogypsum is also used as a retardant in cement, as fertilizer filler, and for direct application to farmland when the soil is having to combat the effects of salinity or alkalinity.

Phosphoric acid production using electric furnace process

The production of phosphoric acid by the electric furnace process involves firstly, the production of elemental phosphorus which on burning in air gives phosphorus pentoxide. This, on hydration, gives phosphoric acid.

Phosphate rock lumps, silica pebble and coke are fed into an electric furnace. The current is applied through graphite electrodes that fuse the rock with silica. At the same time, carbon reduces the phosphate. Phosphorus vapor and carbon monoxide are continuously withdrawn and condensed to a liquid. Molten calcium silicate slag and an iron-phosphorus compound, known as ferro phosphorus, are tapped periodically. The principle reaction taking place in the furnace is

$$Ca_{10}F_2(PO_4)_6+15C+6SiO_2 \longrightarrow 1.5P_4+15CO +3(3CaO\cdot 2SiO_2)+CaF_2$$

The advantage of the electric furnace process lies in its ability to use a low-grade phosphate rock, provided the major impurity is silica. Also, iron and aluminum oxides are not objectionable as in the wet process. Siliceous rocks containing 24% phosphorus as P_2O_5 are acceptable. The by-product carbon monoxide, is used as a fuel for calcination.

The phosphorus recovered as elemental phosphorus is roughly 86 to 92% of that charged to the furnace. 3% of the phosphorus is lost in the slag and 2 to 8% of the phosphorus is recovered as ferro phosphorus. The amount of ferro phosphorus formed depends on the iron oxide content in the phosphate rock.

The main disadvantages of the process is the high capital cost of the plant. Hence, the phosphorus produced is exclusively used in making phosphoric acid for industrial chemicals, insecticides, detergents and additives to food or animal feed. The conversion of elemental phosphorus to phosphoric acid is simple. The overall reaction is

$$P_4 + 5O_2 + 6H_2O \longrightarrow 4H_3PO_4$$

The liquid phosphorus is burned in air and the resulting oxide (P_2O_5) is hydrated to get H_3PO_4. The Tennessee Valley Authority (TVA) developed the process and ran it till it was found that it could no longer compete with the wet process for fertilizer production. The other producers are FMC, Monsanto, Occidental Chemical, Stauffer Chemical and Albright and Wilson. FMC and Monsanto are the two largest producers. All these producers use phosphorus which is made for the production of industrial phosphates.

Phosphoric acid production using hydrochloric acid

Dissolution of phosphate rock by hydrochloric acid results in an aqueous solution of calcium chloride and phosphoric acid. The liquid-liquid contacting stage in a number of solvent extraction steps results in a solution of substantially pure phosphoric acid with around 95% concentration (69% P_2O_5).

The steps involved in the manufacture are (a) dissolution and mechanical separation of insoluble residues in the phosphate rock, (b) liquid-liquid contacting in a number of solvent extraction steps, (c) acid concentration, (d) solvent recovery from the spent calcium chloride brine, and (e) quality and construction materials. These steps are now elaborated below:

(a) Dissolution: Phosphate rocks (fluorapatite) are decomposed by hydrochloric acid in a rubber-lined steel reactor according to the equation:

$$Ca_{10}F_2(PO_4)_6+20HCl \longrightarrow 2HF+6H_3PO_4+10CaCl_2$$

The insoluble residue containing silica, silicates and insoluble organic matter is separated, followed by washing the cake or sediment.

(b) Liquid-liquid contacting: The liquid-liquid contacting stage consists of operations, such as extraction, purification, washing and stripping. The dissolution liquor is extracted by a counter-current contact with an organic solvent in rigid PVC tanks. Phosphoric acid transfers selectively to an organic phase from an aqueous phase. The calcium chloride brine (raffinate) contains substantial amounts of impurities such as fluorine and iron. The solvent extract containing small amounts of Ca^{2+} ions and some other impurities is purified by counter-current contact with the aqueous phase. In the washing step, the acid of the purified extract is transferred to water. The solvent at this stage is almost free of acid. In the stripping step, the acid-free solvent stream extracts the residual acids present in the residue raffinate and is recycled to extraction. The spent calcium chloride brine is stripped by steam to recover any dissolved solvent.

(c) Acid concentration: The dilute aqueous acid emerging from the washings contains phosphoric acid, hydrochloric acid and some dissolved solvent. The separation of phosphoric acid from other components is done by distillation using a multiple-effect evaporator. The solution is concentrated to 95% phosphoric acid. The amount of steam used is less than 0.5 ton/ton of water evaporated. The heat exchangers operating at elevated temperatures are made of impervious graphite.

(d) Solvent recovery from spent calcium chloride brine: The solvent present in the calcium chloride brine forms an azeotrope with water on rectification. Steam stripping is used for the recovery. The recovered solvent is recycled to the liquid-liquid contacting section.

(e) Quality of the acid: The HCl-route phosphoric acid is much cleaner than the wet process acid and the analysis is very similar to that of the thermal acid. The composition of the HCl-route acid is not dependent on the raw material (rock) unlike in the wet process. By making minor adjustments, a food grade acid can be obtained. The calcium chloride can be disposed of into the sea.

The HCl-route phosphoric acid has certain disadvantages. The production of phosphoric acid via the HCl-route is economical only when HCl is available at a nearby place or can be produced at a moderate price. However, unlike the wet process acid, the HCl-route acid does not contain no scale forming components and the quality of phosphoric acid is independent of the phosphate rock used.

Superphosphoric acid can be made easily from the HCl-route acid. Hydrochloric acid is available (a) from chlorine, (b) as a by-product in the sodium hydroxide production, (c) by the hydrolysis of calcined magnesium chloride, and (d) from the production of potassium phosphate from phosphoric acid and potassium chloride.

Only small plants use the HCl-route and the product is used to make industrial phosphates rather than fertilizers.

Phosphoric acid, purification of: See Phosphoric acid production processes

Phosphoric acid, receiving and storing of raw materials: See Phosphoric acid production processes

Phosphoric acid salts

Phosphoric acid salts are known as phosphates which, like silicates, are numerous and complex. The simplest of these salts are **orthophosphates**. The phosphate ore is treated with sulphuric acid or phosphoric acid to give calcium dihydrogen phosphate, known as **superphosphate**, a major phosphate fertilizer. Trisodium phosphate is used as a cleansing agent and water softener. Phosphates are also used for making glass, soaps and detergents. (See also Phosphates.)

Phosphoric acid, sludge disposal of: See Phosphoric acid production processes

Phosphoric acid, transport and storage of: See Phosphoric acid production processes

Phosphoric anhydride

Phosphoric anhydride is another name for phosphorus pentoxide (P_2O_5). Anhydrides react with water to give acids. For example, sulphur trioxide reacts with water to give sulphuric acid, or acetic anhydride reacts with water to give acetic acid. Similarly, phosphorus pentoxide has great affinity for water and dissolves in it to give phosphoric acid, and therefore, is known as phosphoric anhydride.

$$2P_2O_5 + 6H_2O \longrightarrow 4H_3PO_4$$

(See also Phosphorus pentoxide.)

Phosphorite

Phosphorite or mineral phosphate is made by grinding **rock phosphate**, a natural mineral found in the form of sedimentary rocks containing various calcium phosphates. It is used as a phosphatic fertilizer, and is a primary source of phosphorus. It is a mineral containing calcium phosphate with hydroxyl groups or is hydroxy apatite.

Phosphorite is a continental phosphatic rock, consisting of concretions of collophanite, found in decalcification clays. The most famous phosphorites are from **Causses du Quercy** (France). (See also Rock phosphate.)

Phosphorus

Phosphorus (P) is an important nutrient for plants. It is a non-metallic element having an atomic number 15. It belongs to Group 15 of the Periodic Table (Fig.P.15). The use of phosphorus is as high as one tenth of nitrogen.

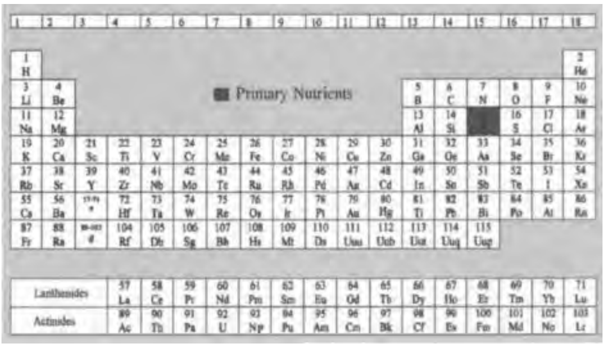


Fig.P.15: Position of phosphorus in the Periodic Table.

Most plants contain phosphorus in concentrations varying from 0.1 to 0.4%, which are considerably lower than for potassium and nitrogen in plants. Phosphorus is an essential part of nucleoproteins in cell nuclei which control the cell division and the DNA molecules, the latter transmitting heredity to living organisms. Phosphorus also plays an important role in (a) stimulating early root growth, (b) hastening plant maturity, (c) transforming energy within the cells, and (d) developing and ripening the fruit and the seed. Phosphorus is rightly called the key to life, as it is directly involved in most life processes.

Relations between phosphorus and N, Cu, Fe, Mn and Zn are well known. Ratios of 3:1 of N to P and 200:1 of P to Zn are considered critical for addressing nutrient deficiency in plants. The ratio of nitrogen to phosphorus (N:P) serves as a Diagnosis and Recommendation Integrated System (DRIS) norm for interpreting results of plant analysis.

Soils have low total phosphate content and hence such soils provide low supplies of available phosphate (400 to 2000 kg/ha) to plants because mineral phosphate forms are not readily soluble. Plants absorb phosphorus as $H_2PO_4^-$ and HPO_4^{2-} ions. On average, a soil solution contains about 0.05 ppm phosphorus which varies from soil to soil. This amount of phosphorus is adequate for plants, as its concentration varies from 0.003 to 0.3 ppm depending on the crop. For instance, maximum corn yields are obtained at 0.01 ppm of the solution-phosphorus, while the incorporation of solution phosphorus in the case of wheat is only marginally more.

Soil phosphorus occurs in both organic and inorganic forms. Plants differ in their ability to compete for soil phosphorus at the growth stage when they need it most. Young plants rapidly absorb phosphorus and accumulate 75% of their requirement when the crop produces 25% of its dry weight. Winter wheat absorbs about 70% of phosphorus between tillering and flowering. For corn, the peak phosphorus demand is during the initial three weeks of the growing season.

Some of the fast growing crops can take from soil as much as 1 kg phosphorus/ha/day, the actual amount varying with the crop. Phosphorus in the soil solution is thus rapidly depleted and must be replenished by labile phosphorus within a short span, i.e., from a few hours to a few days. There is a critical limit on the readily-soluble soil phosphorus, below which the crop yield is adversely affected. It is, therefore, essential to build up and maintain a pool of labile phosphorus in the soil solution as a prerequisite for high production levels and sustainable agriculture.

The original natural source of phosphorus is **apatite** [$Ca_5(PO_4)_3F$], a calcium phosphate of low solubility. The rate of, and the extent to which, phosphorus is immobilized by biological factors influence the concentration of phosphate ions in solution. This in turn, influences the reaction of phosphorus with mineral fractions of the soil.

Soils rich in iron and aluminum react with phosphates to form insoluble compounds, which are unavailable to plants. The availability of soluble phosphates is reduced by the high activity of calcium which precipitates as dicalcium phosphate. Other factors affecting the quantity of phosphorus mineralization or immobilization are temperature, moisture, aeration, pH, cultivation intensity and the type of phosphate fertilizer added. The process of soluble $H_2PO_4^-$ ion rapidly reacting in soil to form an insoluble phosphate is called **phosphate fixation**.

Placing a soluble phosphate fertilizer in a band in the soil enhances phosphorus availability. However, crops use only about 20% of the added phosphorus, including the granulated phosphate material, during the season. Micro-organisms increase the plant-available phosphorus, the phosphorus uptake and the crop yield.

Phosphorus is removed by crops or lost through surface run-off, erosion or leaching. It needs to be replenished to avoid the decline of soil productivity (soil mining). Important sources of phosphorus and the factors leading to its removal from the soil are listed in Table-P.2.

Table-P.2: Factors leading to the depletion of phosphorus, and sources of P.

Factors responsible for P depletion	Phosphorus sources
Harvested crops	Soil reserves
Grazing animals	Incorporated crop residues and green manures
Surface run-off and soil erosion	Animal manures
Phosphate leaching	Mineral fertilizers, phosphate rock and sludge from waste sources

Ground rock phosphate is used as a fertilizer either directly or as superphosphate (mixed with sulphuric acid) or triple superphosphate (mixed with phosphoric acid). Other phosphate fertilizer materials are diammonium phosphate, monoammonium phosphate and ammonium phosphate sulphate. Many polyphosphates with a high phosphate content are also available.

Dissolution of rock phosphate in soil is influenced by its chemical reactivity, the soil pH, the exchangeable calcium and aluminum ions, and the organic matter. To attain the maximum dissolution efficiency. It is necessary to have (a) the soil pH between 6 and 7, (b) fresh soil organic matter, (c) phosphate fertilizers placed in bands for row crops, or broadcast for non-row crops, (d) more phosphorus for aerobic than anaerobic organisms, and (e) an awareness that cold temperatures lower the phosphorus absorption through roots.

Phosphorus deficiency in plants leads to (a) poor roots and disturbed growth, (b) stunted growth of leaves and stems, and (c) change in color of leaves or leaf edges.

Phosphorus deficiency interferes with the normal opening of the stomata of certain plants, resulting in a higher (~10%) leaf temperature during periods of sunshine, thus reducing the yield from plants and crops.

Soils with less than 10 ppm available phosphorus, calculated by **Olsen's method** of analysis, are said to be phosphorus deficient. This deficiency retards the growth, tillering, root development and ripening. The deficiency symptoms start with the older leaves. A bluish-green to reddish color develops which turns to a bronze red tint (Fig.P.16). Tobacco and cotton exhibit dark green leaves owing to phosphorus deficiency. Potatoes show rusty brown lesions on tubers, first as isolated flecks, which grow into larger areas as the flecks merge. Phosphorus deficiencies are corrected by the addition of **phosphate** fertilizers.

Phosphorus or **phosphate excess** causes the deficiency of other micronutrients, especially of zinc or iron, resulting in poor plant yield.

Fig.P.16: Phosphorus deficiency symptoms on leaves.

Phosphorus available form

Phosphorus occurs in soils in both inorganic and organic forms. The concentration of inorganic form ($H_2PO_4^-$, HPO_4^{2-}) in the soil solution is the most important factor governing the phosphorus availability. The ratio of $H_2PO_4^-$ and HPO_4^{2-} depends on the soil pH. The uptake of $H_2PO_4^-$ is more rapid than that of HPO_4^{2-}, the former being abundant at pH below 7.2.

The crystallization of apatite-like minerals is very slow. In the soil, phosphoric acid occurs in sparsely soluble forms of apatite [$3Ca_2(PO_4)_2 \cdot Ca(OH)_2$, or $3Ca_3(PO_4)_2 \cdot CaF_2$)], ferric phosphate and aluminum phosphate. Water-soluble phosphates are rapidly converted into forms that are unavailable to plants with a high content of iron and aluminum.

Phosphates get fixed in lime-rich neutral soils. By placing phosphates in bands or pockets, the fixation process can be relatively delayed. Granulated phosphate material also delays fixation. On soils liable to a quick phosphorus fixation, it is advantageous to use soluble phosphates sparingly, since these react slowly with soil particles.

Phosphate solubility cannot always determine the amount of plant-available phosphorus. The plant-available phosphorus is that which is actually absorbed by plants under favorable conditions.

The phosphorus content in fertilizers is expressed as phosphorus pentoxide (P_2O_5). Terms such as '**water-soluble**', '**citrate-soluble**', '**citrate-insoluble**', **total phosphorus** (as P_2O_5), etc. are used because the solubility of phosphorus varies in fertilizers. The sum of the water-soluble and the citrate-soluble phosphorus estimates the fraction of phosphorus available to plants, and is termed as **available phosphorus**.

Organic matter in the soil is an important source of phosphate. It can retard the inorganic fixation of soluble compounds of exogenous phosphoric acid used by plants. Phosphorus is released into the soil solution by the decomposition of crop residues and by the action of micro-organisms. These two factors significantly make phosphorus available to plants. Since soil phosphates have low mobility, only such portion of phosphorus becomes available to plants as is within a few millimeters of the root surface. Some plants can secrete organic acids which lead to the release of phosphate for plant uptake. Plants respond to phosphate deficiency by increasing the root to shoot ratio. However, this leads to a reduced plant yield.

The availability of soil organic phosphorus is governed by the rate of mineralization of the soil organic matter. The soil pH controls the availability of the inorganic soluble forms of iron, aluminum and manganese in the soil.

The quantity of readily available phosphorus can be estimated by different soil analysis methods. However, the quantitative analysis of extracted phosphorus may vary from one method to another. These methods can correctly diagnose soils as being either deficient, sufficient or excess in available phosphorus, although its exact determination is not possible.

Phosphorus cycle

The cycling of phosphorus between biotic and abiotic components of the environment is known as the phosphorus cycle.

Inorganic phosphates (PO_4^{3-},HPO_4^{2-},$H_2PO_4^-$) are absorbed by plants from soil and water bodies. These are eventually passed on to animals through the food chain. Within the living organisms, phosphates are built-up into nucleic acids and other organic molecules. On the geological time scale, phosphates in aquatic environments eventually form a part of rocks through a gradual process of erosion, and thus return to the soils, seas, rivers and lakes. These phosphorus-containing rocks are mined for the manufacture of fertilizers and provide an additional source of inorganic phosphate to the biotic environment. This completes the **soil phosphorus cycle** (Fig.P.17).

The chemical fixation of phosphorus takes place in soil. Microbial mineralization, solubilization and immobilization are important aspects of the phosphorus cycle. By microbial enzymatic activity, mineralization of organic phosphorus (animal or plant residues) takes place in soils, mostly when rich organic matter or organic manure is added in various forms. Fungi and bacteria bring about solubilization of inorganic phosphate. Unavailable or insoluble forms of phosphates like bone meal, rock phosphate, chemically fixed soil phosphorus, etc. are made available to plants by the activity of these micro-organisms. Such micro-organisms are called **phosphate solubilizing micro-organisms (PSM)**.

Phosphorus deficiency: See Phosphorus

Phosphorus derived from fertilizer

The term 'phosphorus derived from fertilizers' **(Pdff)** is used to distinguish this source of phosphorus from that derived from the soil. Pdff is calculated using radioactive

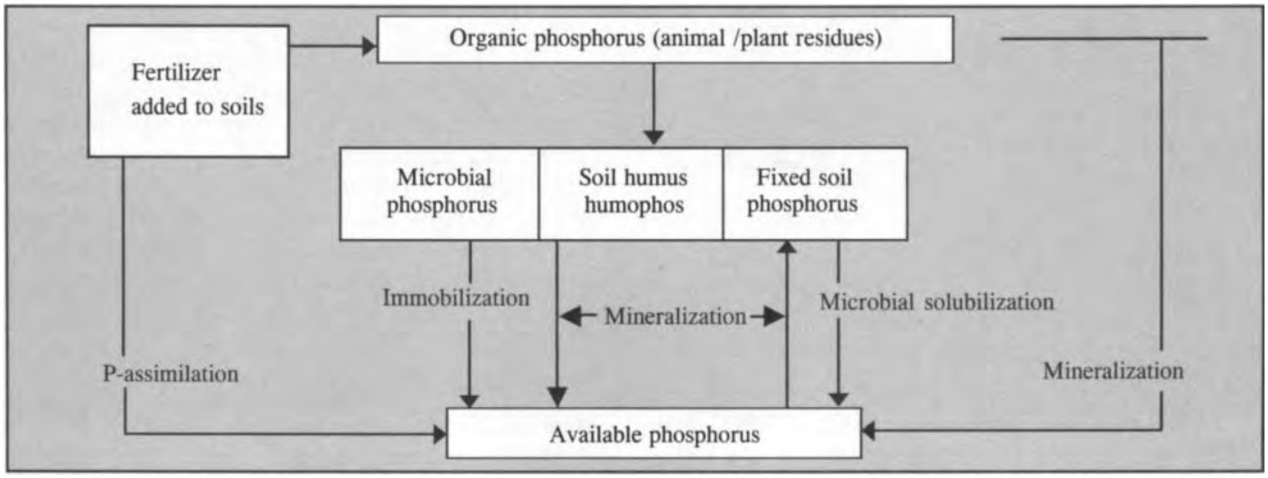


Fig.P.17: Soil phosphorus cycle.

phosphorus (^{32}P) or fertilizers containing phosphorus isotopes.

Phosphorus fertilizers

Phosphorus is essential during the initial growth stage of plant life. Soil phosphorus occurs in both organic and inorganic forms. Plants cannot always compete equally for soil phosphorus. Although most soils contain large amounts of phosphorus, it is present in insoluble forms and makes it inaccessible to the plant.

Soluble phosphate fertilizers are manufactured by treating naturally occurring phosphate rock with sulphuric acid or phosphoric acid, to make superphosphates, a mixture of $Ca[H_2PO_4]_2$ and $CaSO_4$, $Ca[H_2PO_4]_2$ only. The reaction of ammonia and phosphoric acid gives ammonium dihydrogen phosphate $[NH_4H_2PO_4]$ which is a very efficient fertilizer, since it gives both phosphorus and nitrogen.

Phosphorus fertilizers, as a class, generally refers to ammonium phosphates. These are either solid or liquid, and manufactured by reacting anhydrous ammonia with orthophosphoric acid or superphosphoric acid.

Phosphorus inorganic forms

Phosphorus in inorganic forms occurs in minerals as insoluble phosphates of calcium, iron or aluminum. Soil contains phosphorus as fluorapatite, hydroxyl apatite, chlorapatite, iron phosphate or aluminum phosphate (by itself or in combination with a clay fraction).

Calcium phosphate is dominant in neutral to alkaline soils, whereas phosphates of iron and aluminum occur in acidic soils. Sandy soils and some highly weathered tropical soils have a lower capacity for binding phosphates which are prone to losses.

When a water-soluble phosphate fertilizer (such as superphosphate or ammonium phosphate) is applied to soil, it reacts immediately after its dissolution, with calcium, iron or aluminum ions in the soil solution and precipitates as insoluble phosphates or gets adsorbed on the surface of clay particles. These phenomena are known as **fixation of phosphate** or **reversion of phosphate**, and the compounds formed are known as **phosphate reaction products**.

The ionic forms of inorganic phosphorus are pH dependent (Table-P.3).

Table-P.3: pH dependent ionic forms of phosphorus.

pH	Form of phosphorus
<3	H_3PO_4 (acid form)
4 to 6	$H_2PO_4^-$
6.5 to7.5	$H_2PO_4^-$ and HPO_4^{2-}
8 to 10	HPO_4^{2-}
>10	PO_4^{3-}

Labile inorganic phosphorus such as $H_2PO_4^-$ and HPO_4^{2-} are adsorbed to mineral surfaces. In acid soils, adsorption of inorganic phosphorus takes place primarily on aluminum and iron oxide and hydroxide minerals. Adsorption of phosphorus also readily occurs on the broken edges of kaolinite clay minerals.

In calcareous soils, small quantities of phosphorus can be adsorbed through replacement of carbonate ion (CO_3^{2-}) on the surface of calcium carbonate ($CaCO_3$). In alkaline soils, calcium phosphates of low solubility are formed. The retention of phosphorus is frequently a problem in acid soils high in oxides of iron and aluminum. In such soils, the adsorbed phosphorus is held with a 5 times more bonding energy than in calcareous soils.

The forms of inorganic phosphate present in a soil are usually indicative of its stage of weathering; while the phosphates of calcium decrease with weathering, those of iron and aluminum rise. Calcium phosphates are more soluble than aluminum phosphates which in turn are more soluble than iron phosphates.

Phosphorus pentoxide

Phosphorus pentoxide (P_2O_5) or **phosphoric anhydride** is a white, highly deliquescent solid which sublimes at 300°C and reacts violently with water to give orthophosphoric acid. It is prepared by burning elemental phosphorus in excess oxygen, and then purified by sublimation. The compound is used as a drying and dehydrating agent; for example, the amides are converted into nitriles, and sulphuric acid is converted to sulphur trioxide (SO_3). The fertilizer phosphorus is specified as the weight percentage of phosphorus pentoxide.

Phosphorylation

Phosphorylation is the gain or loss of the phosphoryl group $-PO_3H_2$. **Adenosine triphosphate (ATP)**, an energy-rich molecule, transfers a phosphoryl group to another molecule with the release of energy. ATP is converted to **adenosine diphosphate (ADP)**.

$$\text{ATP} + \text{R-OH} \longrightarrow \text{ADP} + \text{R-OPO}_3\text{H}_2$$

ATP is a high energy phosphate and is also a reactive phosphorylating agent.

The most important function of phosphorus in a plant system is to store and transfer energy, the main carrier of chemical energy being adenosine triphosphate (ATP). ATP is generated by the phosphorylation of adenosine monophosphate (**AMP**) and adenosine diphosphate (ADP) in the presence of sufficient phosphorus, using chemical energy released during the oxidation of food. When phosphate ions are transported to an acceptor group within the living cell as a result of phosphorylation, the activation energy barrier is lowered. This enables many biochemical reactions to take place in the cell.

Photoautotrophic organisms

Micro-organisms are classified according to their nutritional patterns, oxygen needs and symbiotic relationships. Micro-organisms that obtain nutrition and energy from sunlight, and nutritive carbon from carbon dioxide are called photoautotrophs. Blue-green algae or cyanobacteria are examples of this type of organisms. Specific groups of autotrophic bacteria can oxidize ammonium, nitrites, sulphides, sulphur as well as ferrous and manganous ions, hydrogen gas and carbon monoxide. The oxidation transforms minerals to some useful forms. For example, the important autotrophic soil bacteria oxidize ammonium to nitrites and then to nitrates.

Photodegradation: See Degradable waste

Photo dissociation

Dissociation is the reversible decomposition of molecules into two or more than two simpler fragments (atoms, radicals or ions). This is brought about by different ways of which photo dissociation is one. When a molecule breaks into atoms consuming energy which comes from light, the dissociation is called photo dissociation. For example, hydrogen bromide when exposed to sunlight, dissociates into hydrogen and bromine by photo dissociation. (See also Dissociation.)

Photoheterotrophic organisms

Photoheterotrophic organisms, or photoheterotrophs, are those that depend on organic matter for their nutrition. These organisms obtain part of their energy from sunlight, and carbon from organic matter. Products broken down in the process of digestion are used to synthesize organic materials required by the organisms. Most soil bacteria (both nitrogen-fixing and non-nitrogen-fixing) belong to this group and carry out much of the decomposition of organic materials.

Photolithotrophic sulphur bacteria

Three types of bacteria are involved in sulphur oxidation, and are active in the rhizosphere. Photolithotrophic sulphur bacteria belong to one type, other types being *Chlorobium* or green bacteria, and *Chromatium* or purple bacteria. Photolithotrophic sulphur bacteria fix photosynthetic carbon using sulphide and sulphur compounds as 'oxidant sinks'. (See also *Thiobacillus*).

Photophosphorylation: See Photosynthesis

Photosynthesis

Green plants synthesize organic compounds from carbon dioxide and water in the presence of sunlight. This happens through a chemical process called photosynthesis which takes place primarily in the green leaves and is the basis of all crop yields (Fig.P.18).

Unicellular marine algae carry out the bulk of photosynthesis in the sea. Two principal reactions are involved in photosynthesis, the **light dependent reaction** and the **Calvin cycle process**. In the light dependent process, sunlight is absorbed by the photosynthetic green pigment chlorophyll, and the energy is used to bring about photolysis of water as:

$$H_2O \longrightarrow 2H^+ + 2e + \tfrac{1}{2}\,O_2$$

Electrons released in the above reaction pass through a series of electron carriers, during which they lose their energy to convert adenosine diphosphate (**ADP**) to adenosine triphosphate (**ATP**) by a process called **photophosphorylation**. The electrons and protons produced by photolysis of water are used to reduce NADP (nicotinamide adenine dinucleotide phosphate) as:

$$2H^+ + 2e + NADP^+ \longrightarrow NADPH + H^+$$

ATP and NADPH produced during the light reaction provide energy and reducing power respectively for the succeeding dark reaction which takes place in the absence of light. During this reaction, known as the Calvin cycle,

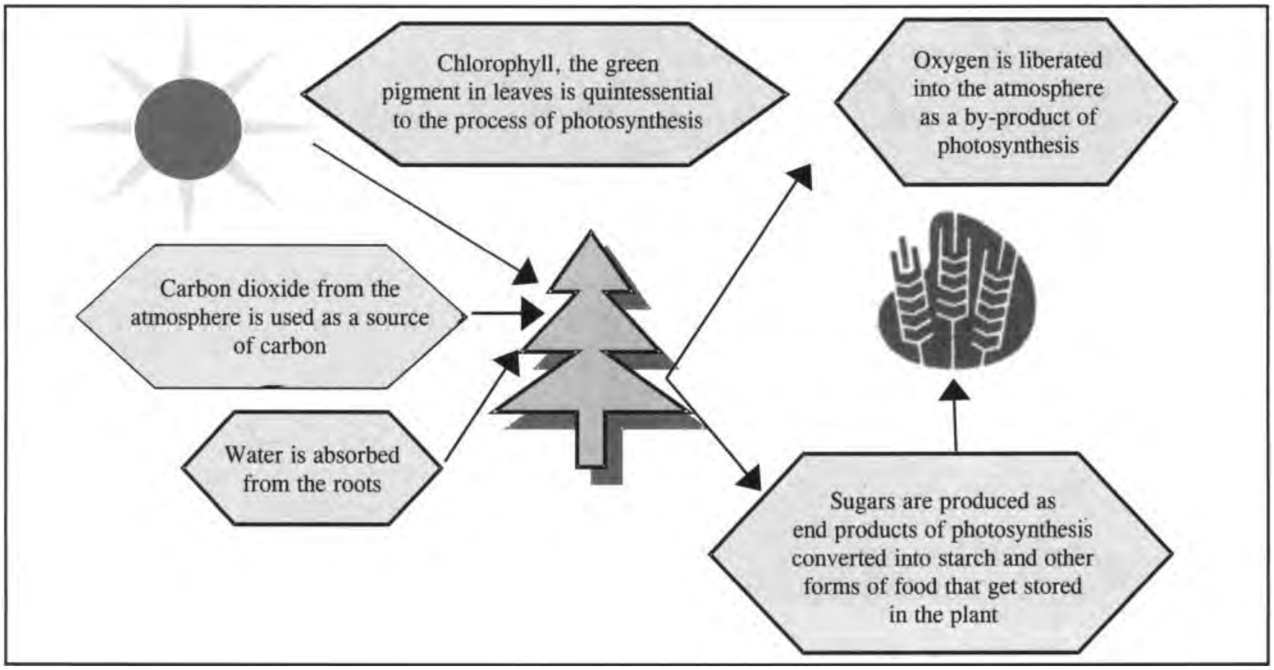


Fig.P.18: Process of photosynthesis.

carbon dioxide is reduced to carbohydrate in a metabolic pathway. Photosynthesis can be summarized thus:

$$6CO_2+6H_2O+(\text{chlorophyll}) \longrightarrow C_6H_{12}O_6+6O_2$$

Since virtually all other forms of life are directly or indirectly dependent on plants for food, photosynthesis is the basis for all life on earth. Furthermore, virtually all the atmospheric oxygen has originated from the oxygen released during photosynthesis.

The maximum possible solar energy conversion efficiency by crops is between 6 and 8%, calculated by using the following formula:

$$\text{Efficiency} = \frac{\text{Energy content of dry matter}}{\text{Total solar energy available}}$$

The low conversion efficiency is attributed to the shortage of nutrients and water, inadequate temperature, poor pest control methods and management practices.

The photosynthetic rate of plant leaf tissues varies significantly. Corn and sorghum exhibit the maximum photosynthetic rate of 50 to 60 mg of carbon dioxide per dm^2 per hour, whereas small grains, temperate grasses and many other plants show a maximum rate of 20 to 30 mg of carbon dioxide per dm^2 per hour. The photosynthetic rate is also dependent on the nitrogen content in the leaves. This rate can be increased through selection and breeding.

The photosynthetic rate depends on the age of the leaf, the **genotype**, the assimilate demands by sinks and effects of the environment. The photosynthetic rate of leaves declines with age.

There exist two groups of plant species with distinct photosynthetic systems. In C_3 plants, the carbon is located in a three-carbon carboxylic acid, phosphoglyceric acid. The carbon dioxide compensation point is high (~ 50 ppm). Net photosynthesis is inhibited by an atmosphere containing more than 1% oxygen. In the C_4 group, the first product of photosynthetic carbon fixation is a four-carbon dicarboxylic acid, oxaloacetic acid. The carbon dioxide compensation point is close to zero and oxygen has no major effect on the rate of net photosynthesis.

Photosynthesis and the subsequent translocation of photosynthetic products take place simultaneously in green plants. In the early stages of plant growth, the photosynthetic product is utilized for the formation of vegetative parts, whereas later it is used in the formation of economically important storage components such as grains, fibers, oils and nuts. If the supply of photosynthetic products exceeds the demand, the same is stored in the stalks and sheaths of leaves and later translocated to the growing parts of the plant, depending on the need.

The **net photosynthesis** is the total photosynthesis minus the respiration component which can be used in determining the crop yield.

Photosynthesis inhibitors: See Triazines

Phreatic water

Phreatic water or **groundwater** or non-artesian water is the highest of the continuous water-bearing strata capable of feeding a well. This stratum can intervene in different ways in soil evolution, particularly when it is very close to the surface. It can dissolve various constituent elements of the soil. Just above the stratum, water rises by capillary ascension to form a capillary fringe which becomes a source of moisture for plants. When the stratum is permanently or transiently very close to the surface, it becomes a major factor for the pedogenesis of soils, such as **hydromorphic soils**.

Phthalate

Phthalate is the salt or derivative of phthalic acid. Potassium hydrogen phthalate is the primary standard for preparing a standard sodium hydroxide solution. Dioctyl phthalate, an ester of phthalic acid and octyl alcohol is used as a plasticizer in plastics. (See also Standard solution.)

Phthalocyanine

Phthalocyanine is a group of benzoporphyrins which have strong pigmenting power, forming a family of dyes.

The basic structure of the molecule comprises four isoindole groups $(C_6H_4)C_2N$, joined by four nitrogen atoms. Four commercially important modifications are: (a) metal free phthalocyanine $(C_6H_4C_2N)_4$, having a blue-green color, (b) copper phthalocyanine in which a copper atom is held by secondary valences of the isoindole nitrogen atoms, (c) chlorinated copper phthalocyanine, green, in which 15 to 16 hydrogen atoms are replaced by chlorine, and (d) sulphonated copper phthalocyanine, water-soluble and green, in which two hydrogens are replaced by sulphonic acid groups. It is used in decorative enamels and automotive finishes; chlorophyll and haems have basic phthalocyanine structures in their molecules.

Phycology

The study of **algae** which are the simplest known green plants is called phycology or **algology**.

Phyllotaxis

The natural arrangement of leaves on a stem, such that lower leaves are not shaded by upper leaves is called phyllotaxis. Thus, phyllotaxis ensures that all leaves get their share of sunlight.

Phylum of simple animals

Various phyla of kingdom Protista are a group of unicellular or acellular, microscopic, essentially aquatic **eucaryotes** or **protozoa** that do not have a true cell wall. This classification was formerly known as phylum of simple animals. (See also Protozoa.)

Physical analysis of fertilizer

Physical analysis means physical determination of the composition of a substance. The physical property is an important criterion in selecting a fertilizer. The acceptability of a fertilizer in the market place depends not only on the chemical properties, (such as the form, nutrient content, availability to crop, etc.), but also on its physical characteristics (such as particle size, dustiness, flowability, hygroscopicity, caking and segregation tendency).

The physical properties of a fertilizer also include particle size, density, angle of repose, granule hardness, sphericity, surface area, porosity, melting point, etc., which can be quantitatively evaluated. Physical properties of a fluid fertilizer relate to density or specific gravity, viscosity, crystallization temperature, pH, settling time, gel strength, clarity, solidification temperature and pourability.

Physical compatibility of fertilizer blends

The physical compatibility of fertilizer blends is the ability of two or more materials to remain thoroughly mixed during storage, handling and application. Techniques based on the particle size analysis are employed to determine physical compatibility. (See also Compatibility.)

Physical equilibrium: See Equilibrium

Physical weathering

Under natural conditions, physical **weathering** causes mechanical disintegration of rock materials or reduction in the particle size. Physical weathering is caused by (a) sudden and wide variations of temperature, (b) abrasive action of particles present in the wind, (c) rain (particularly hail) falling with force, and (d) the roots of trees, or vegetation growing into the cracks and joints. Freezing and thawing can also break large particles into smaller ones. Growth of salt crystals can do the same. These changes in volume shatter rocks and minerals along the lines of weakness.

Physico-chemical profile

In the context of analyzing various aspects of soils, one can draw up a profile of all the constituents and all such properties of the soil as its acidity, porosity, particle size distribution, content of nitrogen, organic matter, calcium carbonate, etc. Such aspects and properties make up for the physico-chemical profile of the soil. (See also Soil profile.)

Physiological efficiency of nutrients: See Nutrient efficiency

Physiological maturity of plants

Physiological maturity is defined as the period of advancement in the cycle of a plant, in which it reaches the state of full growth. For cereals and grain legumes, it is related to the full development of the grain (Fig.P.19). Grain crops should be harvested at their physiological maturity. Premature harvesting reduces yields owing to low grain weight. Delayed harvesting reduces yield owing to the shattering of grains. Harvesting at an inappropriate time adversely affects the quality of grain. Harvesting over-ripe grain reduces the milling quality of rice. (Total milled rice yields were found to be 3% less after a two-week delay in harvesting.)

Fig.P.19: Matured pearl millet crop.

Systematic sampling and dry weight determination can help define the physiological maturity of a crop. When no further increase in grain weight is observed, the plant is said to have reached physiological maturity. Physiological maturity is realized at 38 to 43% moisture level in wheat, 42 to 48% in barley and 41% in triticale. The maximum rice in Colorado, USA, was obtained when the grain moisture was 28 to 30% at harvest. Most early-maturing rice varieties in California are harvested when the average moisture content is 24 to 26%. The moisture content at the time of harvest is different for mechanized harvesting than for manual harvesting.

The determination of physiological maturity via moisture content is laborious and time consuming. At physiological maturity of corn, an abscission layer gets formed in the basal region of the placental tissue of the carpel. This layer, called **black layer**, restricts the translocation of carbohydrates to the mature seed. In sorghum, a dark layer appears which coincides with the appearance of the cut-off of radioactive assimilate translocation to the developing kernels. A non-destructive estimation of the physiological maturity in oats is based on the observation that half of the glum tips no longer take up red dye and approximately 75% of the glum surface remains yellow.

Physisorption

Depending on the forces involved, there are three types of adsorption – **chemisorption, electrostatic adsorption** and physisorption. Physisorption is a type of adsorption in which the adsorbate adheres to the surface only through van der Waals forces. The hygroscopic nature of fertilizers is due to physisorption of water on the surface. The control of odor in airconditioned places uses activated carbon which works on the principle of physisorption. Military gas masks work on this principle. (See also Adsorption.)

Phytic acid

Phytic acid is inositol hexaphosphoric acid which exists in several stereoisomers. It is a source of phosphorus compounds for seeds and young plants. (See also Phytin.)

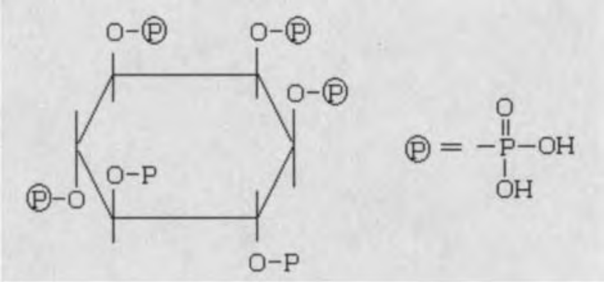


Fig.P.20: Structure of myo-inositol hexaphosphate.

Phytin

Phytin is a major organic phosphorus compound in seeds and is the source of phosphorus for new seedlings, till they start absorbing it from the soil. The phosphorus reserve in seeds is the calcium/magnesium salts of inositol hexaphosphoric acid (phytic acid). It is used as a fertilizer since it can advantageously be absorbed by plants, and is found in the soil as a product of the degradation of organic matter.

Inositol phosphate is thought to be of microbial origin and can exist in several stereoisomeric forms; phosphate esters of myo-, scyllo-, neo- and chrio-inositol have been characterized in soil. Myo-inositol hexaphosphoric acid (**phytic acid**), as in Fig.P.20, is usually a major pool of organic phosphorus, which is fairly stable in an alkaline medium but which gradually hydrolyzes (optimum pH 4.0) to a range of intermediate inositol phosphates, and finally, to inositol in acidic media. Enzyme phylase also hydrolyzes myo-inositol phosphates. Myo-inositol phosphates account for between less than 1 and 62% of the total soil phosphorus.

Phytobland oil-water emulsion

Oil adjuvants are of many kinds, one of them being phytobland oil-water emulsions. These are nearly-saturated light oils. They are not phytotoxic and are added to herbicides for better penetration in foliage. They are called by different names, such as **corn oils**, **superior spray oils**, **supreme spray oils**, etc. (See also Adjuvants.)

Phytochemistry

Phytochemistry is the branch of chemistry dealing with (a) plant growth and metabolism, and (b) plant products.

The study relating to plant growth includes the absorption of inorganic nutrients (nitrogen, phosphorus, potassium, carbon dioxide, water, etc.) to form sugars, starches, proteins, fats, vitamins, etc. and is closely associated with photosynthesis.

Plant products comprise a vast group of natural materials and chemicals. These include alkaloids, cellulose, lignin, dyes and glycerides (fats and oils). Some of these are basic raw materials for industry (paper, pharmaceuticals, food, paint, perfume, flavoring, leather and rubber). Many miscellaneous plant products are also used as drugs, poisons and pigments.

Phytochemistry also embraces the study of plant hormones or growth regulators (**auxins**, cytokinins, **gibberellins** and synthetic types).

Phytodegradation: See Phytoremediation

Phytoextraction

Phytoextraction is another name for **phytoremediation**.

Phytogenic soils

Soils that develop in temperate regions under the influence of natural vegetation are called phytogenic soils. These soils are found in humid conditions with the accumulation of organic matter.

Phytohormones

Hormones that play a prominent role in plant growth are called phytohormones. The mode of transport of phytohormones is not fully understood, despite many on-going studies to establish their mechanism of operation. The movement of **auxins** in young stems is active and unidirectional, away from the stem tip.

An important recent concept relates to the interaction of different types of phytohormones. For example, altering the ratios of kinetin and indolacetic acid can vary the development of leaf and root formation in tissue culture.

Phytolith

The silica accumulated in a plant tissue is called phytolith. It looks like a gem and remains in soil even after the softer plant tissues decompose. The presence of phytolith in a particular layer of the soil indicates that the latter is a formed soil and not an unconsolidated deposit.

Phytometer

A plant used for measuring physical factors of a habitat, based on the physiological activities of the plant is termed as phytometer. The device for measuring transpiration consists of a closed vessel containing plants growing in soil. Water can escape only by transpiration from the plant (Fig.P.21).

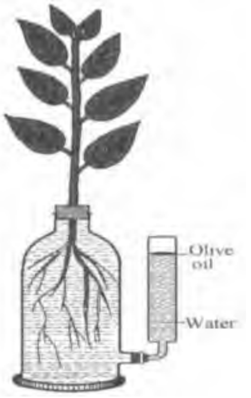


Fig.P.21: Phytometer.

Phytomorphic soil

Phytomorphic soil has a morphology which is influenced by the accumulation of plant debris from the region or zonal soils of that area; for example, peat soil. In Canada, a well-drained soil that develops under the dominant influence of natural vegetation of the region is called phytomorphic soil.

Phytoremediation

Certain plant species, by virtue of their unique properties, can reduce, remove or degrade such contaminants as toxins, hazardous heavy metals, etc. present in the soil. The process by which these plants do so is called phytoremediation. Phytoremediation is understood, in common parlance, as **bioremediation through green plants**.

Phytoremediation occurs through the action of internal enzymes, micro-organisms, plant roots, leaves, etc. The contaminated soils are redeemed and restored by cultivating such plant species.

There are many aspects of phytoremediation like phytoextraction, phytodegradation, phytovolatilization, etc.

When plants absorb these toxins through the roots and transport them to the aerial parts, it is called **phytoextraction**. Some plants that absorb large quantities of such toxins (especially a metal or metalloid) throughout their lives are called **hyperaccumulator plants**. This property is called continuous phytoextraction. Soils can be restored by cultivating hyperaccumulator plants. Continuous phytoextraction can be complemented with a technique called induced phytoextraction, in which accelerants or chelators are added to speed up mobilization of such metals like cadmium, lead, copper, chromium, etc. Plants like mustard and sunflower are known to respond to induced phytoextraction. Soils get redeemed of these unfavorable elements when such plants are harvested.

Another technique of phytoremediation is called **phytodegradation** in which plants convert organic pollutants into less toxic substances by secreting enzymes that act upon them. Hybrid poplar trees, *Datura innoxia*, etc. are known to convert RDX and TCE into their metabolic components through enzymes like laccase, nitrilase and peroxidase. Upon such enzymatic action, these components are believed to become less potent.

Some plants absorb toxins through roots and transport them to the leaves and volatilize them into the atmosphere through the stomata. Such a phytoremediation technique is called **phytovolatilization**. Yellow poplars and alfalfa are found to remove mercury by this method. Similar volatilization has also been observed in nature, by the action of some microbes, which, for instance, volatilize selenium into dimethylselenide.

Some deep-rooted grasses, some legumes and alfalfa contribute to phytoremediation by encouraging microbial activity that breaks down organic pollutants. Microbes oxidize the chemical residues which either get volatilized or degraded. The practice of growing grasses and forage plants for ground cover on polluted sites reduces water and wind erosion and is a healthy strategy for mine sites and arid regions. Planting deep-rooted hyperaccumulator trees and perennials is also ideal for reducing pollution from the groundwater. (See also Bioremediation through green plants.)

Phytotoxicity

When some chemicals, fertilizers or herbicides produce a poisonous effect on plants, these substances are considered phytotoxic and this characteristic is referred to as phytotoxicity.

For example, the presence of biuret of more than 2% in urea is harmful to plants and can be considered phytotoxic. Phytotoxicity of metals can be correlated to their **ionic potential**.

Phytotoxic, non-selective adjuvants

Phytotoxic, non-selective adjuvants are highly unsaturated (e.g., diesel oil) and readily sulphonated, giving them a low unsulphonatable residue character. Oils of this category are added to the knock-down type herbicides for spraying so that they can get absorbed by weeds in canals, ditch-banks, etc. (See also Adjuvant.)

Phytotoxic oil adjuvants

Adjuvants are substances that are added to herbicides to improve penetration and/or application. Oil adjuvants, useful in foliar penetration are of three types: **Phytotoxic non-selective**, **Phytotoxic selective**, and **Phytobland oil-water emulsions**.

Phytotoxic selective adjuvants

Phytotoxic selective **adjuvants** are not actually adjuvants, and may be sprayed directly without mixing with water, or in combination with herbicides.

Phytovolatilization: See Phytoremediation

PI

PI is short for **productivity index of soil**. (See Soil productivity index.)

Pie

Indoor storage of potatoes is called pie, **pit**, hog, bury or grave. It is different from clamp, which is the traditional way of storing potatoes - neatly piled and covered with earth and straw.

Pierre method of determining acidity or basicity

Chemical fertilizers make the soil acidic or basic. The basicity forming effect of chilean nitrate ($NaNO_3$) is one such instance.

The Pierre method to determine acidity or basicity of fertilizers is based on the following two assumptions: (i) The acid-forming effect of a fertilizer is caused by all of the chlorine and sulphur, one-half of the nitrogen and one-third of the phosphorus. **Andrews** modified this assumption to say that the entire amount of nitrogen contributes to soil acidity. (ii) The presence of Ca, Mg, K and Na in the fertilizer raises the soil pH, for example, applying ammonium sulphate to soil may induce the following reactions:

$$(NH_4)_2SO_4 + 2H_2O \longrightarrow H_2SO_4 + 2NH_4OH$$
$$2NH_4OH + 4O_2 \longrightarrow 2HNO_3 + 4H_2O$$
$$H_2SO_4 + CaCO_3 \longrightarrow CaSO_4 + H_2O + CO_2$$
$$2HNO_3 + CaCO_3 \longrightarrow Ca(NO_3)_2 + H_2O + CO_2$$

Thus, when all nitrogen is considered to be responsible for soil acidity, as proposed by Andrews, each molecule of ammonium sulphate (containing 28 g nitrogen) will require two molecules of calcium carbonate ($CaCO_3$, 2 × 100 g). This is equal to 7.14 kg of lime ($CaCO_3$) per kg of nitrogen in the fertilizer. If, however, only half of the nitrogen contributes to soil acidity, as suggested by Pierre, then each molecule of ammonium sulphate will react with 1.5 molecules of calcium carbonate [0.5 molecule for nitrogen and 1 molecule for sulphate ion (SO_4^{2-})]. Thus, 28 g nitrogen will react with 150 g calcium carbonate, or 5.35 kg calcium carbonate per kg of nitrogen. The amounts of lime ($CaCO_3$) needed for 100 kg of the fertilizer is calculated by multiplying the percent nitrogen in the fertilizer with equivalent acidity factor of 7.14 or 5.35. For ammonium sulphate, the values will be $7.14 \times 20.5 = 146$, or $5.35 \times 20.5 = 110$, using Andrews' or Pierre's assumption, respectively.

The equivalent acidity and basicity of a few chemical fertilizers is shown in Table-P.4.

Table-P.4: Equivalent acidity and basicity of chemical fertilizers.

		Lime required to neutralize acidity Pierre method	
Chemical fertilizer	**%N**	**Per kg N**	**Per ton fertilizer**
Ammonium sulphate	20.5	5.35	1100
Anhydrous ammonia	82.2	1.80	1480
Urea	46.6	1.80	840
Triple super phosphate	0	0	0
Muriate of potash	0	0	0

Pierre modification to soil productivity index

Pierre modified the **soil productivity index** to include the assumption that with invariant climate management and plant differences, nutrients are not a limiting factor for productivity. In another approach, productivity index (PI) of soil is given by:

$$PI = H \cdot D \cdot P \cdot T \cdot N \text{ (or S)} \cdot O \cdot A \cdot M$$

where H is the soil moisture, D is the soil drainage, P is the effective soil depth, T is the soil texture or structure, N is the base saturation, S is the soluble salt status, O is the organic matter content, A is the CEC/nature of clay and M is the mineral reserve.

Piezometric head

An artesian well is one which is bored vertically into the water table, in order that the natural pressure continually ejects water without pumping. Artesian conditions prevail whenever an imaginary surface that coincides with the head of the water, (measured in a vertical hole drilled into the aquifer) called the piezometric surface, rises above the ground water table. The level, to which the water rises in a pipe placed in the water-bearing formation, is known as the piezometric head.

Pig manure

Pig manure is wet, runny and slow-acting. But compared to horse manure, it loses lesser nitrogen and rots faster.

The nutrient value of pig manure is 0.5% N, 0.3% P and 0.45% K. Quantities of around 140 kg are required to be spread per 100 sq m of land.

Pigment

Any substance, usually in the form of a dry powder that imparts color to another substance or mixture is called a pigment. Most pigments are insoluble in organic solvents and water. Exceptions are natural pigments, like chlorophyll which are generally soluble in organic solvents.

To qualify as a pigment, a material must have positive colorant value. This excludes whitening barites, clays and talc. Some pigments like zinc oxide and carbon black are also reinforcing agents, but the two terms are not synonymous. In paint and rubber industries, these distinctions are not always observed.

Pigments may be classified as inorganic and organic. They are further subdivided as follows:

1. Inorganic

(a) metallic oxides (iron, zinc, cobalt, titanium, chromium); (b) metal powder suspensions (gold, aluminum); (c) earth colors (siennas, ochers, umbers); (d) lead chromate; (e) carbon black

2. Organic

(a) animal (rhodospin, melanin); (b) vegetable (chlorophyll, xanthophylls, indigo, carotene); (c) synthetic (phthalocyanines, lithols, toludine, para red)

Plant pigments are natural colorants of organic nature produced by plants, with the exception of fungi and lichens. They may be classified into three groups:

(i) The chlorophylls (types a,b and c): green color.

They are magnesium containing porphyrins, and are technically considered to be microcrystalline waxes.

(ii) The carotenoids: yellow and orange colors: (a) carotene (straight-chain hydrocarbon), and (b) xanthophylls (straight-chain hydrocarbons containing two oxygen molecules)

(iii) The flavanoids: red, yellow, blue, orange, ivory colors. They are oxygen containing heterocyclic compounds: (a) catechins, (b) flavones, flavanols, anthocyanins, (c) flavanones and leucoanthocyanidins, and (d) flavonols.

Some of these pigments can be made synthetically. They have limited use in textile and pharmaceutical products.

Pile set

Caking of fertilizers is caused by the formation of contact points among the particles. The fertilizer material when stacked in bags or piled in bulk, forms lumps, and is usually referred to as **bag set** or pile set. Under these conditions, **adhesive contacts** (**capillary adhesions**) are formed between the surfaces coming in contact as a result of molecular attraction, known as **van der Waals forces**. This type of contact is influenced mostly by the plasticity of the particles and the pressure exerted on the material. With minimal handling, the material normally reverts to the free particulate form.

Pinch test

To estimate the quality of clay, certain simple tests are carried out which do not need any empirical data. These are called **puddle tests**. They are qualitative but very useful. The pinch test is one of such puddle tests. In the pinch test, the clay is kneaded and formed into a ball of about 75 mm diameter. The ball is squeezed between the hands until it forms a disc of about 25 mm thickness. If there is no crack in the disc, the clay is considered to have passed the test. (See also Puddle tests.)

Pipe-cross reactors: See Pipe reactor

Pipe reactor

A pipe reactor is commonly used in the manufacture of ammonium polyphosphate. A pipe reactor consists basically of a 5 to 15 meter long corrosion-resistant pipe, to which ammonia, phosphoric acid and sometimes water are simultaneously added at one end through a T-shaped pipe. The latter gives the reactor the name **Tee** (T) **reactor** (Fig.P.22).

In a simple reaction chamber, anhydrous ammonia and phosphoric acid react to produce a mixture of ammonium phosphate, ammonium orthophosphate and polyphosphates.

Tee reactors are also used to manufacture fluid fertilizers and ammonium nitrate by the **AZF Grand Paroisse process**. In the early 1970s, the conventional tank-type pre-neutralizer was replaced by a novel device, referred to as a pipe or tee reactor, which is now used to react large amounts of ammonia with phosphoric acid.

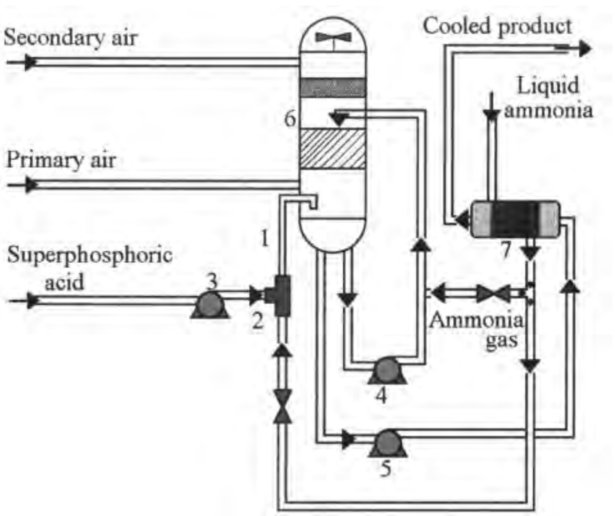


Fig.P.22: Flow-chart of a pipe-reactor plant for the production of ammonia polyphosphate solution. 1. Pipe reactor, 2. Pipe tee, 3. Variable speed gear pump, 4. Circulation pump, 5. Product pump, 6. Integral mix tank, cooler, scrubber, 7. Ammonia vaporizer. (Source: "Fertilizer Manual", 1998. UNIDO, IFDC and Kluwer Academic Publishers, The Netherlands. With permission).

The pipe reactor is inexpensive, simple to operate, and does not need pumping slurries. Its main advantage is that it can produce more amounts of concentrated slurry than a pre-neutralizer can; thus, the specific process water requirement is much less. This enables the use of phosphoric acid of 54% concentration (instead of 40 to 42%) which allows reduction in the size of the material handling equipment.

Other advantages of the pipe reactor process compared to the pre-neutralizer process are (a) lower investment costs, (b) lower operating costs, (c) high adaptability concerning feed stocks, (d) amenability to a wide variety of product formulations, (e) low environmental impact, and (f) high operating flexibility and stability. The diammonium phosphate produced by a pipe reactor is almost completely citrate-soluble.

Several variations of the pipe-type reactor are currently used in the NPK, DAP and MAP production plants. In the **pipe-cross reactor**, as in a T-reactor, ammonia enters the pipe along the horizontal axis and phosphoric acid enters at right angles. An additional inlet is provided directly opposite the phosphoric acid inlet, through which another feed can be added at a right angle to the ammonia stream. This allows sulphuric acid to be added to the reaction mixture. Typically, the pipe-cross reactor is operated below one atmosphere (pressure unit) and also used in the manufacture of ammonium nitrate by the AZF-Grand-Paroisse process.

Pipette method for soil texture determination

The pipette method is based on the rate of fall of solid particles in a liquid medium as per Stokes' law. Assuming average particle sizes of sand, silt and clay as 50, 5 and 2 μm, respectively, quantities of particles are calculated and the textural class determined.

Pit

Pit is another term for **pie**, the indoor storage place for potatoes.

pK

pK is the logarithm of the reciprocal of the dissociation constant (K).

$$pK = \log_{10}\frac{1}{K}$$

The symbol pK is used to express the strength of an acid or a base. If an acid has a dissociation constant of 10^{-3}, its pK is 3.

The pK values are often more convenient to tabulate and use than the equilibrium constants themselves. The value of K for the HSO_4^- ion in aqueous solution at 25°C is 0.0102 mole/liter. The logarithm is $0.008_6 - 2.000$ = minus 1.992_4. The pK, is therefore, minus 1.992_4. The choice of algebraic sign, although arbitrary, results in positive values for most dissociation constants applicable to aqueous solutions.

Placement drill for fertilizers

Placement drill is a machine that can place fertilizers close to the rows of seeds and at a slightly lower depth. This improves the efficiency of the fertilizer by ensuring that the nutrients are available to the actively growing roots of young seedlings.

Drill placement is a method of applying fertilizer by a drill along with the seeds. The method gives good results with wheat, maize and other cereals, which can withstand contact with the fertilizer; however, application of more than 25 kg/ha nitrogen along with the seeds is inadvisable in view of possible seed burn.

Placement of fertilizer

Fertilizers are placed in specific zones of the soil, so that the fertilizer comes within the feeding range of the plant roots. The placement can be on the soil surface, under the surface, around the plants, etc. Fertilizers are placed as per the crop need and according to the crop growth pattern. (See also Fertilizer placement.)

Plaggen horizon

Plaggen is one of the six epipedons or surface horizons recognized in soil taxonomy, the others being mollic, anthropic, umbric, histic and ochric. Plaggen horizon is a result of human activity. It is very rich in humus because of continued manuring and mixing. This horizon is about 50 cm thick and dark in color. (See also Soil horizon.)

Plagioclase feldspars

Feldspars are a group of silicate materials. These are the most abundant minerals in the earth's crust and have a structure in which tetrahedral is linked with potassium, sodium and calcium.

Plagioclase feldspar is one of the two subgroups of feldspars, the other being **alkali feldspars**. Plagioclase feldspars vary in composition in a series that ranges from pure sodium feldspar (**albite**) to pure calcium feldspar (**anorthite**) with negligible potassium.

Plains

A hard or loose rock, from which a **solum** (or a layer above it) is formed directly or through an intermediate laterite, is known as parent material or **parent rock**. The parent material mass has a distinct shape and a characteristic particle size. The characteristic minerals or organic masses of the parent material are known as **landforms**. The name of one such landform is plains. Other familiar landforms are mesas, butters, plateaus, **glacial moraines** and **terraces**.

Flood plains are created by sediments deposited by flowing waters; **peneplains** are formed by streams and are nearly levelled near the streams. **Out-wash plains** are formed by the sand and gravel particles carried by gushing water from the melting ice mass.

Planosols

Planosols is one of the 106 soil units described by the FAO-UNESCO legend of the soil map of the world. It is a poorly-drained soil, developed above a hard pan or a clay pan. Planosols has an E horizon, showing stagnic properties at least in parts of the horizon and abruptly overlying a slowly permeable horizon within 125 cm of the surface and lacking a natric or spodic B horizon.

In the French system of soil classification, planosols is a soil having eluvial horizon, the lower boundary of which is marked within 100 cm from the soil surface by an abrupt textural change associated with stagnic properties above that boundary. Planosols can be eutric, dystric, mollic, umbric or gelic.

Plant

The earth has a huge plant kingdom which includes algae, fungi, mosses, grasses, vegetables, trees, etc. Plants are stationary and have no nervous system, and the cell wall contains large amounts of cellulose. They are the primary source of food for all other living organisms. All plants, except fungi, contain chlorophyll. In addition to sunlight, water and carbon dioxide, plants need nutrients for their normal growth. Their metabolic processes are vital to the maintenance of life on earth and are the result of following products: (a) oxygen (from respiration), (b) carbohydrates (from photosynthesis), (c) amino acids and proteins (from nitrates and nitrogen-fixing bacteria), (d) fats and oils, (e) vitamins, (f) natural fibers, (g) coal, and (h) various other substances like alkaloid drugs, rubber, etc.

Green plants are unique in being able to synthesize their own organic molecules from carbon dioxide and water using light energy by a process known as **photosynthesis**.

Although the more primitive plants vary considerably in their overall structure, the higher plants (gymnosperms and angiosperms) are much the same in their anatomy and morphology. In a typical angiosperm, four main regions or parts can be recognized: the root, the stem, the leaf and the flower. Each part has one or more basic functions.

Any plant portion contains thousands of tiny cells packed tightly together. The cells are not all alike and each has to perform a certain function. The basic plant cell tends to be rectangular and has a tough wall of cellulose which gives it its shape. The cell membrane, just inside the wall, contains protoplasm which contains the nucleus, the chloroplasts and many other microscopic structures. In the center of protoplasm, there is a large sap-filled vacuole, which maintains the cell's shape and plays an important part in the working of the whole plant.

Both sexual and asexual reproductions are possible in the plant kingdom.

Plant analysis

Plant analysis, or **leaf analysis**, is a technique to determine the elemental contents of tissues of particular plant parts. It plays a major role in diagnosing mineral nutrition problems in the field.

Two types of plant analysis are performed. One is a tissue test on fresh tissues in the field, and the other is a tissue test performed in the laboratory. Plant analysis is based on the assumption that the nutrients present in the plant are proportional to that available in the soil. The shortage of a nutrient may retard plant growth. Sometimes, the shortage of a nutrient may lead to the accumulation of some other nutrient in the cell sap. For example, a low nitrate supply for corn shows a high phosphorus level. These tests help in (a) finding out the nutrient-supplying power of the soil, (b) identifying nutrient shortages before deficiency symptoms appear, (c) determining the effect of fertility treatment on nutrient supply in the plant, and (d) studying the relationship of the nutrient status of the plant with the crop performance.

Tissue tests are rapid where plant parts may be chopped and extracted with reagents. The intensity of the color developed is compared with the standard and used to measure the concentration of the nutrient. In a more rapid test, the tissue is squeezed with pliers to transfer the plant sap onto a filter paper, followed by the addition of color-developing reagents. The color that develops is compared with the standard. Generally, a newly matured leaf is used for testing. The time of the day can influence the level of nutrients in a plant. For example, the nitrate presence is higher in the mornings than in the afternoons. Hence, the test is done early in the morning or late in the afternoon.

A total analysis is done on the whole plant or a part of it. The sample is dried and ground; the nutrient content is determined after digesting and ashing the material. The content of all essential elements as well as non-essential elements can be determined, although it is a slow and time-consuming process. The **critical nutrient concentration** (CNC) is used in interpreting the results of the plant analysis and in diagnosing the nutrient problems. CNC is the level of nutrients in the crop field or plot vs. nutrient concentration in the tissue, below which the crop yield, quality or performance becomes unsatisfactory. Since nutrient concentrations vary greatly among crops, regions or climates, and also in the transition region between deficient and adequate nutrient concentration areas, it is considered prudent to think in terms of the range of concentrations, rather than a specific concentration. **Critical nutrient ranges** have, therefore, been developed for most of the essential nutrients in many crops.

Plant available phosphorus: See Citrate-soluble phosphorus

Plant available water

Plant available water is that portion of water in the soil that the plant roots can readily absorb to sustain plant life. The water held with water potential between minus 1500 kPa and minus 33 kPa becomes available to plants (between minus 0.33 and minus 15 bars).

The available water is also that water which is between the **field capacity** and at the **wilting point**.

Plant density

Plant density is another term for **plant population** in a unit area.

Plant food

Plant food is a term used to express plant nutrients in a fertilizer.

Plant food content of fertilizer

The plant food content of a fertilizer is the total content (expressed in percentage) of the guaranteed plant nutrients in the fertilizer. For example, the percent nitrogen, phosphorus and soluble potash indicate the plant food content of the fertilizer.

Plant food ratio

The ratio of nitrogen to phosphorus and potash in a fertilizer is known as plant food ratio (**PFR**). It is a guide to the type of compounds used in it. Thus, a compound fertilizer containing 20% N, 10% P and 10% K has a ratio of 2:1:1. A number of fertilizers may have the same PFR, and hence have the same application, but the quantity required to be applied varies with the actual percentage of the nutrient content in the fertilizer. (See also Fertilizer.)

Plant growth media

Soil is the most important and widely known medium for plant growth since the beginning of history. The other natural media for plant growth are peat and coco peat. Besides these natural plant growth media, some artificial media such as foams, colloidal silicates, polymer dispersions and tensides have been developed for special purposes.

Zeoponics is one such medium developed by NASA of which zeolite is the major constituent. Zeoponics acts as a nutrient delivery system that increases nutrient retention and reduces loss of nutrients to the atmosphere. **Hydroponics** is another artificial medium developed for plant growth. It has aggregates (made of sand, gravel, crushed bricks, vermiculite or rice husk) for root support and nutrient solutions for growth. Some soil conditioners, like foamed phenolic and **polyurethane** resins, are also used as plant growth media. (See also Growth media for plants.)

Plant growth regulators

Plant growth regulators inhibit or encourage plant growth in certain sections so as to influence the overall growth and development of the plant.

In the USA, plant growth regulators have been successfully used to increase corn yield. **Mixtatol** is one such plant growth regulator. It controls lateral shoots by inhibiting the development of auxiliary buds, as in the tobacco plant. In ornamental plants, mixtatol does chemical pruning and leads to abundant flowering.

Planting fertilizer

Planting fertilizer is another name for **starter fertilizer**. (See also Starter dose.)

Plant kingdom

Plant kingdom is one of the two major groups of living organisms. The plant and animal kingdoms together embrace all living things except viruses. The plant kingdom is extremely diverse and is found in almost every conceivable habitat. Plants range in size from microscopic bacteria to even 120 m tall sequoias.

The plant kingdom is arranged into an orderly hierarchical pattern of classification containing divisions, classes, orders, families, genera and species. It should be noted that the distinction between the plant and animal kingdom is not absolutely sharp among the unicellular flagellates. Some of the groups, such as the euglenoids, that are classified as plants are treated as protozoan animals by many zoologists.

Plant nutrients

A substance that nourishes an organism and provides energy or a structural component is a nutrient. A mineral element is considered essential for plant growth and development, if it is involved in the metabolic functions of the plant life cycle. Such an element is called a plant nutrient.

The seventeen elements, essential for plant growth, are called nutrient elements. They are C, H, O, N, P, K, S, Ca, Mg, Fe, Zn, Mn, Cu, B, Cl, Mo and Ni. Additional elements, such as Na, Co, V, Si, I, Sr, F and Br are **non-essential nutrients**, but are beneficial to some plants which absorb them from the soil solution. Plants get carbon from atmospheric carbon dioxide and hydrogen and oxygen from soil water.

Nutrient elements are divided into the following groups: (a) **macronutrients** or **major nutrients** which are N, P, K, Ca, Mg and S. These are further divided as **primary nutrients** (N, P, K) and **secondary nutrients** or **mesoelements** (Ca, Mg and S), and (b) **micronutrients** which are Cl, Fe, Mn, B, Zn, Cu, Mo and Ni, also referred to as **trace elements** (Fig.P.23). These elements are essential and beneficial to plants. Nutrient elements such as sodium, iodine, strontium, fluorine, vanadium, cobalt, silicon and bromine fall under the category of beneficial elements. Apart from these, plants need other growth promoting nutrients called **accessory nutrients**, like vitamins, purines, pyrimidines and amino acids.

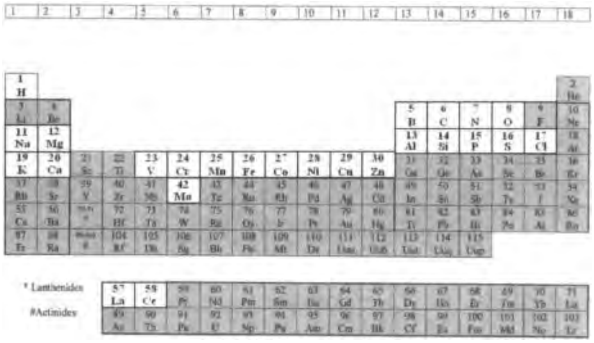


Fig.P.23: Periodic Table showing positions of plant nutrients.

Primary and secondary nutrient elements, required in large amounts, are constituents of many plant compounds such as proteins, nucleic acids, chlorophyll, etc. and are essential for energy transfer, maintenance of internal pressure and enzyme function. Primary nutrients are most commonly applied to almost each crop unless organic farming is practiced. On average, most plants need to contain N, P and K in the ratio of N: P: K = 2: 0.44: 0.83 (or N: P_2O_5: K_2O = 2: 1: 1).

Micronutrients are required in small or trace quantities and have a variety of essential functions in plant metabolism. Most of the micronutrients are constituents of enzymes.

Irrespective of the class to which they belong, all essential nutrients are equally important for plant growth. For better crop yields, these elements have to be present in soils in adequate amounts, and in their available forms. A plant nutrient, present in amounts exceeding the plant's needs, may become toxic to the plant or may cause deficiency of some other nutrient. The margin between critical deficiency and toxicity limits is quite narrow for elements such as copper, boron and iron.

Two ways of expressing plant nutrient content are: in their elemental form or as oxides. In both, nitrogen is expressed as elemental N, whereas P and K are expressed either as the oxides (P_2O_5 and K_2O) or as elements phosphorus and potassium. The conversion factors are phosphorus × 2.29 = P_2O_5 and potassium × 1.2 = K_2O on weight basis. The nutrients are not added in the same ratio as the plant content since mineral fertilizer is only one of the nutrient sources, and other sources differ in their efficiency in delivering the nutrients.

Production of materials containing one or more of these three nutrients is a major goal of the fertilizer industry. Some of these fertilizers also contain secondary nutrients and micronutrients. Of all the nutrients, nitrogen has the most pronounced effect on the development and growth of plants.

General functions of macro and a few micronutrients are given in Table-P.5.

The primary nutrients are important mainly for root, shoot and vegetative growth, flower and fruit formation and fruit and seed quality. Secondary nutrients and micronutrients are involved in various metabolic functions, enzymes, photosynthesis, etc., as also the overall development and growth of plants.

Primary nutrients are required in large quantities and micronutrients in very small quantities.

Nutrient requirement of a crop, wheat, for example, could be 80 to 120 kg N/ha, 40 to 60 kg P (as P_2O_5)/ha and 40 kg K (as K_2O)/ha.

Zinc sulphate is recommended at the rate of 5 to 15 kg/ha.

Zinc is required in plants in very small quantities. Its concentration in plants, when below 20 ppm is considered deficient and when above 400 ppm is considered toxic.

Table-P.5: Nutrient elements and their functions.

Element	Function
Nitrogen (N)	Part of all amino acids, proteins, chlorophylls, enzymes, alkaloids, vitamins, hormones, nucleic acids, and responsible for vegetative growth of plants
Phosphorus (P as P_2O_5)	Stimulation of early root growth, hastening plant maturity, energy transformation within the cells and development and ripening of fruit and seed
Potassium (K as K_2O)	Important for healthy root development, crop quality, improving sugar, starch and oil content in plants, taste, size and keeping quality of fruits, induces resistance in plants to disease and insect attacks
Calcium (Ca)	Major role in metabolic control. Controls many enzyme reactions, enhances uptake of nitrate
Magnesium (Mg)	Constituent of chlorophyll, protochlorophyll, pectin and phyllis. Gives green color to leaves, role in photosynthesis, regulates uptake of other materials by plants
Sulphur (S)	Required for synthesis of sulphur-containing amino acids (cysteine, cystin and methionine), chlorophyll, coenzyme A, biotin, thiamine and glutathione. Enhances formation of oil in crops like soybean and flax
Boron (B)	Metabolism and transport of carbohydrates, regulation of meristematic activity
Chlorine (Cl)	Light reaction of photosynthesis, protection against oxidation
Cobalt (Co)	Symbiotic nitrogen fixation, redox reaction, other metabolic reactions involving use of cobamide coenzyme
Copper (Cu)	Constituent of several enzymes, role in photosynthesis, respiration and protein and carbohydrate metabolism
Iron (Fe)	Constituent of cytochromes, metalloenzymes. Role in photosynthesis, symbiotic N-fixation

Plant nutrient cycle

The plant nutrient cycle represents the different stages of plant evolution. It includes plant development, growth, propagation and ultimately its biological decomposition by soil micro-organisms. In this cycle, organic residue supplies cations, phosphorus and nitrogen to the soil, and thus helps the growth of a new generation of plants. This biological cycle is faster in tropical regions than in the temperate ones.

Plant population

Plant population, also called **plant density**, is the number of plants per unit area. Adequate spacing of crops is important for good farm yields (Fig.P.24). It also helps reduce interplant competition for air, moisture, nutrients and sunlight. An excessively wide or narrow spacing leads to a reduction in the yield. In tillering crops like rice, narrow spacing discourages the production of fertile tillers, whereas in maize, narrow spacing leads to low yields. Optimum plant population is a pre-requisite for high yields, through the satisfactory use of fertilizers.

Ideally, crops should be grown in square stands using small mounds which is the common spacing pattern on local farms. With ridges, it is possible to maintain equidistant spacing except where machinery is used. The exact spacing for any crop depends on the soil productivity, location and planting time. A closer crop spacing is acceptable on fertile and moist soils, but not so on poor, moisture-stressed soils. This accounts for sustained yields from close spacing and high plant populations as compared to rain-fed crops.

Fig.P.24: Appropriate plant population in a field leads to maximum yield production.

In several principal crops, higher plant populations or closer row spacing is practiced. In many regions, a narrower row spacing of 7 to 10 cm is advantageous for small grains such as wheat and barley. Higher plant populations and closer row spacing can affect nutrient needs, as was seen when the plant population was raised for two corn hybrids from 47500 to 97500 plants per hectare. The potassium uptake increased from 150 to 200 kg potassium/ha for one hybrid and from 125 to 175 kg potassium/ha for another.

Plant quarantine

The term 'quarantine' refers to the isolation imposed on an imported organism to prevent the possible spread of non-indigenous, potentially damaging pests and infectious diseases. It is necessary to eradicate such pests and diseases before they can become widespread and well established in the new country. It is in this context that quarantine is extremely important. The period of isolation imposed on plant samples or plant parts is referred to as a plant quarantine.

Developing countries are generally vulnerable to the damaging effects of exotic pest introductions owing to an inadequate infrastructure and the fragility of their economies. For instance, the importation of germplasm for agricultural development constitutes a further risk of introducing such quarantine pests. To be able to participate in world markets, nations must have stronger phytosanitary services.

The International Plant Protection Convention (IPPC) is an international treaty to secure action to prevent the introduction and dissemination of pests from plants and plant products, and to promote appropriate measures for their control. IPPC is governed by the Commission on Phytosanitary Measures (CPM) which adopts international standards for such preventive measures. The CPM has confirmed the IPP as the preferred forum for national IPPC reporting and for exchange of more general information among the phytosanitary community. The IPPC Secretariat coordinates the activities of the Convention and is hosted by Food and Agricultural Organisation (FAO).

Biosecurity is the key requirement for achieving safety for food, agriculture, fisheries and forestry. Biosecurity has direct relevance to food safety, the conservation of the environment, and sustainability of agriculture. Biosecurity encompasses all policy and regulatory frameworks to manage risks associated with food and agriculture (including fisheries and forestry) and constitutes three sectors, namely food safety, plant life and health, and animal life and health. These sectors include food production in relation to food safety, the introduction of plant pests, animal pests and diseases, and zoonoses, the introduction and release of Genetically Modified Organisms (GMOs) and their products, and the introduction and safe management of invasive alien species and genotypes.

Plant sample

A plant sample is a small representative quantity of the plant selected from a large lot received for plant analysis, to diagnose nutrient-related yield limitations. A semi-gravimetric analysis of a green plant tissue to determine the concentration of soluble nutrients, correlates well with more precise analyses leading to quick **tissue tests**.

The interpretation of plant analysis requires the knowledge of the crop nutrient composition or critical nutrient levels for a given crop. As the concentration of most elements changes with crop maturity, a critical plant composition criterion must be obtained for specific sampling periods in the developing plant.

Important components of proper tissue collection are: (a) plant parts taken from a specific location, (b) the stage of plant growth or specific time of sampling, (c) the number of parts taken per plant, and (d) the number of plants selected for sampling. Sampling instructions are very specific in terms of the plant part and its growth stage. When specific sampling instructions are not available, the general rule is to select the upper leaves. It is important to avoid plants which (a) have suffered long term climatic or nutritional stress, (b) have been damaged mechanically or by insects, (c) are infested by disease, (d) are covered with dust, soil or foliar spray material, (e) are border row plants or have shaded leaves within the plant canopy, and (f) contain dead tissue.

Normally, the tissue sample should be of the same morphological type such as leaves, petiole or stems, but not a mixture. Generally, the upper and recently matured leaf taken just before flowering or fruiting, represents better nutritional status of the crop. To evaluate plant nutrients accurately, the plant should be sampled at a regular interval, which can be 6 times, throughout the growing season. To evaluate the nutrient status of the plant in the field at least 10 to 15 samples from the average plants within the area should be tested by **green tissue test**.

The plant tissue sample collected in the field must be oven-dried at about 80°C to prevent spoilage of the sample as lower temperatures tend to reduce the dry weight. Plant samples should not be transported in polythene bags or other airtight containers to avoid spoilage. The plant tissue covered with dust, soil or foliar-applied material requires decontamination before drying. Mechanical wiping, brushing or washing with phosphorus-free detergent solution followed by a rinse in pure water effectively decontaminate most of the extraneous materials.

To determine the elemental concentrations of the plant tissue, the organic portion must be destroyed either by high temperature-oxidation or hot acid-digestion. These procedures have their advantages and disadvantages but do yield satisfactory results for most elements. The average adequate concentrations of essential nutrients in a plant dry matter, sufficient for adequate growth of field crops, are given in Table-P.6.

Table-P.6: Concentrations of nutrient elements in plant dry Matter.

Major elements	Nutrient percentage in plant dry matter	Micronutrients	Concentration in plant dry matter (ppm)
Nitrogen (N)	1.5	Zinc (Zn)	20
Phosphorus (P)	0.2	Boron (B)	20
Potassium (K)	1.0	Copper (Cu)	6
Calcium (Ca)	0.5	Iron (Fe)	100
Magnesium (Mg)	0.2	Manganese (Mn)	50
Sulphur (S)	0.1	Molybdenum (Mo)	0.1
		Chlorine (Cl)	100

On average, nutrient concentrations below the indicated values signify a deficiency of the given nutrient. Among **macronutrients**, nitrogen and potassium are required in large quantities, followed by Ca, P, Mg and S. Among **micronutrients**, iron is required in large amounts, followed by Mn, Zn and B. The requirement of molybdenum is the lowest, with that of copper being the second lowest.

Standardization of sampling procedures is essential for the maximum usefulness of leaf analysis. If a plant sample is contaminated (from the soil, chemical sprays or the residues of other materials), it is cleaned before drying, especially when micronutrient analyses are to be performed.

The number of plants to be sampled depends on the general condition of plants, soil homogeneity and the purpose of the test. Normally, the mean value of several composite sample assays gives a more accurate estimate than a single assay result, based on a single composite sample consisting of the same total number of individual samples. The lack of homogeneity within a plant and its parts is due to (a) the movement of mobile elements from an older tissue to a newly developing tissue, (b) accumulation of the immobile elements, and (c) a reduction in the dry matter content.

Petioles are not a part of leaf blades and should not be included in the leaf samples. However, for certain crops like grapes, sugar beets and cotton, the petiole should be assayed, and not the leaf blade. The petiole and the conductive tissue normally contain higher K, P and nitrate N than the attached leaf blade.

Compound leaves pose sampling problems because these comprise mixtures of petioles, conductive tissues and leaf blades. However, the terminal leaf at the end of a compound leaf of tomato or potato, and middle pairs of leaves for nut trees such as pecan and walnut may be selected.

Plant water requirement

Plants vary in their demand for water and their tolerance to dry periods. And yet, most crop plants need continuous water supply. Shortage of water reduces their growth pattern. For example, if the period of dryness or the rate of transpiration increases, crop yields suffer. That is why it is necessary to know the amounts of water needed for each crop. There are some crops like barley and sorghum which require very low amounts of water and, therefore, can survive in water-scarce regions. Short-growing seasonal crops like lettuce and beans can make best use of limited water resources. The daily water consumptive use varies from about 2 mm to about 1.5 cm.

Plasma membrane: See Cell

Plasmodesmata

Plasmodesmata are the delicate protoplasmic strands that extend from the protoplasm of one cell to that of another. These plasmodesmata facilitate the interchange of foods and other materials like hormones from one cell to another. They are so thin and delicate that they cannot be seen under ordinary microscopes.

Plasmolysis

A plant cell demonstrates the law of diffusion, by which water moves out of the plant cell when the relative concentration of water outside the cell is lesser than inside the cell. This is a continuous process in living plant tissues, with each cell filling up the shortage of water supply of the next one. However, if a cell loses its water because of its movement toward a region of lesser water concentration, and if this cell does not get replenished, it results in shrinkage of the protoplasm away from the cell wall because of the increased pressure inside. This is plasmolysis. If cells are subject to severe plasmolysis, they can die.

Plaster of Paris

Calcium sulphate ($CaSO_4$), occurring naturally as mineral anhydrite is found more commonly as dihydrate **gypsum** ($CaSO_4 \cdot 2H_2O$). When heated, gypsum loses water at 128°C and gives a hemihydrate ($2CaSO_4 \cdot H_2O$), which is known as plaster of Paris. When mixed with water, it rehydrates and may be used for casts.

Plasticity index of clay

A soil can be solid, plastic or liquid depending on the quantity of water it contains. Plasticity is the property by which a soil, while deformable, can still maintain the shape given to it. This property enables clay to change its shape without cracking when subjected to deforming stress. If clay is wetted till it flows by itself and allowed to dry progressively, it will go from the liquid stage to the plastic stage after which it can be moulded to retain its shape. Thus, we pass from the liquid limit (wL) to the **plasticity limit** (wP). If we continue to dry the clay, it passes the plasticity limit and becomes solid; at this stage it is friable and breaks spontaneously. The difference between the liquid limit of clay and its plasticity limit is the plasticity index (PI). The PI is given as

$$PI = wL - wP$$

where wP is the water content of the clay when it can be hand-rolled into a thin rod and wL is the water content at which a groove of a well-defined size gets closed over 1 cm after 25 strokes in a standard apparatus.

The plasticity index denotes the range of water content over which the clay exhibits plastic behavior. The index increases with the colloid content; the larger it is, the more permeable is the soil. If PI < 10, the soil is not very plastic and crops can be grown favorably. A PI value of 10 to 20 is indicative of moderately plastic soil, while a value above 20 indicates that the soil is very plastic and difficult for crop growth. The Atterberg limit includes both the plasticity limit and the liquid limit. Plasticity is also the property that causes clays to change permanently in size or shape by application of a stress in excess of a certain value called the **yield point**.

Plasticity limit: See Plasticity index of clay

Plastic soil

The resistance of a soil to deform is its consistence. It also means the degree of cohesion of the soil mass. The attributes of the soil material are expressed in terms of (a) its degree of cohesion and adhesion (or its resistance to deform or rupture), and (b) the content of water. Accordingly, if a soil changes its shape under pressure and gets back to original shape when the pressure is removed, it is called plastic soil. A soil can be non-plastic, slightly plastic, plastic or very plastic.

Plateaus: See Parent material

Platinum recovery in catchment gauzes process: See Nitric acid production processes

Pleistocene clayey marine sediments

Pleistocene clayey marine sediments are agricultural lands reclaimed by constructing dikes and canals, and by draining swamps, lakes or shallows. These lands are seen in The Netherlands. The **polders** of Flanders are Pleistocene clayey marine sediments accumulated since the Flemish transgression and later isolated naturally from the sea. Pleistocene relates to the first epoch of the quaternary period marked by great fluctuation in temperature with glacial periods followed by interglacial periods. (See also Polder.)

Plow

The plow is one of the oldest agricultural tillage implements. It is used to break up the land, turn over the soil into ridges and furrows, and bury vegetation. Plowing exposes new soil to the air in preparation for sowing. The basic plow has a horizontal blade to cut the furrow and a projecting moldboard to turn the soil over. Plows have been used since the Bronze Age.

There are two types of plows, the moldboard and the disc. The earliest types of plows were wooden. The modern plow has a steel frame to which a number of objects are fixed (Fig.P.25) including a coulter for cutting vertical slices and a shear for making a horizontal cut under the furrow slice before it gets turned by the moldboard. The lateral accuracy and stability of each body is maintained by the two land sides.

Fig.P.25: Modern plow.

Three main categories of tractor-drawn plows (Fig.P.26) are commonly used. They are (a) a fully mounted type, attached to the three-point linkage and raised or lowered hydraulically, (b) a semi-mounted type in which a rear wheel partially supports the weight, and (c) a trailed type, pulled by a drawer.

Fig.P.26: Tractor-drawn mouldboard plow.

A few modern plow types are: (i) Digger. (ii) Semi-Digger. (iii) Disc (Fig.P.27). (iv) Lea. (v) Reversible and Ridger. The effectiveness of plowing may be materially increased by attachments. A jointer, or a jointer and coulter combination, which cuts a small furrow in front of the plow shin permits complete coverage of the sod. A weed chain or wire can be used to drag any debris (like

Fig.P.27: Disc plow.

crop residue or other rubbish) into the furrow and hold it there until covered. A furrow wheel may reduce landslide friction, and a depth range on the beam may help secure uniform depth. A modified form of plow bottom, called **lister**, is in effect, a right and a left moldboard joined at the shin to throw the soil to both right and left, which produces a furrow or trough, called list, in which the seed is planted. This method is used in areas of light rainfall. The disc plow consists of a number of disc blades attached to one axle or gang bolt and used for rapid, shallow plowing. In fields, where numerous rocks and roots are present, the disc plow which rolls over obstacles, is substituted for the moldboard. The disc is also used for sticky soil that will not scour on a moldboard.

Plow-in

The term plow-in means the act of burying the crop, stubble, weeds, etc., by turning them under the soil using a plow.

Plow layer

The plow layer is the layer broken or penetrated by a plow; it is rich in organic matter and easily soluble plant nutrients. The plow layer is a surface layer approximately 12 to 20 cm deep. (See also Soil horizons.)

Plow pan

Plow pan is the bottom of the plow furrow, compressed and hardened under the weight of the tractor and by the repeated passing of the plow. Plow pan is an induced subsurface soil horizon or layer having a higher bulk density and lower total porosity than the soil material directly above and below it but similar in particle size analysis and chemical properties. The pan is usually found just below the maximum depth of primary tillage and frequently restricts root development and water movement. Plow pan is also called **pressure pan** or **plow sole**.

Plow sole: See Plow pan

Plow-sole placement

In applying a fertilizer to the soil, the fertilizer is spread in a continuous band at the bottom of the furrow while plowing. Each band is covered as the succeeding furrows are turned over. This method is known as plow-sole placement. At that depth, the soil is moist and the nutrients are readily available to plants. This method is useful in regions where the sub-soil becomes dry to a few centimeters during the growing season.

Podsol: See Podzol

Podzol

Podzol is one of the 106 soil units of the FAO-UNESCO legend. It is a highly developed soil with ABC profile, the evolution of which is conditioned by a 10 to 20 cm thick, highly acidic and slowly decomposing humus (**mor**). The E horizon is bleached and ash-like with the leaching ratio above 4 while the B horizon contains organic matter, amorphous iron and aluminum. **Bleicherde** is the light-colored, leached A_2 horizon of the podzol.

Podsol is a type of soil with an ABC profile, in which minerals leach from the surface layer and deposit in the subsoil, often forming a hard pan impenetrable by the roots. The upper leached layer, which is usually extremely poor in mineral salts and consists of bleached sand, is mostly covered with very acidic decomposing plant material. The profile is found in humid climate under vegetation producing acid humus in quick draining sandy heaths, and under conifer forests, particularly in the cool, wet areas of northern and western Britain. **Bluff podzol**, which is also called **prairie podzol** or **swamp podzol**, is a poorly drained soil with depressions found in the Canadian prairies and characterized by a fine textured B horizon and the presence of a leached E horizon.

Podzolic soils

Podzolic soils are one of the six soil zones in the world. Podzolic soils exist in humid temperate forests. They have been formed wholly or partly under the influence of **podzolization**, a process by which soils gradually become acidic.

Podzolization

Podzolization refers to the process or processes by which soils lose bases and become acid; they develop eluvial A horizons and illuvial B horizons. Podzolization is a process in which aluminum and iron cations are leached from soluble oxides in the upper soil zone and deposited with organic matter in the deeper portion of the soil.

Podzolization involves immobilization of Al and Fe relative to Si. The podzolization ratio is the ratio of the clay, organic matter or iron content of the A horizon to that of the B horizon.

Podzoluvisols

Podzoluvisols is one of the 106 soil units as described by the FAO-UNESCO legend of the soil map and intermediate between the soil luvisols and the soil podzols. Podzoluvisols has an argillic B horizon with an irregular or broken upper boundary caused by a deep penetration of the E into the B horizon. These soils form discrete aggregates or nodules (2 to 30 cm in diameter) surrounded and cemented by iron oxides which give a red tint to the soil.

Podzoluvisols can be eutric, dystric, stagnic, gleyic and gelic.

Point injection: See Fertilizer placement

Point injector applicator

Point injector applicator is an implement used to apply a side dressing of both solid and fluid fertilizers (Fig.P.28). Side dressing is a method of doing **post-plant fertilization**. Nitrogen is generally applied with this applicator to corn, sorghum and cotton.

Fig.P.28: Point injection of liquid fertilizer in a pot cultured plant (shown by arrows).

Polar solvent

Solvent is a substance in which a solute is dissolved to form a solution at the molecular or ionic size level; in this solution, the viscosity of the solvent does not change. Polar solvents are one of the two types of solvents, the other being **non-polar**. Polar solvents like water and liquid ammonia have dipole moments and high dielectric constants and they dissolve ionic or covalent compounds that ionize.

Polder

The land that once used to get flooded and was later reclaimed after adopting some draining techniques is called polder. It is a low-lying land reclaimed from the sea or a river for agricultural use.

The polders of Flanders are **pleistocene clayey marine sediments** accumulated since the Flemish transgression and later isolated naturally from the sea. Pleistocene relates to the first epoch of the quaternary period marked by great fluctuations in temperature with glacial periods followed by interglacial periods. The Dutch have become polder specialists. They reclaim low lands by constructing and building dikes and canals and draining swamps, lakes or shallows.

Pollutant, PAHs type: See Persistent organic pollutants

Pollutants

Pollutants refer to substances that are produced and released into the environment and have a damaging effect on living organisms. Pollutants are mostly the result of human activities. Pollutants may be toxic substances (e.g., pesticides) or natural constituents of the atmosphere (e.g., carbon dioxide). Excessive amounts of carbon dioxide, emitted during the burning of harvest remnants, (a common practice followed) before starting the next seasonal crop, is an example of pollution.

Pollutants, OC type: See Persistent organic pollutants

Pollutants, organic chlorines type: See Persistent organic pollutants

Pollutants, polycyclic aromatic hydrocarbon type: See Persistent organic pollutants

Pollution

Pollution is a state of the environment represented by undesirable changes in the physical, chemical or biological characteristics of the biosphere brought about by human activities. Pollution is harmful to human- plant- and animal life. Air, water and soil are the natural resources chiefly affected by pollution.

The two classes of pollutants are: (a) biodegradable materials like sewage, which can be dangerous unless rendered harmless by specific processes, and (b) non-biodegradable materials like Pb, Cd and Hg which are part of industrial effluents. Dichlorodiphenyltrichloroethane (DDT) and other chlorinated hydrocarbons used as pesticides accumulate in the environment and enter the food chain. Other forms of environmental pollution include noise pollution (such as from aircraft or traffic or industrial processes) and thermal pollution (such as excessive heat released into rivers and lakes causing harm to aquatic life). Populations of organisms thriving abnormally at the expense of other populations may themselves be regarded as pollutants.

Some of the recent pollution problems also stem from acid rain, radioactive waste and photochemical smog. Exorbitant levels of carbon dioxide and other green house gases such as chlorofluorocarbons (CFCs) in the atmosphere damage the ozone layer. Inland waters mixed with agricultural fertilizers, as also sewage effluents, when discharged into the sea, kill marine life.

The need to control environmental pollution in all its aspects is now widely recognized. Attempts to contain or prevent pollution include strict regulations concerning (a) limits on factory emissions, (b) use of smokeless fuel, (c) use of certain pesticides, (d) use of lead-free petrol, (e) limited use of chlorofluorocarbons, and (f) use of catalytic converters to cut pollutants in car exhausts.

Pollution abatement in ammonium nitrate: See Environmental impact of fertilizer industry

Pollution abatement in calcium ammonium nitrate: See Environmental impact of fertilizer industry

Pollution abatement in complex fertilizers: See Environmental impact of fertilizer industry

Pollution abatement in nitrophosphate fertilizers: See Environmental impact of fertilizer industry

Pollution abatement in phosphogypsum: See Environmental impact of fertilizer industry

Pollution abatement in urea: See Environmental impact of fertilizer industry

Pollution and environmental laws on tail gas and nitric acid plants: See Nitric acid production processes

Pollution and its control in urea production: See Urea production processes

Pollution prevention and control in ammonia production: See Environmental impact of ammonia industry

Pollution prevention and control in fertilizer production: See Environmental impact of fertilizer industry

Pollution prevention and control in nitric acid production: See Environmental impact of nitric acid industry

Pollution prevention and control in phosphoric acid production: See Environmental impact of phosphoric acid industry

Pollution prevention and control in sulphuric acid production: See Environmental impact of sulphuric acid industry

Pollution sources and control in urea plants: See Urea production processes

Polyborate

Polyborate is a type of borate, and is a salt of boric acid. Polyborate is used as a fertilizer to reduce boron deficiency. **Solubor** and **borax** are examples of polyborates.

Polycultural farming methods for rice

Polycultural farming is a system of generating a variety of products from the same piece of land, while increasing the land productivity, and maintaining the ecological balance. This is an old traditional method followed in Asia, necessitated by population pressures and small land holdings.

A rice-fish system is an integrated polycultural method. Fish is grown along with rice to an economic advantage. Depending on how well the bunds can be made secure, the fish may be appropriately stocked. Local varieties of fish, such as danios, barbs, catfish, eels and tilapias can be cultivated. Other aquatic animals like shrimp and crabs can also be grown. Fish yields can range widely from 1.5 to 174 kg/ha/season provided that water is not allowed to dry up while fish stocks are present. This gives the farmer a supplemental income. In addition, dead fish renders nutrition to the soil, thus helping the crop. It should be noted, however, that fish culture areas within the field may not yield as much rice.

Polycultural farming methods can be further improved with the use of ***azolla***. A combination of the three - fish, rice and *azolla* increases soil fertility and reduces weeds.

Farming of rice with the help of ducks is another method of polycultural farming. Rice crops are benefitted by the bird droppings and because their paddling prevents too much settling. The ducks get a safe home and lots of weeds, insects, etc. And, additionally, the farmer benefits by selling the ducks.

Growing gliricidia around rice fields is also a way to perform many activities in the same plot of land. The leguminous plant grows fast because of abundant water supply. It provides wood for fuel, gives shade, prevents erosion and supplies nitrogen to the soil. At the same time, it is used as an excellent source of **green manure** enriching the land. Gliricidia is also a source of crude protein which is good for livestock.

Optimum use of land for mutual benefit has been practiced since olden times, before mechanized farming came into existence. It is believed that there is wisdom in following such practices, since many parts of the world have small pieces of infertile soils, and not too much money for fertilizers.

Polycyclic aromatic hydrocarbons: See Persistent organic pollutants

Polydentate ligand

Ligand is an ion or molecule attached to a metal atom by coordinate bonding. Polydentate ligands are those ligands that have two or more possible coordination points. For example, ethylene diamine and bipyridyl are bidentate ligands. Ethylenediaminetetraacetic acid (EDTA) is a hexadentate ligand. As expected from the large number of coordination sites, EDTA forms very stable complex ions with most metal ions and is used as a scavenger to remove toxic heavy metals such as lead, from the human body. It is also used as a reagent to analyze solutions for the metal ion content. Some even more complicated ligands are found in biological systems, where metal ions play crucial roles in catalyzing reactions, transferring electrons and transporting and storing oxygen.

Polymer coatings: See Coated fertilizers

Polymer dispersions and emulsions as soil conditioners

Soil conditioners are substances added to the soil in small quantities to improve its biotic, chemical and physical structure. **Soil conditioners** can also be made by synthetic material and classified as (a) foams, (b) colloidal silicates, (c) polymer dispersions and emulsions, and (d) tensides.

Polymer dispersions and emulsions as soil conditioners include polyvinylacetate, polyvinylpropionate, butadiene-styrene copolymer, cis-polybutadiene and various acrylic polymers in aqueous solutions. These are applied to soils to crosslink the particles of the uppermost soil layer to form a closed film or coating. These are permeable to precipitation but diminish evaporation. They promote the formation of crumbs.

Polymer dispersions are degraded by UV radiation and hence limited in their time of usage and in their stability, unless under ambient conditions. They are employed for seed protection, in landscaping, and in vegetable and flower-bulb growing. They are applied at planting time by spraying along with fertilizers and can also be sprayed after planting. The quantities of polymer dispersions used vary between 10 and 50 g/m^2. Their dilution with water depends on the purpose and varies between 1:1 and 1:60.

Polymer emulsion

Polymer emulsion is a formulation in which a polymer is dispersed uniformly in another liquid, usually water. Emulsion needs an emulsifier to prevent droplets from coagulating together. Paint is an example of polymer emulsion. Polymer emulsions are used as soil conditioners.

Polymer-encapsulated controlled-release fertilizers

A range of polymer-coated controlled-release fertilizers is available for use in high-value crops to meet their requirements. The nutrient release can last from 1 to 24 months. Changing the composition and thickness of the coating can alter the rate of nutrient release. The rate of nutrient release in polymer-coated fertilizers is more proportioned and uniform compared to that in sulphur-coated ones.

Polymer coatings can be semi-permeable or impermeable. Most polymers used in coating conventional fertilizers decompose in the soil extremely slowly, if at all, and leave residues of up to 50 kg/ha annually. This may be considered as an environmental disadvantage even though only 500 kg accumulates over 10 years representing 200 ppm in dry soil. Extensive research is being carried out for the development of polymer coatings that are biodegradable after application. In the case of polythene, polypropylene and ethylene co-polymers, incorporation of ethylene-carbon monoxide copolymer promotes photochemical degradation of the coating.

Three manufacturing processes namely, **Sierra process**, **Chisso-Asahi process** and **Pursel Technologies' reactive layers coating process** are used for producing polymer-encapsulated controlled-release fertilizers.

In the Sierra process, a co-polymer of dicyclopentadiene with drying or semi-drying oils in an organic solvent is used as the coating material. The fertilizer granules are coated with two layers in a coating drum operating at 65 to 70°C. The addition of maleic acid improves the drying time of the oil.

In the Chisso Asahi process, finely powdered inorganic materials like talc and silica are used as coating material to produce controlled-release fertilizers. These fertilizer granules are coated with polyolefins, ethylene vinyl acetate co-polymers, poly vinylidene chloride and mixtures thereof in a hydrocarbon or chlorinated hydrocarbon solvent in a fluid bed reactor at 60 to 70°C. The moisture permeability is modified by means of a suitable ratio of ethylene vinyl acetate to polythene.

The reactive layers coating process of Pursel Technologies involves producing attrition-resistant controlled-release fertilizers by coating a plant nutrient with a material that chemically bonds to it. Solvent-free polyols and polyisocynates are applied sequentially in ultra thin layers on the surface of preheated urea granules, where they polymerize directly to form a continuous encapsulating membrane. The first layer of polyisocynate can also react with urea granules, chemically bonding the polymer coating to its surface. Polyester polyols are used and the preferred isocynate is diphenylmethane diisocynate.

Polymer gasoline: See Gasoline

Polyon PCU-AF: See Antifloat materials

Polypeptide: See Amino acid

Polyphosphate

Polyphosphate is a term used to describe two or more orthophosphate ions (PO_4^{3-}) combined with the loss of one water molecule per two H_3PO_4. Polyphosphates are salts of polyphosphoric acid or pyrophosphoric acid, the latter being produced by the dehydration of the wet process phosphoric acid. Polyphosphates are available both in liquid as well as solid forms. (See Ammonium polyphosphate.)

$$2H_3PO_4 \xrightarrow{\Delta} H_4P_2O_7 + H_2O$$

$$H_3PO_4 + H_4P_2O_7 \xrightarrow{\Delta} H_5P_3O_{10} + H_2O$$

Polyphosphate fertilizers

Polyphosphate fertilizers are a class of phosphate fertilizers characterized as condensation products of orthophosphates, and available in either solid or fluid forms, the latter being more common.

Ammonium polyphosphate solutions are the most popular phosphatic solutions as fertilizers for direct application. The usual grades are 10-34-0 and 11-37-0. Most ammonium polyphosphate solutions are produced from the wet process pyrophosphoric acid, ammonia and water.

The **superphosphoric acid** or **pyrophosphoric acid** is produced by vacuum concentration of merchant grade phosphoric acid (54% P_2O_5) and contains about 68 to 70% phosphorus (as P_2O_5), of which 20 to 35% is present as polyphosphate.

Prior to the absorption by plants, polyphosphates must undergo hydrolysis to change into orthophosphates. Hydrolysis is brought about by the soil-held enzyme, pyrophosphatase; the rate of hydrolysis is the fastest for laterite, intermediate for sodic, and the slowest for alluvial soil. Factors affecting the hydrolysis of ammonium polyphosphate are the soil pH, temperature, texture and water content. The half-life values for the polyforms of phosphorus in liquid ammonium phosphate range from 1.6 to 2.0 days for anaerobic conditions, and from 5.2 to 8.7 days for aerobic conditions.

Granulation during the manufacture of ammonium polyphosphate (**APP**) results in a solid product of the 11-55-0 composition. The addition of 99.5% urea solution to APP gives a granular **urea-APP** with a product analysis of 28-28-0. Liquid APP is a popular fertilizer and it is generally mixed with other liquid fertilizers like **urea ammonium nitrate** (**UAN**).

A unique property of APP is the **chelation** or **sequestration** with metal cations. The chelating property allows higher concentration of micronutrients in APP than in orthophosphate solution. For instance, APP can accommodate 2% zinc in solution, compared to 0.05% zinc in orthophosphate.

Polyphosphoric acid

Polyphosphoric acid is obtained by heating the wet-process phosphoric acid. It contains around 72% phosphorus (as P_2O_5) and represents a series of phosphoric acids containing more than one atom of phosphorus (such as $H_4P_2O_7$). The general formula is $H_{n+2}P_nO_{3n+1}$. (See also Ammonium pyrophosphate; Ammonium polyphosphate.)

Polysaccharides

Compounds containing carbon, hydrogen and oxygen with a general formula of $(CH_2O)_n$ are called **carbohydrates**. They are classified as **monosaccharides**, **oligosaccharides** and polysaccharides.

Non-sugars like starch, dextrin and cellulose are polysaccharides, which on hydrolysis, yield a large number of monosaccharide molecules. These units are held together by glycoside linkages which can be broken by hydrolysis. Polysaccharides are structures of sugar molecules that keep soil aggregates together. They are amorphous, tasteless, non-reducing and mostly insoluble in water, and are further classified as **homo-polysaccharides** and **hetero-polysaccharides**. Their molecular weight is usually very high, and many of them, like starch or glycogen, have molecular weights of several million. Both are produced by plants from carbon dioxide and water, by the process of **photosynthesis**. Starch makes up the reserve food supply of plants and occurs chiefly in seeds. It is more water-soluble than cellulose, more easily hydrolyzed and hence more easily digested. Cellulose is exploited for its structural properties – like wood for house making, cotton or rayon for clothing, paper for writing, printing and packaging, and potatoes, corn, wheat, rice, cassava, etc. for the food industry.

Polystyrene foam as conditioner

Foamed polystyrene and foamed urea-formaldehyde resins are used as **foamed soil conditioners**. Closed-cell expandable polystyrene foams are used as soil conditioners in the form of flakes, beads or rasping.

Polystyrene foams are largely resistant to attack by acids and alkalis, and are resistant to degradation by soil bacteria. The range of foam use is quite wide – from incorporation into soils and garden substrates to the conditioning of weak-structured peat. Foamed phenolic and polyurethane resins are also used as **florists' mounting media** or **plant growth media**.

Polythene-coated urea

A range of polymer-coated and controlled-release fertilizers has been developed for applications to high value crops. The composition and thickness of polymer coating, control the rate of nutrient release. Urea, coated with polythene or polyethylene, is one such fertilizer that is commercially available as 40-0-0 and 38-0-0. Polymer-coated urea has longevity from 1 to 24 months, depending on the thickness of the polymer coating. The nutrient release pattern is determined by a water-leach at 25°C. For example, polythene-coated urea releases 80% of its nutrient in 180 days at 25°C in water.

Polymer coatings are semi-permeable membranes with tiny pores. These coatings are not degradable in soil, and are thus environmentally disadvantageous. However, extensive research is under way all over the world on the development of **biodegradable polymer coatings**. In the case of polythene and polypropylene polymers, a copolymer of ethylene and carbon monoxide is found to be photochemically degradable. Coatings containing poly 3-hydroxyl-3-alkyl propionic acid as an active ingredient, are biodegradable.

Polyurethane

Polyurethane is a polymer containing the urethane group. Polyurethanes find a wide variety of applications in many industries. In fact, mollifiable polymers (hydrophobic) like bitumen, polyvinyl acetate and polyurethane form a major class of **soil conditioners**. Polyurethane resins and the foams are also used as **florists' mounting media** or **plant growth media**. (See also Synthetic soil conditioners.)

Pomology

Pomology, a sub-division of **horticulture**, deals with the art and science of fruit crop production. It focuses on different techniques of growing fruit trees, with the objectives of improving quality of fruit, longevity of the trees, etc.

Pool dilution method for mineralization-immobilization turnover

Pool dilution method for **mineralization-immobilization turnover** (MIT) is one of the two methods (the other being the **tracer method**) to measure the actual or gross rates of mineralization and immobilization. In this method, ^{15}N or $^{15}NH_4^+$ is added to the product pool to follow the mineralization-immobilization turnover.

Poor heart

An infertile soil with a poor nutrient status is termed poor heart.

Poorly drained soil

Poorly drained soils are those that have slow internal drainage because of a clay texture or dense impermeable horizons. The climate, the level of water table with its fluctuations, the permeability of the soil and the topographic conditions influence water flow through the soil. The soil that is not drained well, often has red and yellow mottles in the wet zone.

Poor soil

Poor soil is one of the classes of soils which has low fertility status. The **Storie's index rating of fertility** is based on the numerical estimation of fertility (NF) which is evaluated as:

$$NF = a\,b\,c\,x$$

where a is the profile character of the soil, b is the particle size distribution of the surface soil, c is the slope of the soil (all the three parameters being in comparison with a maximum value of 100 for NF) and x covers miscellaneous factors such as drainage, chemical reaction, erodibility, etc. Poor soil is represented by values vis-à-vis the NF which are less than 10.

POP

POP is short for **persistent organic pollutants**.

Pop-up fertilizer

'Pop-up' or **starter fertilizer** is used at the stage of seed planting for subsurface band application to enhance early seedling vigor, especially in cold and wet soils. It usually contains water-soluble ingredients high in phosphorus.

A pop-up fertilizer leads to (a) early germination, (b) better weed competition, (c) reduced heat stress during pollination, and (d) early harvest. It enhances the development of roots and plant parts above the ground, and provides quicker soil cover. It also results into decreased (a) run-off, (b) erosion potential, (c) grain moisture content at harvest, and (d) production costs. Importantly, a pop-up fertilizer improves the efficiency of nitrogen use, increases the production efficiency, reduces the potential for water pollution, and improves crop quality.

Starter or pop-up fertilizers, in both fluid and solid forms, can be placed near the seed, instead of being incorporated with the seed. Generally, small amounts of fertilizers are applied to avoid damage to germination or seedling. Starter solutions may be added to the transplanting water, in order to maximize absorption, stimulate early growth and supplement regular fertilizing programs. An application of 25 kg N/ha to a legume crop can be encouraging for early growth till the plant starts to fix nitrogen with the help of respective *Rhizobium* species. (See also Starter dose.)

Pores

Pores are the voids in a substance occupied by air and water. Soils have pores and their size influences the flow of water through it. The total pore space influences the water content in that soil. (See also Soil Porosity.)

Pores in soils

Pore space in soil consists of that portion of the soil volume not occupied by either minerals or organic solids. Irregular shapes of soil particles, aggregation of particles, penetrating roots of plants, activity of worms and insects, and expanding gases (entrapped by water) create pores in soils. Under normal field conditions, air and water occupy pore spaces. The percentage of the total space that is occupied by pores is **porosity of soils**.

A heap of sand has large and often continuous pores. In contrast, clays have a large total pore space because of the minute size of each clay particle, but have very small continuous pores because of which, the passage of air or water can get blocked. The latter adversely affects the plant root growth in some clayey soils. The most rapid water and air movement is in sands because they form a continuous passage through many large pores.

The pores in soils are broadly classified according to their average diameter in millimeters as follows:

(a) Very fine pores < 0.5 mm
(b) Fine pores of 0.5 to 2 mm
(c) Medium pores of 2 to 5 mm
(d) Large pores > 5 mm

Water drains down by gravitational force in the soil if the pores are larger than 30 to 60 microns (μm). In comparison, the smallest plant roots are between 8 and 12 μm in diameter. When most pores in the soil are smaller than 30 μm, the forces of attraction retain water within the fine pores and this leads to water being logged and very poor aeration in the soil. Thus, for the growing plant, the pore sizes are more important than the total air space.

Pore space percentage

Pore space percentage is another term for **pore space ratio**.

Pore space ratio

Total pore space (or voids in the soil) is the volume of soil occupied by air and water. One of the physical properties of soil is porosity, that is, the void volume percentage of the total pore space. Pore spaces get formed by the arrangement of solid particles within the soil. For example, irregular shapes of primary particles cause pore spaces. Similarly, penetrating roots and the activity of soil organisms create pore spaces. Generally, pore space constitutes 45 to 50% of soil volume. Water moves through the pores which are of more than 0.3 mm diameter.

In soil micromorphology, pore space is considered as an integral part of the physical constituents of soil. Pore spaces can thus be classified on the basis of (a) size, which can be anything from microvoids ($>75\mu$m) or ultramicrovoids ($<5\mu$m), (b) shape, further divided on the basis of structure of soil particles (curved, regular, etc.) and smoothness (either with smooth sides or rough sides), (c) arrangement (intrapedal, interpedal, transpedal), and (d) soil morphology (cracks, channels, chambers, etc.)

Spherical particles in closest packing result in 26% pore space, whereas open packing results in 48% pore space. This is true regardless of the particle size. Single-grained sands have a pore space percentage of 40, suggesting that sand particles are not perfectly spherical and the packing is not perfectly closed.

Pore space ratio or **pore space percentage** relates to the space not occupied by soil particles. It is expressed as percentage of bulk volume of the soil.

$$\%\ \text{Pore space} = 100 - \frac{\text{Bulk density of the soil}}{\text{Particle density}} \times 100$$

$$\text{Pore space ratio} = 1 - \frac{\text{Bulk density of the soil}}{\text{Particle density}}$$

At a bulk density of 1.3 g/cm^3 and a particle density of 2.65 g/cm^3, the total pore space is 50%. Pore space ratio is a measure of soil compaction, which influences root growth, water infiltration, and the availability of oxygen or air. To growing plants, pore sizes are more important than pore spaces. (See also Soil porosity.)

Porosimeter

Porosimeter is an apparatus which determines the distribution of pores according to their diameter, in a natural medium of soil aggregate, rock, fiber, etc. The mercury porosimeter estimates the force required for mercury to penetrate the pores. The force depends upon the circumference of the pore, the surface tension and the wetting coefficient of mercury, the pore cross-section and the pressure applied. The following simplified formula, derived from experimental observations, gives the pore diameter:

$$R = \frac{75{,}000\ \text{Å}}{P}$$

where R is the radius of the pore and P is the pressure in kg/cm^2. The apparatus records both the increase in pressure and the quantity of mercury penetrating these pores. The sample is first subjected to a vacuum of the order of 10^{-5} Torr. The range of measurement is from 4,60,000 Å to 37.5 Å.

The nitrogen porosimeter is a gas phase chromatograph which determines the adsorption of nitrogen at low temperatures volumetrically. The chromatograph has a reference cell and a measuring cell, between which the natural sample is kept immersed in liquid nitrogen (at minus 196°C), and it receives a mixture of nitrogen and helium. Inert nitrogen progressively fills up the pores, because at the end of the operation, a pressure reaching ±5 kg is attained in the apparatus. For technical reasons, the nitrogen desorption is measured. The recorder coupled with thermistors indicates the volume of the nitrogen desorbed corresponding to the linear fall in pressure. The measured porosity covers the range of 15 to 150 Å.

Porosity of soils

The percentage of the total space that is occupied by pores in the soil is porosity. It is calculated as:

$$\text{Porosity} = \frac{\text{Volume of pore space}}{\text{Volume of soil}} \times 100$$

Plant root development is closely linked with soil porosity and bulk density. An increase in the porosity not only enhances the aeration and permeability of water but also reduces the mechanical resistance to the penetration of roots. To the growing plants, pore size is more important than the total pore space. The best balance of the water retention time with adequate air and water movement is found in a medium-textured soil, like loam.

Porphyrin

Porphyrins are physiologically active nitrogenous compounds occurring widely in nature. The parent structure is comprised of four pyrrole rings, together with four nitrogen atoms and two replaceable hydrogen atoms, for which various metal atoms can be readily substituted. A porphyrin molecule has the structure given in Fig.P.29.

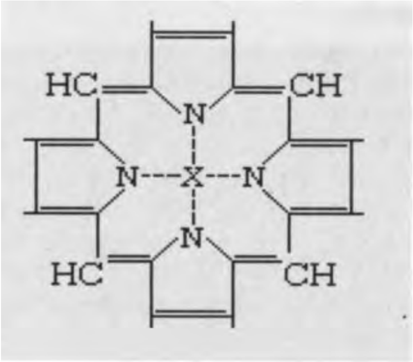


Fig.P.29: A porphyrin molecule structure.

Porphyrins of this type have been made synthetically by passing an electric current through a mixture of ammonia, methane and water vapor. Biochemists believe that this phenomenon may account for the original formation of chlorophyll and other porphyrins which have been essential factors in the origin of life.

The most important porphyrin derivatives are characterized by a central metal atom. Hemin is the iron-containing porphyrin essential to mammalian blood and chlorophyll is the magnesium-containing porphyrin that catalyzes photosynthesis. Other important derivatives are cytochromes which function in cellular metabolism and the phthalocyanine group of dyes.

Positional unavailability of nutrients

The absorption of nutrients into plants takes place by simple diffusion and ion accumulation. These processes take place through the absorption of solutes by root hair cells which absorb the solute ions from the soil solution and from the surfaces of soil particles. The rate of absorption of solutes and water is determined by many factors like the rate of evaporation of water from leaves, osmotic concentration of the soil solution and the soil moisture. It also depends on the structure and growth of root systems.

The extent of the development, branching and penetration of the roots, as also the root hair zone, determine the amount of root surface available for absorption. If any of these conditions are underdeveloped or unfavorable, positional unavailability of nutrients occurs. For instance, if **roots** are only in the upper part of the soil (shallow roots), or if the number of root hairs is inadequate, or if dry surface conditions prevail, plants may show deficiency symptoms in spite of sufficient supply of nutrients in the soil.

Positive catalyst

A **catalyst** is a substance which, in small quantities, facilitates a reaction or alters the rate of a chemical reaction without itself undergoing any permanent chemical change. Generally, a substance that increases the reaction rate is known as a positive catalyst. In a living organism, protein catalysts, called enzymes, speed up many chemical reactions.

Positive interaction of crop growth factors

When the effect of one growth factor is influenced by another, the two factors are said to be interactive. The interaction can be positive, negative or neutral. When the effect of two or more growth factors on a crop is more than the sum of their individual effects, the interaction is said to be positive or **synergistic**. Typical positive interactions are the N-K and N-P interactions. Crop response to nutrients also differ with parameters like the cultivar, plant spacing, planting date, placement method, tillage and pest control method.

Positive interactions occur in accordance with the law of minimum. When two factors are limiting, the further addition of just one has little effect on the growth, whereas the addition of both at the same time has a much greater influence. In severe deficiencies of two or more nutrients, responses to all fertilizers lead to strong, positive interactions.

In the field experiment with mustard grain, the response of mustard to nitrogen was greater when sulphur was applied. The combined effect of nitrogen and sulphur was greater than the sum of their individual effects. The yield with both nitrogen and sulphur was 1.2 ton/ha, compared with 0.77 plus 0.22 ton/ha when the two nutrients were considered separately. A number of reported results support the positive nitrogen-phosphorus interaction, as in the case of sorghum and finger millet grown under similar conditions (Table-P.7).

Table-P.7: Positive interaction of nutrients.

Response to nutrients (kg/ha)	Crop	
	Sorghum	Finger millet
N	110	390
P	490	170
N + P	1570	1300

Source: Singh R.P. and Venkateswarlu J, 1985. As adapted by Rajendra Prasad and James F. Power in "Soil Fertility Management for Sustainable Agriculture, 1997. CRC Press LLC (CRC Lewis Publishers), USA. With permission.

When the combined effect of two factors together is lesser than the added effect of the two individually, the phenomenon is called negative or **antagonistic interaction**. In **negative interactions**, two nutrients combined bring about a yield which is lesser than the resultant yield if these were applied separately. The examples include the effects of lime + P, lime + Mo + P and Na + K. The negative interaction is due to the substitution or interference of one treatment with the other. The pH changes the result in many interactions, especially when one ion or nutrient interferes or competes with the uptake and utilization of the other nutrients.

Micronutrients interact among themselves or with secondary or primary nutrients. One of the most studied interactions is of phosphorus and zinc. Phosphorus above 44 kg/ha reduces the corn yield significantly, the reduction being due to decreased roots, stems, leaves and shoots. This represents a negative interaction which is overcome only by adequate applications of zinc. The reasons for phosphate-induced zinc deficiency are (a) phosphorus depresses zinc availability to the soil, (b) phosphorus induces zinc absorption by the roots, but subsequently retards zinc translocation from the roots to the shoots, (c) zinc dilution in the plant tops, arising from phosphorus-induced growth response, (d) phosphorus-zinc imbalance-related metabolic disorders, and (e) phosphorus-activated interference in zinc functioning.

The yield increase by the application of one nutrient can result in the reduced concentration of the second nutrient, leading to a greater uptake of the latter. This is called the **dilution effect** and is different from the **negative effect**.

Positively charged ion: See Ion

Post-plant fertilizer

A post-plant fertilizer means a fertilizer applied after planting. Two methods by which fertilizers are applied to small grains and pastures are **side dressing** and **top dressing**. Side dressing application of nitrogen is very common for corn, sorghum, cotton and other crops and is done with a **standard knife** or **point injector applicator**. This method can be used for both solid and fluid fertilizers. For most crops requiring nitrogen, a second dose of nitrogen is applied by broadcasting on the soil surface close to the plants when the crop is 3 to 4 weeks old. To a partly grown or 4 to 8 week old crop, a third application of nitrogen fertilizer is given as a continuous band near the crop row to a depth of 4.5 cm or is dribbled in between plants. Top and side dressings of phosphorus and potassium are not effective as those of **pre-plant fertilizers**, as these fertilizers are required early in the season and at the reproductive growth stage. Side dressing can be made anytime during the growing season without damage to the crop.

Post-rainy season

Post-rainy season is the other term for the *Rabi* crop season. This season is also called the **dry season**.

Potash

The term potash designates potassium oxide (K_2O). Potassium oxide is never used as such in fertilizers. The term potash is loosely applied to potassium salts, but it generally refers to potassium carbonate (K_2CO_3), or potassium chloride (KCl). Potash in fertilizers is usually present in the form of a muriate or sulphate, and occasionally in the form of a carbonate or nitrate.

The ores of naturally occurring potassium salts are called **potash ores**. Low-grade potash materials are kainite, basalt, sylvinite, carnalite and schoenite. The potassium content of fertilizers is expressed as percent potash (K_2O).

Potash available form

Soil potassium exists in four forms, each differing in its availability to crops. These are minerals containing potassium to the tune of (a) 5000 to 25,000 ppm, (b) 50 to 750 ppm non exchangeable or fixed, (c) 40 to 600 ppm exchangeable, and (d) 1 to 10 ppm, solution. The relative importance of these groupings depends on the mineralogical composition of the soil. Potassium cycling (or transformations) among potassium forms in the soils are dynamic, and equilibrium is generally not attained. However, equilibrium exists between exchangeable and fixed potassium in the soil solution (Fig.P.30).

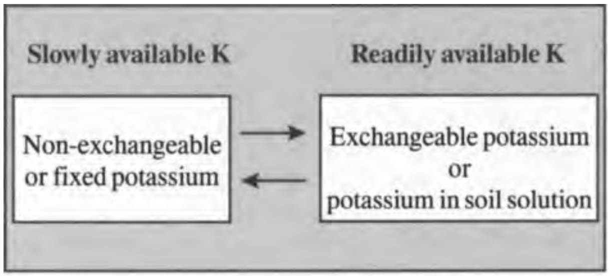


Fig.P.30: Availability of potassium in soils.

When a potassium fertilizer is applied to soil, the equilibrium shifts toward the exchangeable potassium. The shift is reversed as potassium is absorbed from the soil solution by the roots. The potassium level increases with an increased anion concentration in the soil solution.

Large quantities of monovalent, positively charged potassium ions are adsorbed on the colloids of many soils, and only a small fraction is available to plants. Out of this, a small quantity is dissolved in the soil solution, and the rest adsorbed on the colloids of clay minerals and humus. This can be taken up by plants in exchange for a hydrogen (H^+) ion, hydronium ion (H_3O^+) or bicarbonate (HCO_3^-) ion. However, potassium in soil minerals is unavailable to plants directly, and has to be first liberated during weathering.

Feldspars (orthoclase, microline, etc.) and **micas** (biotite, muscovite, etc.) are among the important groups of minerals in the soil which supply potash. In contrast, clay minerals, except the illite group, do not contain much potash; the amount of potassium contained in the illite group is hardly availed by plants. Soils, which can fix the supplied potassium, do so in a form that is not available to plants.

Among the other natural sources of potassium are granite dust, greensand, **langbeinite** (non-synthetic potassium sulphate or sulphate of potash), **kelp**, animal manure, wood ash, **fishmeal**, etc.

Granite rock dust, a source of silica, contains slow-release potassium, supplying around 4% total potash. Depending on the composition of granite rock, the potash percentage can vary. Besides being a major source of silica (60%), granite dust has many other micronutrients, albeit in minute quantities.

The organic farming structure allows the use of this dust, but only if it is free from petroleum products. One disadvantage from the viewpoint of crop yield is the very slow solubility of granite rock dust.

Greensand is a natural mineral source derived from glauconite and hydrous potassium silicate. The mineral rock is found only in very few places and is a slow-release source of potash and some other micronutrients. Potash content is generally found to be 5 to 7% in these mineral rocks.

Potash fertilizers

Potassium is one of the three major plant nutrients (the other two being nitrogen and phosphorus) and is added periodically to all intensive farming soils as potassium gets depleted (Fig.P.31). Over 95 to 97% of the world's potash is used in agriculture. The function of potassium in plant metabolism is different from that of other major nutrients. The latter become part of the plant structure, whereas potassium largely remains as an ion in the cell sap, and helps control the water intake and metabolism of the plant. Some of the specific effects of potassium are seen in increased root growth, improved drought resistance and reduced energy losses.

Fig.P.31: Monopotassium phosphate, a potash fertilizer.

Potassium chloride, potassium nitrate, potassium sulphate, potassium carbonate, potassium thiosulphate and potassium phosphate are different salts used in potassium fertilizers. Commonly used forms of potassic fertilizers are potassium chloride, potassium sulphate and potassium nitrate, all of which are water-soluble. Since potassium is a major plant nutrient, it is needed in large quantities. Potassium chloride is cheaper than the other potassic fertilizers and is used extensively, unless chlorine is undesirable. In the latter case, there are other useful forms of potassium, like potassium sulphate.

Large potash producers are the USA, Canada, Russia, Germany and France, from where countries like India import potash. Israel, Spain and Congo also produce some potash.

Potash is manufactured from raw materials available throughout the world. Potash minerals are mined from the earth. Sylvite and langbeinite are two major minerals from which potash fertilizers are made.

Potassium helps to (a) form cellulose and reduce lodging, (b) enhance many enzyme actions, (c) photosynthesize, (d) translocate sugars and starch, (e) increase the starch and protein content of the plant, and (f) retard crop diseases. Hence, potassium is sometimes called a "**quality nutrient**". To attain the maximum effect, potassium needs to be supplied to the soil for plants to absorb.

About 85% of potassium movement in the soil is by diffusion through the water films found around soil particles. As diffusion is relatively a slow process, potash fertilization may be needed to maintain high levels of exchangeable potassium. Rapid plant growth and uptake may deplete potassium in the soil around the root surfaces. At high soil potassium levels, readily available soil moisture and warm temperatures increase the potassium movement from the soil to the roots, and ensure adequate levels to sustain growth.

The levels of potassium and nitrogen are closely related in plants. Generally, the abundance of nitrogen increases the sensitivity to diseases and infection, while potassium increases the resistance to infection. Nitrogen stimulates the rapid growth of soft tissues whereas potassium promotes the growth of firmer tissues.

Potash is applied to a majority of crops as potassium chloride or **muriate of potash**. Chloride ion, in addition to its role as a plant nutrient, suppresses some diseases like 'take-all' of wheat and 'stalk-rot' of corn. For an efficient use of potash fertilizers, factors relating to soil, weather (especially precipitation) and type of crop, need to be considered. The split application of potash is recommended to avoid the salinity effect and leaching losses in annual and perennial crops. Potassium sulphate is commonly applied to tobacco because excessive chloride uptake may impair the burning quality of the cured leaf.

Potash fertilizers production processes

Potash fertilizer generally refers to potassium chloride. However, it also includes other potassium compounds such as potassium nitrate, potassium sulphate, etc. Naturally occurring minerals containing potassium, like mica and feldspar, release potassium slowly as weathering takes place. Potassium goes into solution and becomes available to plants. Potassium from fertilizers may also get ion exchanged with clays or organic matter near the surface and become less mobile. Therefore, the placement of potash fertilizers is important in soil.

The following factors and processes are important in the production of potash fertilizers.

(i) **Potash quality**: The 'standard' non-granular potash has an average size of 0.8 mm. The coarse material for bulk blending has a size of 0.8 to 2.0 mm. The quality and size of particles depend on the floatation and purification methods. Crystallization allows the production of rounded grains of about 1.0 mm size which are suitable for compaction. Potash, however, tends to cake and there is also crystal breakage during transportation and handling which creates dust problems. To avoid caking, potash is often coated with anti-caking agents like amines.

(ii) **Granular potash materials**: Compaction or granulation is an important beneficiation process.

Compaction means agglomeration of particles under force to get a densified and coherent sheet-like material, referred to as flake. The potash compaction/granulation is composed of four groups of equipments for (a) storage and feeding, (b) compaction, (c) size reduction and classification, and (d) finishing.

There are two types of feeders, the first is the gravity type and the other, the force type feeders. The gravity feeder consists of a slightly diverging chute located above the rolls and an adjustable vertical feed control tongue to keep the level constant. The force feeders are equipped with single and multiple screws. These screws are positioned either vertically or horizontally. Tapered screws de-aerate and pre-densify the feed for the compactor. Force feeders facilitate automation of the process. The amount of de-aeration depends on the size of the material and compaction ratio. The amount of air removed is about 0.5 Nm^3/t of the product for compacting potash from a specific gravity of $1 g/cm^3$ to $2 g/cm^3$. The feed, passing between the two counter rotating rollers, is transformed progressively from a loose to a dense state. The surface of the rollers can be smooth, corrugated, waffled or pocketed.

The selection of equipment depends on the material and the properties of the material like the shape, size, size distribution and compaction force needed. The general rule for compaction is that the fines should accompany larger particles, to fill the annular spaces. The van der Waals forces are not sufficient to produce flakes with sufficient strength and hence sometimes binders are added to create crystalline bridges. Elevated temperatures are beneficial for the formation of crystal bridges in view of the plasticity of the material. Compaction is a dry agglomeration process but sometimes addition of water (not more than 2%) is beneficial. Potassium chloride is compacted in a dry state. The product from the compaction process is the flake and the average thickness is about 20 mm. After compaction the flake is cured in a conveyer system. Pin-type breakers and coarse tooth rollers are used to break the flakes.

(iii) **Granulation**: Potash granulation mainly consists of primary and secondary crushers in closed circuit with a multi-deck screening system. The primary crusher crushes the over-sized granules. Hammer mills, cage mills or chain mills are used as primary crushers while roll crushers with toothed rolls are used as secondary crushers. The rotational speed, size and shape of the crusher tooth are important parameters for the roll crusher. The discharge from the compression (roll) crusher is controlled by the gap setting.

(iv) **Finishing**: The finishing phase includes polishing, coating and storage. The particles, after granulation, assume irregular shape and sharp edges. To reduce crushing of the material during handling and dust creation, the potash particles are quenched, dried and passed through polishing screens. Quenching involves wetting of particles with water (a maximum of 5% water) or brine by spraying or mixing in screw conveyers. During quenching, sharp edges or corners break and a coating of dissolved salt envelops the particles. In the final stages, the product is cooled and coated in a rotary drum with anti-caking agents.

Major dust sources are hoppers (where the material is dumped), crushers, transfer points and the screens.

Potash finishing: See Potash fertilizers production processes

Potash granulation: See Potash fertilizers production processes

Potash magnesia fertilizer

Potash magnesia fertilizer, also called **potassium schoenite**, is obtained from salt bitterns recovered from the sea. It is a double sulphate of potassium and magnesium.

Potash materials, granular: See Potash fertilizers production processes

Potash mica

Potash mica is also known as **muscovite** or **white mica**. It is a layer-structured aluminosilicate mineral group of 2:1 type which is characterized by a high layer charge satisfied by potassium. Potassium is located in the interlayer of micas. Weathering of micas results in the migration of the potassium ion out of the interlayer space along the edge of the mica particles. The potassium ion is adsorbed onto a cation exchange site or appears in the soil solution. (See also Muscovite.)

Potash nitrate

Potash nitrate, also called **nitrate of potash**, is a naturally occurring fertilizer, containing about 15% nitrogen and 40 to 45% potash. It is derived from deposits found in Chile and is mainly used for top-dressing, although it is also useful in fertigation. Potash nitrate benefits tobacco as it contains no chlorine or sulphur, both of which affect the quality of tobacco. It is a transparent and colorless powder (it also occurs as crystals), and is slightly hygroscopic. It is a powerful oxidizing agent used in pyrotechniques, explosives, matches and fertilizers.

Potash ores

The ores of naturally occurring potassium salts are called potash ores. The minerals of potassium are **sylvite** (KCl), **sylvinite** (NaCl and KCl), and **langbeinite** (K_2SO_4 and $MgSO_4$).

Potash quality: See Potash fertilizers production processes

Potassium

Potassium is a soft and silvery metallic element of Group 1 (formerly IA) of the Periodic Table (Fig.P.32).

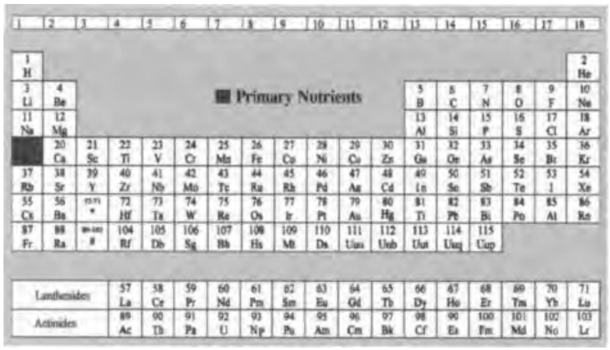


Fig.P.32: Position of potassium in the Periodic Table.

Since the beginning of the 19th century, potassium has been recognized as an essential element and a major nutrient for plant growth, needed in large quantities. The exact function of potassium is not fully understood.

Potassium makes plants more resistant to fungal diseases and insect attacks. It is good for healthy root development and crop quality. For instance, potassium improves the (a) texture, color and combustibility of tobacco leaf, (b) sugar, starch and oil content in many plants, and (c) taste, size and keeping quality of fruits.

Potato, tobacco and sugar use potassium, especially during their early growth stages. A small quantity of potassium is essential near young seedlings, while an excessive quantity causes salt damage.

The requirement of potassium varies in growing plants. Most seeds contain 0.1 to 1.0% potassium, which is sufficient for germination and early growth. The vegetative growth is characterized by a progressive increase in the absorption of inorganic elements like potassium. In tobacco, potassium is absorbed at the rate of 0.1 kg/ha/day from the 21st day of transplanting; a maximum uptake of 2 kg/ha/day occurs 49 days after transplanting. The minimum level of readily available potassium in the soil is around 175 kg/ha.

Potassium is present in the cell sap solution or plasma, and is almost fully extractable with water from plant tissues. It accumulates at the site of cell division, and helps in maintaining the physiological state of the swelling of plasma colloids which is necessary for all normal metabolic processes. It maintains the balance of anabolism, **respiration** and **transpiration** of a plant or leaf, and keeps the plant's water economy in equilibrium (in turn, reducing the plant's tendency to wilt.)

Potassium has a very important role to play in plant energy metabolism. Its liberal use helps to harden the supporting tissues which, in turn, improves the keeping qualities of fruits, and consequently leads to a stronger structure.

Potassium does not become a part of the plant structure as P, S, Ca and Mg do. But it helps in carbon dioxide assimilation, translocation of proteins and sugars, enzyme activity, cell division, reduction of nitrates and fat synthesis. The influence of potassium in these activities is now well established.

The levels of potassium and nitrogen are closely related in most plants. Nitrogen stimulates the rapid growth of soft tissues, whereas potassium promotes the growth of firmer tissues. If sufficient potassium is unavailable, nitrogen level increases in the outer leaves of cabbage and in the upper stems and leaves of tomato. In the sheath tissue of sugar cane, the relationship of potassium to nitrogen depends on their respective concentrations.

Ammonium has a greater depressing effect on potassium in soil-grown plants than in solution, because ammonium interferes with the diffusion of potassium from the clay lattice. Potassium influences the uptake of the two forms of nitrogen. The relative presence of K, Ca and Mg influences the concentration of each individual cation within the plant. In this, potassium seems to be the most active. In plants, magnesium has a greater depressing effect on the content of potassium than that of calcium.

Because potassium ions (K^+) and sodium ions (Na^+) are similar in size and chemical properties, sodium may replace potassium in several essential roles. However, potassium is an essential element, whereas sodium is not. Therefore, use of sodium may compensate for the potassium shortage to some extent, but sodium will not produce healthy plants in a situation when potassium deficiency is large.

There is a close relationship between carbohydrates and the potassium level. When soil potassium concentration is insufficient for optimum growth, it is commonly transported from more mature tissues to the meristems, so that older leaves exhibit early deficiency symptoms. Chlorosis appears first around the edges and tips of the leaves, and then spreads to the mid rib, followed finally by necrosis.

In many crops, **potassium deficiency** is characterized by a contrast between chlorosis, necrosis and healthy green areas of leaves. In the advanced stages of potassium starvation in corn, leaf edges become necrotic, the tissue disintegrates, and the leaf gets a ragged appearance. This condition is called **leaf scorch**. Potassium deficiency in alfalfa is seen as white spots on the leaf edges, whereas chlorosis and necrosis of leaf edges are observed in other grasses.

Potassium deficiency can also occur among young upper leaves in some high-yielding, fast-maturing crops like cotton and wheat. Insufficient potassium weakens the straw in grain crops, causes lodging in small grains and stalk breakage in corn and sorghum. Potassium deficiencies greatly reduce crop yield. A phenomenon in which deficiency symptoms are not visible is called **hidden hunger**. Potassium stress increases the degree of crop damage by bacterial and fungal diseases, insect and mite infestation, and nematode and virus infection. Lack of potassium in wetland rice greatly increases the sensitivity of foliar diseases such as stem rot, sheath blight and brown leaf spot.

Soil humus is a major source of sulphur, but not of potassium. Potassium ion is a highly soluble cation in solution, but it moves slowly in soils (unlike sulphur which is soluble and a readily mobile sulphate ion).

Diffusion and mass flow of potassium to plant roots account for a large portion of absorbed potassium. In decaying humus, the potassium ion is first leached into the soil solution and then to cation exchange sites on the humus and clay particles. A non-decomposed organic mass added to the soil replaces large amounts of potassium which flows with the water to the roots.

In plant cells, potassium is the most abundant metal cation. On decomposition, fresh plant residues give all the potassium the plant needs for growth as a mobile soluble ion. Soluble potassium can be immobilized into the bodies of microbes, lost in leaching waters, or held between layers of hydrous mica and similar clays during drying. High yielding crop plants take potassium ions from a small reservoir of readily available potassium, namely the exchangeable source. For a good crop, at least 170 to 200 kg/ha potassium is considered essential. Soluble potassium may suffice if the soil is neutral or basic.

Using potassium fertilizers in excess, or too frequently, may result in an excess uptake of potassium by plants and in lowering their potassium-magnesium absorption. The effectiveness of the soil solution-potassium for crop uptake is influenced by the presence of other cations, especially Na, Ca, Mg and Al. The absorption of potassium, in excess of that required for optimum growth, results in the accumulation of the nutrient without a corresponding increase in the growth, and is known as **luxury consumption**. The exchangeable or water-soluble potassium is converted by the **potassium fixation** process to a form, not easily exchangeable from the adsorption complex, by a cation of a neutral salt solution.

Muriate of potash is the major potassium supplying material used for direct application to the soil, and for manufacturing NPK fertilizers. The other materials are sulphate of potash, sulphate of potash-magnesia, potassium nitrate, potassium polyphosphates, potassium carbonate, potassium thiosulphate and potassium polysulphide. Potassium sulphate finds greatest use in potato and tobacco, which are sensitive to chloride ions. Potassium nitrate is used on fruit trees and crops such as cotton and vegetables. The mineral forms of potassium, such as micas and orthoclase feldspar, are very slowly soluble. The mineral form of potassium has very little potassium for plant growth although potassium in most of them is sufficient enough to last for centuries.

Potassium is present in relatively large quantities in soil, averaging about 1.9%. Depending on the circumstances, soil potassium can be (a) not easily available, (b) slowly available, or (c) readily available. The first category accounts for 90 to 98% of the total soil potassium, which is only slightly soluble. The minerals containing potassium include orthoclase feldspars and muscovite mica and belong to the first category. The second category constitutes 2 to 10% of the total mineral soil, as represented by biotite, mica and illite. The third category makes up for about 1% of the total soil mineral. Equilibrium exists between the readily available and slowly available potassium. The relationships and transformations among the various forms of potassium in soils are known as the **potassium cycle**, as in Fig.P.33. In normal temperatures, gaseous K does not exist.

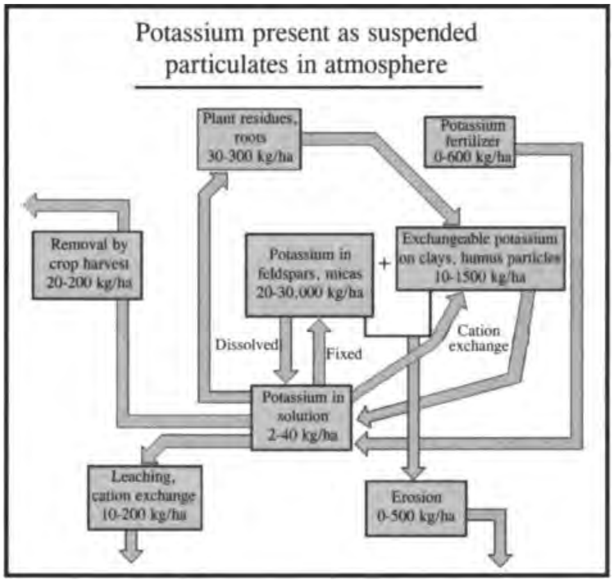


Fig.P.33: Potassium cycle.

Potassium deficient soil can be left on its own for a few years so that the low solubility mineral gets onto active exchange sites and raises the potassium level of that soil over a period. Adding a potassium fertilizer also raises the level of potassium.

Management of soil potassium warrants (a) maximizing the efficiency of the added potassium, (b) minimizing the excess absorption of potassium by plants, and (c) maximizing the use of natural potassium sources. Small split applications of potassium fertilizers, instead of heavy applications, prevent excessive uptake by plants.

Maintenance of soil pH at 6 to 6.5 with lime reduces potassium losses from leaching. The addition of crop residues and manure amounts to increasing potassium in the soil.

Potassium can significantly correct adverse consequences of excess nitrogen to the plant. Indeed, an appropriate proportion of nitrogen and potassium are beneficial to plant nutrition.

Potassium activity ratio

Potassium activity ratio is another term for **potassium adsorption ratio**.

Potassium adsorption ratio

The potassium adsorption ratio (PAR) estimates the exchangeable potassium percentage of a soil, and expresses the relative activity of potassium (K^+) in the exchange reactions with soil as:

$$\text{Potassium adsorption ratio} = \frac{K^+}{\sqrt{\frac{(Ca^{++} + Mg^{++})}{2}}}$$

The ionic concentrations are expressed in milliequivalents per liter or millimoles per liter. Since this ratio shows the activity of potassium (K^+) ions, it is referred to as **potassium activity ratio**.

Potassium bicarbonate

Potassium bicarbonate ($KHCO_3$), also called potassium hydrogen carbonate, is a white crystalline solid, soluble in water (insoluble in ethanol). It decomposes at about 120°C. Potassium bicarbonate contains about 28% potassium (K_2O) and used as a potassium supplying fertilizer.

Potassium bicarbonate, which occurs naturally as calcinite, is made by passing carbon dioxide into saturated potassium carbonate solution. It is used as baking powder and as a fire extinguisher.

Potassium carbonate

Potassium carbonate (K_2CO_3) in solution form can be used as a liquid fertilizer. A limited quantity of the solid is used as a non-chloride form of potassium for tobacco.

Potassium carbonate is obtained from ash. It is made by electrolysis of potassium chloride. Potassium hydroxide on reaction with carbon dioxide gives potassium carbonate. Liquid carbonate contains about 50% potassium carbonate in water. The solid product, which contains over 70% potassium carbonate is fairly expensive and is of use in only limited types of acid soil. Neutralizing caustic potash with carbon dioxide gas also produces potassium carbonate.

Potassium chloride

Potassium chloride (KCl), also known as **muriate of potash**, is generally blended with other components to make it a multinutrient fertilizer. It is a white crystalline solid, available in fine, coarse and granular grades. It is the least expensive carrier of potassium in the fertilizer market. This important fertilizer contains about 48 to 52% plant food as potassium and about 48% chloride. Coarser potassium blends well with granular N-P compounds to form an NPK-blended multinutrient fertilizer.

At least 78% of the potassium salts are estimated to be consumed worldwide, in the form of potassium chloride, and over 90% of all processed potassium is used as fertilizer. Muck, peat and sands are generally potassium-deficient, whereas arid soils are mostly potassium-rich, with 448 kg/ha or more of readily available potassium.

Potassium chloride is neutral and totally water-soluble. It can be applied to all soils and crops that are not sensitive to chlorides. Soluble soil-potassium is adsorbed and retained by soil colloids and thus prevented from leaching. Roots take up potassium in the ionic form.

Potassium chloride is best applied either while sowing or prior to it. However, when soils are light or coarse-textured, the applied potassium may be lost through leaching. So, it is preferable to apply potassium in split doses. On heavy soils, the fertilizer is placed advantageously in bands, as in the case of phosphatic fertilizers.

Potassium chloride is manufactured from potash minerals or brine. **Sylvinite**, which is a mixture of potassium chloride and **halite**, is the major potash mineral used for potassium chloride manufacture. A large percentage of potassium chloride is mined and refined either by the floatation or crystallization process. Both processes, of which the floatation process is more common, involve the separation of potassium chloride from sodium chloride. Fine potassium chloride is a free-flowing material which does not cake in dry places.

Potassium cycle

When plants are dormant and leaching is minimal, weathering of potassium minerals results in an increase in solution potassium. This leads to an increase in exchangeable potassium, and in turn, an increase in the amount of fixed potassium. Normally, this occurs in autumn and winter, in minimally and moderately weathered soils.

When plant uptake, weathering and leaching occur, normally in spring and summer, there is a decrease in solution potassium, followed by a decrease in exchangeable potassium, and in turn, the amount of fixed potassium.

This series of actions create soils with few potassium minerals and very low available potassium. This is true of intensively weathered soils. Potassium does not complex with organic compounds; that is, it is not an integral part of any organic molecule in plants. Therefore, potassium availability is minimally related to the organic matter content in mineral soils. (See also Potassium.)

Potassium deficiency

Potassium deficiency in plants is seen initially as a chlorosis along the leaf boundary, followed by the scorching and browning of the tips and edges of older leaves (Fig.P.34), and is known by names such as **hidden hunger**, **leaf scorch**, etc. Soils having less than 108 kg/ha of exchangeable potassium are said to be deficient in potassium. In some plants, slow and stunted growth is seen followed by weak stalks and susceptibility to lodging. Resistance levels in plants come down and they easily become infested with disease and pests, resulting in poor quality and yield. (See also Potassium.)

Fig.P.34: Potassium deficiency symptoms on leaves.

Potassium fixation

The process of converting exchangeable or water-soluble potassium to its non-exchangeable or water-insoluble form is known as potassium fixation. In micas, potassium occupies the tetrahedral layers or interlayer spaces and hence becomes non-exchangeable. In some clayey soils like illite soils, non-exchangeable potassium ions can get trapped and thus be unavailable. Soils which exhibit this character are usually of 2:1 clay type. This is also the process in which exchangeable or water-soluble potassium is converted into a form that is not easily exchanged from the adsorption complex with a cation of a neutral salt solution. Though non-exchangeable, it can be released for crop use depending on the soil. (See also Potassium.)

Potassium magnesium sulphate

Potassium magnesium sulphate is a double sulphate of potassium and magnesium ($K_2SO_4 \cdot MgSO_4$) obtained from salt bitterns recovered from sea water. This double sulphate contains 18% potassium (22% K_2O), 11% magnesium and 22% sulphur. It is classified as a mixed fertilizer and is neutral when applied to soil. It supplies both sulphur and magnesium in addition to potassium when applied to soils deficient in these nutrients. Potassium magnesium sulphate occurs naturally as **langbeinite** ($K_2SO_4 \cdot 2MgSO_4$) and as **schoenite** ($K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$).

Potassium metaphosphate

Potassium metaphosphate is the salt of metaphosphoric acid. It is a readily available source of phosphorus and potassium to plants, and comprises 60% phosphorus and 40% potassium (K_2O). When pure, it contains almost 100% plant food. Potassium metaphosphate, $K_6(PO_3)_6 \cdot H_2O$, is made by reacting phosphorus pentoxide (P_2O_5) with potassium chloride (KCl) at a high temperature. It is slightly soluble in water and makes phosphate available after hydrolysis. Although slightly soluble in water, it is readily soluble in ammonium citrate solution.

Potassium nitrate

It is a potassium salt of nitric acid. Potassium nitrate (KNO_3), also known as **saltpeter** or **nitrate of potash**, is a white crystalline salt which occurs naturally in **nitre** or saltpeter. It is a useful fertilizer for normal application and **fertigation**. Potassium (44% K_2O) and nitrogen (13%) are the constituents of NK fertilizers, which serve as a source of potassium, where extra chloride is not desired.

The agricultural grade of potassium nitrate is free-flowing and non-caking, with a particle size in the range of 1500 to 400 microns.

Potassium nitrate, which is slightly hygroscopic and granulated, can be spread on soil by trucks, fertilizer distributors or by aerial spraying. In a mixed fertilizer, a powdered grade of nitrate of potash does not cake. Potassium nitrate is made by the reaction of potassium chloride with nitric acid as:

$$4KCl + 4HNO_3 + O_2 \longrightarrow 4KNO_3 + 2Cl_2 + 2H_2O$$

The nitrate of potash forms an easily breakable crust on top. It is chemically neutral and its nitrogen and potassium oxide ratio is roughly 1:3. It has been used successfully as a source of nitrogen and potassium for tobacco, tomato, potato, corn, citrus and carnations.

Potassium nitrate production process

Potassium nitrate is a potassium salt used most widely as a fertilizer. The natural ore containing sodium nitrate, potassium nitrate and some chlorides and sulphates is leached and the crystallized sodium nitrate is removed. To this, potassium chloride is added and the resulting sodium chloride is separated. Cooling the solution to 5°C crystallizes potassium nitrate which is removed by centrifugation. The residual brine is concentrated by solar evaporation to remove sodium salts. A further addition of potassium chloride leads to crystallization of potassium nitrate.

Synthetically, potassium nitrate is made by a low temperature reaction of potash with nitric acid and the solvent extraction of hydrochloric acid. The solvent is recycled. The reaction follows as per the following equation:

$$KCl + HNO_3 \longrightarrow KNO_3 + HCl$$

Potassium chloride and a stoichiometric quantity of 60 to 70% nitric acid is fed to a reactor at 5 to 10°C in the presence of a solvent. During the process, potassium nitrate crystallizes from the solution, which is centrifuged and dried. Both the unreacted nitric acid and hydrochloric acid can be removed by a counter of water in the current liquid extraction system. The remaining nitric acid and solvent are recycled through a refrigeration unit to the first reactor. The water is stripped from the solvent which is recycled. The low concentration of hydrochloric acid is concentrated to 22% in the multiple effect evaporator.

In another process, using the same reactants, a higher reaction temperature is employed to take advantage of the high oxidizing power of nitric acid. Potassium chloride is slurried with 65% nitric acid and cooled to prevent a reaction occurring before feeding the slurry into the reactor. The slurry, after feeding into the reactor, is heated to 75°C when the following reaction takes place:

$$3KCl + 4HNO_3 \longrightarrow 3KNO_3 + Cl_2 + NOCl + 2H_2O$$

Around 90% of chlorine is removed in gaseous form. Because of the corrosive nature of the reaction, the reaction vessel is made of titanium and lined with acid resistant bricks. The solution from the reactor flows to a stripping column where it is heated to 150°C. This completes the reaction and gives a solution containing 10 ppmw of chlorine. The reaction goes to completion at a nitric acid concentration of 55% in the solution. The gaseous mixtures of nitrosyl chloride and chlorine from the reactor are oxidized in the gas reactor by nitric acid at 150°C. This reaction gives more chlorine and nitrogen dioxide.

$$NOCl + 2HNO_3 \longrightarrow \tfrac{1}{2}Cl_2 + 3NO_2 + H_2O$$

The chlorine and nitrogen dioxide are separated. The nitrogen dioxide is oxidized with air and absorbed in water to get a 65% concentration of nitric acid as per the following chemical equation:

$$2NO_2 + H_2O + \tfrac{1}{2}O_2 \longrightarrow 2HNO_3$$

The overall reaction of the process is given by

$$2KCl + 2HNO_3 + \tfrac{1}{2}O_3 \longrightarrow 2KNO_2 + Cl_2 + H_2O$$

Potassium ore beneficiation processes

The ore composition, the ore grade, the proportion of oversized particles required to allow separation of different minerals, and the type and the amount of insoluble slimes (such as clay, anhydrite, dolomite, silica, etc.) are different for different deposits and may perhaps even be highly variable within a single deposit.

The beneficiation of raw potash ore requires a somewhat different scheme and equipment for each processing plant. Four basic beneficiation techniques are: floatation, heavy media separation, electrostatic separation and thermal dissolution crystallization. The other techniques include ammoniacal leaching and gravity separation using shake tables. The ammoniacal leaching is costly and the gravity separation gives only about 80% pure concentrates.

The first step in the beneficiation of a solid potash ore is to reduce the size to a point where the potash is liberated from the other ore constituents. Care should be taken to ensure that crushing and grinding generates minimum amount of fines. Fine particles of both the ore minerals and the insolubles are removed to the maximum possible extent before the potash separation step.

Floatation is a selective beneficiation process that utilizes the differences in surface properties of various minerals. In floatation, the fine particles having high surface areas tend to adsorb excessive quantities of the floatation reagent, raising reagent costs and contaminating the product. The residual slimes are finally thickened and sent to tailing areas for disposal. The most important reagents used in floatation are collectors. In the case of floatation of sylvinite ores, a cationic collector is added to the closely sized and deslimed ore slurry. These collectors are mostly straight chain aliphatic amines derived from natural fats and oils that are neutralized by acetic or hydrochloric acid before use.

Frothers are another category of reagents that are commonly used. These are used to aid the formation and stabilization of floatation froth, which are organic heteropolar compounds (e.g., pine oil and methyl isobutyl carbinol)

Modifiers or regulators is another class of compounds and are used to control the floatation process. In potash floatation, slime depressants such as starch, guar gum, dextrin and synthetic compounds are typically used.

In potash floatation, the aim is to separate sylvite from halite by using cationic collectors. When potash ores contain sulphate minerals like kieserite, sulphate salts are floated using fatty acids or sulphated fatty acids as collectors. Potash floatation circuits always have both rough and clean cells. In the rough cells, as much potash as possible is made to float while in the cleaner cells the purity of the floated product is the prime consideration. The coarse particles of the rough tailings and the tailings from the clean cells are usually re-ground to a smaller size and re-floated. With very fine ores, sometimes counter-current floatation is used.

Another beneficiation process is heavy media separation. This process uses the difference in specific gravity of sylvite (KCl, 1.9) and halite (NaCl, 2.13). In a liquid of intermediate specific gravity, halite will sink and sylvite will float. Commercial heavy media operations use a very finely divided weighing agent, generally ferrosilicon or magnetite of 200 mesh, which is slurried to create an artificial heavy medium at the specific gravity required for separation. After separation, the magnetite or ferrosilicon is recovered by magnetic separation and recirculated to the system.

Electrostatic separation is a dry technique in which a mixture of minerals is differentiated according to their conductivity. Potash minerals are not naturally conductive, so the separation is preceded by a conducting step that induces the electrostatic charges of minerals of different magnitude. For potash, fractional or triboelectric charging is used. The charges are induced through repeated physical contact between different materials.

In Germany, potash ore is conditioned with aromatic and aliphatic monocarboxylic acids. The mixture is heated in a fluid bed and the RH is adjusted to enhance the charging of particles. The ore is then fed to an electrostatic separator to give three fractions, that is of product, residue and middlings. The method has two advantages of cost and environmental impact. Using a dry process to improve the product grade also eliminates the drying costs.

Thermal dissolution and crystallization are possible because of the higher solubility of potassium chloride (KCl) in hot water than in cold water compared to that of sodium chloride (NaCl) which is slightly more soluble at 100°C than at 20°C. When a mixture of sylvite and halite is dissolved in water and heated to 100°C, KCl is substantially in solution but not NaCl. The ore is crushed to minus 3 mesh and washed with cold water and a NaCl/KCl solution. Clays are removed by desliming and the clarified solution is then heated and used to dissolve the potash in the washed ore. Undissolved NaCl is discarded as tailings. The brine solution on cooling under vacuum separates out KCl, which is filtered, washed and dried. The remaining brine is recycled. It is once again recrystallized to meet the needs of high purity KCl.

Carnallite ores ($KCl \cdot MgCl_2 \cdot 6H_2O$) are a low grade ore. They are deliquescent for use directly as fertilizer. Dissolution and recrystallization methods used for carnallite processing are energy intensive and expensive. A large volume of magnesium chloride ($MgCl_2$) is formed which poses disposal problems. The conventional mining and beneficiation sequence for potash recovery from carnallite encompasses many operations. These operations include mechanically mining the ore, hoisting to the surface, beneficiating the ore to a carnallite concentrate, dissolving the carnallite, recrystallizing potassium chloride (KCl), disposing saline solid wastes and saline liquid effluents.

Carnallite ore processing methods vary widely and depend upon accessory minerals that are associated with the ore. The two general methods of carnallite processing are cold leaching and hot leaching. Cold leaching is carried at 20 to 25°C while hot leaching is done at 100°C to dissolve $MgCl_2$, KCl and NaCl, if any.

Langbeinite ($K_2SO_4 \cdot 2MgSO_4$) is separated from sylvite and halite by selective washing, froth floatation, or heavy media separation. Langbeinite may be marketed as a fertilizer or animal feed as a source of K, Mg and S or it may be converted into other products.

Potassium sulphate (K_2SO_4) is produced by reacting one molecule of langbeinite with four molecules of KCl. Potassium magnesium sulphate is produced by refining. The reactions are as follows:

$$K_2SO_4 \cdot 2MgSO_4 + 4KCl \longrightarrow 3K_2SO_4 + 2MgCl_2$$

$$2[K_2SO_4 \cdot 2MgSO_4] + 2KCl \longrightarrow 3(K_2SO_4 \cdot MgSO_4) + MgCl_2$$

Fractional crystallization is used to separate the final potassium sulphate product from other minerals.

Alunite [$K_2 \cdot Al_6(OH)_{12}(SO_4)_4$] is a source of potassium sulphate and alumina. Sulphur dioxide is the by-product. The economics hinge on the value of alumina. The processing involves ore comminution, roasting and leaching to recover the potassium sulphate solution. Filtered solids can be processed for alumina in a Bayer-type process plant.

Potassium phosphates

Potassium phosphates are excellent fertilizers because of their very high phosphorus content. At present, most potassium phosphates used in fertilizers are produced from potassium hydroxide or carbonate, and various phosphoric acids as per the following chemical reactions:

$$H_3PO_4 + 3KOH \longrightarrow \underset{\text{(Potassium phosphate)}}{K_3PO_4 + 3H_2O}$$

$$H_4P_2O_7 + 4KOH \longrightarrow \underset{\text{(Tetra potassium pyrophosphate)}}{K_4P_2O_7 + 4H_2O}$$

$$HPO_3 + KOH \longrightarrow \underset{\text{(Potassium metaphosphate)}}{KPO_3 + H_2O}$$

These phosphates are used in liquid fertilizers for foliar application or other speciality uses. Their advantages arise from their (a) high analysis, (b) low salt index, (c) ability to produce clear fluid fertilizers which are high in potassium (K_2O), (d) route to making polyphosphates with a controlled solubility, (e) status of being free from fluorine and chlorine, which makes them well-suited for use on tobacco, potato and other crops sensitive to excessive amounts of chloride ions, and (f) containing major nutrients like potassium and phosphorus. Table-P.8 shows examples of some potassium phosphate fertilizers with their respective grades.

Table-P.8: Some potassium phosphates and their grades.

Compound	Formula	Grade
Monopotassium phosphate	KH_2PO_4	0-52-35
Dipotassium phosphate	K_2HPO_4	0-40-54
Tetrapotassium pyrophosphate	$K_4P_2O_7$	0-40-57
Potassium metaphosphate	KPO_3	0-60-40

In addition, a potassium phosphate solution of 0-26-27 grade has been produced from superphosphoric acid and potassium hydroxide; it contains a mixture of ortho-, pyro- and higher poly-phosphates.

Potassium schoenite

Potassium schoenite, also called **potash magnesia fertilizer** ($K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$), is prepared from a mixed salt obtained from the solar evaporation of bitterns in saltpans. This fertilizer contains 22 to 24% potash (K_2O), 8 to 10% MgO, and 2 to 3% sodium chloride (NaCl) as impurity.

Potassium schoenite is used as a fertilizer for crops like sugar cane, tomato, pineapple, etc. in the laterite soils of Orissa (India), the southern states of Tamil Nadu, Karnataka, Kerala (India), in the podzolic soils of Himachal Pradesh (India) and the magnesium-deficient sandy loam soils and calcareous soils of north Bihar (India).

Potassium sulphate

Potassium sulphate, also called **sulphate of potash**, is a white crystalline material, moderately hygroscopic, available in fine, granular and semi-granular forms. It contains 48 to 54% potassium (as K_2O) and supplies 17 to 20% of sulphate. Chloride-sensitive crops like tobacco, grapes and potato require chloride-free potassium fertilizers. Therefore, these crops are fertilized with potassium sulphate, although this is more expensive than potassium chloride. These three crops, being major crops, account for about 7% of the total potash consumption. For best results, potassium sulphate should contain at least 50% potash by weight.

Potassium sulphate occurs in nature as 'langbeinite', a double sulphate of potassium and magnesium ($K_2SO_4 \cdot 2MgSO_4$) and made from **burkeite** ($Na_2CO_3 \cdot 2Na_2SO_4$), kainite ($KCl \cdot MgSO_4 \cdot 3H_2O$) or potassium chloride (KCl) as follows:

$$Na_2CO_3 \cdot 2Na_2SO_4 + 4KCl \longrightarrow 2K_2SO_4 + 4NaCl + Na_2CO_3$$

$$K_2SO_4 \cdot 2MgSO_4 + 4KCl \longrightarrow 3K_2SO_4 + 2MgCl_2$$

$$KCl \cdot MgSO_4 + H_2SO_4 \longrightarrow KHSO_4 + MgSO_4 + HCl$$

$$KCl + KHSO_4 \longrightarrow K_2SO_4 + HCl$$

$$2KCl + SO_3 + H_2O \longrightarrow K_2SO_4 + 2HCl$$

When applied to soil, potassium ion from the water-soluble potassium sulphate is retained in the soil colloids and not easily leached out. This makes potassium sulphate an excellent fertilizer, useful for all soils and crops while sowing or before sowing. It is also a safe ingredient of powdered, mixed fertilizers.

Potassium sulphate production processes

Potassium sulphate is the second largest tonnage of potassium compound and is primarily used as a fertilizer. Potassium sulphate can be made either by the Mannheim process where potassium chloride is reacted with sulphuric acid, or, made from natural complex salts like kainite or langbeinite.

(I) **Mannheim process**: The Mannheim process was originally developed for sodium sulphate production. For making potassium sulphate, sodium chloride is replaced with potassium chloride. The reaction takes place in two steps:

$$KCl + H_2SO_4 \longrightarrow KHSO_4 + HCl$$
$$KHSO_4 + KCl \rightarrow K_2SO_4 + HCl$$

Potassium chloride reacts with sulphuric acid during the slow mixing of the ingredients in the gas-heated Mannheim furnace. The potassium sulphate fertilizer is cooled and the lumps, crushed and granulated. Potassium sulphate is twice as costly as potassium chloride. Granulation adds further to its cost. The hydrogen chloride gas is cooled and absorbed in water to produce 33% hydrochloric acid as a by-product. Potassium sulphate contains over 50% potassium (as K_2O) and less than 1% chlorine.

(II) **Recovery from natural complex salts**: Potassium sulphate occurs naturally as complex salts. The major ones are: (a) kainite ($KCl{\cdot}MgSO_4{\cdot}3H_2O$), (b) langbeinite ($K_2SO_4{\cdot}2MgSO_4$), and (c) carpathian polymineral ores. The basic reactions leading to potassium sulphate from kainite are by transformation of kainite to schoenite followed by water leaching.

$$\underset{\text{(kainite)}}{2KCl{\cdot}MgSO_4{\cdot}3H_2O} \longrightarrow \underset{\text{(schoenite)}}{K_2SO_4{\cdot}MgSO_4{\cdot}6H_2O} + MgCl_2$$
$$K_2SO_4{\cdot}MgSO_4{\cdot}6H_2O \longrightarrow K_2SO_4 + MgSO_4 + 6H_2O$$

The Italkali's Pasquasia potassium sulphate process of recovery of potassium sulphate from kainite consists of four basic elements, and they are (a) preparation of the ore and floatation, (b) production of schoenite and its recovery, (c) leaching of schoenite to potassium sulphate, and (d) liquor treatment.

Other processes involve addition of sylvite to kainite, langbeinite or kieserite. The reactions are as follows:

(i) Mixing of kainite with sylvite

$$KCl + KCl{\cdot}MgSO_4{\cdot}3H_2O \longrightarrow K_2SO_4 + MgCl_2 + 3H_2O$$

(ii) Mixing of sylvite with kieserite and other magnesium salts

$$KCl + MgSO_4{\cdot}H_2O + 2H_2O \longrightarrow \underset{\text{(kainite)}}{KCl{\cdot}MgSO_4{\cdot}3H_2O}$$

A Russian Kalush plant method of potassium sulphate production uses potash ores as the starting material. The Carpathian ore contains about 9% potassium and 15% clay. The ore is leached with hot synthetic kainite solution in a dissolution chamber. The langbeinite, polyhalite and halite remain undissolved and are discarded. The overflow from the dissolution chamber is directed to a Dorr-Oliver settler where clay is settled and directed to a washer and discarded. The slurry of schoenite is filtered and the crystals, leached with water, to produce potassium sulphate crystals.

Potassium sulphate from langbeinite is produced by mixing large amounts of muriate of potash, sylvite and langbeinite.

$$4KCl + K_2SO_4{\cdot}2MgSO_4 \longrightarrow 3K_2SO_4 + 2MgCl_2$$
$$2KCl + 2(K_2SO_4{\cdot}2MgSO_4) \rightarrow 3(K_2SO_4{\cdot}MgSO_4) + MgCl_2$$

The langbeinite ore is separated from sylvite and halite by selective washing, froth floatation and heavy media separation. Langbeinite must be powdered and mixed with potassium chloride solution to get crystalline potassium sulphate and brine. The crystals are centrifuged or filtered, dried and classified to the required size.

Potassium taranakite

Taranakite represents a group of products formed by phosphorus fertilizers reacting with soil constituents. When potassium ion is used, it becomes potassium taranakite.

Pot culture experiments with fertilizers

Pot culture experiments with fertilizers is another term for **greenhouse experiments**. Pot culture provides suitable conditions for raising young plants; it enables plants to grow in unfavorable climate, to blossom and bear fruit out of season. (See also Diagnostic techniques.)

Potential acidity

There are two kinds of acidity – the potential acidity and the **active acidity** or **actual acidity**. The soil solution **pH** gives an idea of the active acidity and the stored reserve acidity. Potential acidity, also called **exchange acidity** or **reserve acidity**, is caused by hydrogen ions (H^+) and trivalent aluminum (Al^{3+}) ions on the exchange sites, which are in an exchangeable form on the soil exchange complex. This behavior resembles that of weak acids. Aluminum ions either create acidity or react with water and form hydrogen ions. Aluminum, being a trivalent ion, nearly saturates the exchange sites of many soils below pH 5.5. Above pH 5.5, it begins to precipitate in inactive forms. Soluble aluminum is one of the most damaging elements for plant roots. It restricts the growth and development of apex cells in the root systems in acid soils below pH 5.5.

Potential evapotranspiration

Evapotranspiration refers to the sum total of water or moisture lost by evaporation from (a) the soil surface,

(b) the surface of vegetation after precipitation, and (c) plants by transpiration. Potential evapotranspiration (PE) is defined as evaporation that would occur from the soil as well as by transpiration from vegetation, if water were available. PE combines the factors of moisture and heat in the climate. PE is also the evaporation which occurs from a land which is completely shaded by an actively growing green crop, and which is never short of water.

Measuring or estimating potential evapotranspiration in a field is useful in many ways and the water loss is measured by (a) direct measurement using evaporation pans, atmometers, lysimeters or evapotranspirometers, (b) meteorological formulae using aerodynamic approach (based on the physics of vapor transfer process) or energy budget approach or a combination thereof, (c) using empirical formulae, and (d) using water moisture budget methods.

From the estimate of water loss, designers of irrigation systems must know the quantity of water required for a particular crop, and the type of water delivery system and the frequency of water supply (daily or weekly) suitable for a particular crop.

Atmometers measure water evaporated from surfaces such as porous filter papers, porous porcelain spheres or plates, all of which are very sensitive to wind speed. They do not indicate evaporation from an open water surface and are generally of value only in relative comparisons between identical instruments exposed similarly.

Evaporation pans provide a very useful field method. Usually, pan values are converted into the corresponding open water evaporation values by applying a pan coefficient or correction factor which varies with the type of pan, site and climate.

The **U.S. Weather Bureau Class A Pan** (122 cm diameter, filled with water to a depth of 19 cm) is adopted by the World Meteorological Organization as the standard instrument. **Lysimeters** (Fig.P.35) are simple instruments, which consist of a drum of 58 cm diameter, placed in a collection chamber. The drum is filled with soil over a layer of gravel (to facilitate drainage) and grass is grown in it. The soil is kept at field capacity by supplementing the rainfall with a daily irrigation system. Simulating the natural conditions as much as possible, the evapotranspiration is determined.

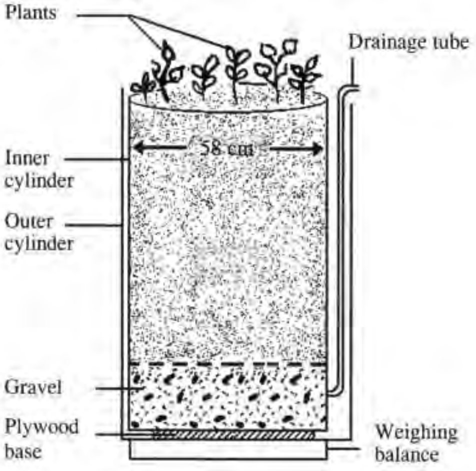


Fig.P.35: A diagrammatic representation of a simple lysimeter.

Potential evapotranspiration (PE) is determined as the difference between the water gain and water run-off. This is a water-balance method.

PE = (Precipitation + Irrigation) – Run-off

The **aerodynamic methods** use meteorological formulae based on factors influencing the removal of water vapor from the evaporating surface, the vertical gradient of humidity and the airflow turbulence, which can be assessed by the vertical gradient in wind speed. The energy balance approach improves the aerodynamic method.

Potential hydrogen

Potential hydrogen is the expanded version of **pH**.

Pot herbs

In the science of horticulture, pot herbs are one of the classifications of vegetables. (See also Horticulture.)

Potting compounds: See Encapsulation

Poultry manure

Poultry manure is richer in nitrogen and phosphorus than **Farm Yard Manure (FYM)** and also contains a good amount of potassium (Fig.P.36). Fresh droppings are decomposed by microbes followed by the release of ammonia. Ammonia is lost to the air, unless saved by keeping the manure covered, or by adding superphosphate to the manure. If the droppings are composted, the loss of nitrogen is minimal.

Fig.P.36: Poultry droppings are collected and used as poultry manure.

The nitrogen content in animal manure (on a dry weight basis) varies from 3 to 4% in poultry to 12% in dairy cattle manure, while the phosphorus content varies from 1 to 2% in poultry to 0.2 to 1.0% in dairy cattle manure. Farmers simply spread the waste over the cropland and do little else to recycle them. The droppings cannot be allowed to accumulate because (a) they cause an obnoxious odor, (b) they are breeding places for vermin, and (c) they are a source of unsavory dusts when dry and a polluting run-off when wet. Hence, it is important to consider the value of the manure. The value of animal manure, for instance, is based on the composition of the manure. It varies with factors such as the kind of animal, its age and condition, the food it consumed, the kind of litter used, and handling and storage it has received.

The use of livestock manure as a nutrient source for crop production has its own problems. For instance, transport beyond 10 km of a low nutrient-containing manure is uneconomical. Since the chemical composition is highly variable, it is difficult to comment on the amount of nutrients applied to the soil when the manure is spread.

Pourability of fluid fertilizer

Pourability denotes the extent to which a fluid fertilizer can be emptied from the container by gravity, or pumped or transferred from one container to another. Pourability is determined by rotating a string rod twice around the inside surface of the storage container (which is generally a 250 to 500 ml bottle) to apply gentle agitation to the fluid. The container is turned down at 45° angle for a minute and the content that pours out (as percentage by volume) is determined. Field tests show that fluid products that are at least 98% pourable by this procedure will flow freely by gravity from the storage container.

Powder

Powder is a dry and fine particle form of a solid substance. The particles in powder are extremely small in size.

Powders, which are so fine that their particles cannot be detected by rubbing between the thumb and the forefinger, are called **impalpable**. Metallic powders can be made by atomizing molten metals, or by chemically decomposing organo-metallic compounds of the metal or by crushing and grinding the metal. The particle size in metal powders ranges from 0.045 to 0.060 mm. Metal powders have industrial applications.

Specific powders are used in cosmetics, inorganic pigments, metals, plastics (moulding powders), dehydrated dairy products, pharmaceuticals and explosives. Thermoplastic polymers are used in powder moulding applications, whereas thermosetting polymers are used in spray coatings of automobiles, machinery, etc. on account of the many advantages thermosetting polymers offer over sprayed solvent coatings.

Fertilizers of very low solubility are generally ground to fine powders to ensure their rapid dissolution in soil and utilization by plants. For example, the effectiveness of a raw phosphate rock generally increases with fine grinding, down to a particle diameter of about 150 μm.

The **angle of repose** of a fertilizer powder is of interest while considering the storage capacity and design of hoppers, chutes, conveyors and sloped roofs of bulk-storage buildings. A **powdered fertilizer** tends to cake, when exposed to humid atmosphere. This property restricts its free flow by contact points between the particles. For this reason, very few fertilizer materials are now sold in powder form.

A powdered fertilizer is also referred to as **non-granular fertilizer** and is sometimes defined as a fertilizer containing fine particles, usually with some upper limit of fineness (such as 3 mm). Powdered materials are susceptible to the forces of wind, and can lead to undesirable dustiness and other handling difficulties.

The x-ray diffraction powder method is used for identifying minerals of rocks or clay.

Powdered fertilizer: See Powder

Power

Power (p) is the rate of doing work (w) and is defined as

$$p = \frac{w}{t}$$

where t is the time. Because work (w) equals distance (d) multiplied by force (f) we have:

$$p = \frac{F \times d}{t} = f.v$$

where v is the velocity (d/t).

Thus, power is force multiplied by velocity. Like work, power is a **scalar** quantity that is, a quantity with only magnitude but no direction. Some units used in measuring power are watt (1 joule of work/sec) and horsepower (550 foot pounds of work/sec).

The concept of power is used to describe the operation of any system or device in which a flow of energy occurs. In equipment design, power (rather than the total work to be done) determines the size of the components used. Any device can do considerable work by performing for a long time at a low rate of power, that is, by doing work slowly. High-powered machines are usually larger, more complicated, and more expensive than low-powered equipment. A motor, which must lift a certain weight, will have to be larger and more powerful if it has to lift the weight rapidly than lift it slowly.

In transportation, what matters is the power that a given machine can deliver or utilize, i.e. the rate at which it can handle energy, and not the absolute energies involved. A high power machine is one that can convert or deliver energy quickly. While mechanical power is derived by multiplying force and velocity, electrical power utilized in a circuit is a product of potential drop and the current flowing in it (volts × ampere = watts).

ppb

ppb is short for parts per billion. Such measures are used to express very small quantities of impurity or a useful element in a compound. ppb is 1/1000th of a part per million, expressed as micrograms per kg.

PPD

PPD is short for **phenyl phosphorodiamidate**.

ppm

ppm is short for **parts per million**, a unit for expressing low concentrations, such as the impurities present in pure raw materials and chemicals. Some plant nutrients are required only in small amounts by plants, and the amounts are expressed in metric unit or as milligrams (of say a micronutrient) per kilogram of soil, and milligrams per liter in liquid units.

PPNT

PPNT is short for **pre-plant nitrate test**.

Prairie podzol

Prairie podzol is a poorly-drained soil with depressions. It may have a fine-textured B horizon and a leached E horizon. Prairie podzol is also known as **bluff podzol** or **swamp podzol**.

Prairie soil

Prairie is a large open area of grassland that once covered much of the interior of North America and Canada.

Prairie soil is an isohumic soil, partly desaturated, characterizing the transition zone between the steppe and the forest. It is synonymous with brunizem.

There are three types of prairies: tall grass, midgrass or mixed grass and short grass (found in the driest areas). Typical prairie animals are coyotes, badgers, prairie dogs, jackrabbits, bisons and wolves.

The parent rock is mostly calcareous or at least rich in bases (moraine deposits or **loess**). The profile is normally well-drained and the microclimate of the soil is humid. Weathering affects the mineral horizons. Generally, prairie soil refers to a fertile soil used for the cultivation of maize and soybean. The organic matter in the surface horizon decreases gradually with depth and has a carbon to nitrogen (C/N) ratio of approximately 11:2. The exchange complex contains a less exchangeable hydrogen ion than other cations.

Prayon Mark IV dihydrate process for phosphoric acid: See Phosphoric acid production processes

Prayon process for phosphoric acid production: See Phosphoric acid production processes

Precipitated phosphate

Phosphorus supply in most soils is low and is not readily available for plant use. The soluble $H_2PO_4^-$ rapidly reacts in the soil to form insoluble phosphate, the process being called **phosphate fixation** (precipitation and adsorption).

In acid soils, phosphate ions react with soluble iron and aluminum ions to form insoluble phosphates. In alkaline soils, low soluble calcium triphosphate is formed. Thus, soil phosphorus is precipitated and adsorbed to soil minerals or made less available. This form of phosphate is known as precipitated phosphate.

The precipitation reactions are favored by very high phosphorus concentrations existing in close proximity to granules, droplets and bands of fertilizer. Adsorption reactions are important at the periphery of the soil-fertilizer reaction zone. The precipitation reactions usually account for the presence of most of the phosphorus in that vicinity.

Precipitation

Precipitation refers to water in liquid or solid forms falling on the earth, either as rain, drizzle, fog, mist, snow, hail or sleet. **Sleet** is rain, containing some ice (as snow) that melts as it falls. Precipitation is the source of almost all available fresh water and is very important for vegetation, crops and livestock. A variable amount of water vapor is always present in the lower layers of the atmosphere.

In the process of precipitation, air cools down below the condensation level. Water vapor forms water droplets or ice crystals in the presence of condensation nuclei. The size of a droplet increases until it becomes too heavy to remain suspended in air and ultimately falls as rain or snow.

The dominant factor in the type and distribution of precipitation is the uplift of moist air masses in which water condenses and falls as precipitation. The uplift is aided by the following factors: (i) Convection currents: the heated moist air rises and cools followed by condensation and precipitation. (ii) Meeting of air masses of different temperatures and humidities. For example, when warm, moist air is lifted above the cool dense air, the moist air cools and precipitation occurs, which is known as the **frontal effect**. (iii) Moist air mass hits a relief barrier like a mountain range. The air mass rises and cools, bringing precipitation on the windward side as relief or **orographic rain**.

The total annual precipitation alone does not reflect its distribution throughout the year. In agriculture, seasonal precipitation is crucial. In most parts of the tropics, the entire agricultural year is geared to the time at which precipitation occurs and often a slight delay or deviation from the seasonal pattern can affect the crop.

A simple instrument used for measuring rainfall is the **rain gauge**. The rain gauge consists of a funnel, an inner collecting jar, a copper container, and an outer container to fit all these, and a measuring cylinder. During rains, the rainwater that gets collected in the inner container is poured into the measuring jar and the total rainfall is recorded. Measurement is carried out once a day. For recording the time of occurrence and determining the intensity and duration of the rainfall, the **Dyne's self recording rain gauge** is used. The continuous type recording rain gauge uses a calibrated spring balance to record the precipitation weight on a clock-driven chart.

Precipitation also means the emergence of an insoluble substance from a solution, for example, precipitation of chloride ion (Cl^-) from a soil solution by the addition of silver nitrate in acid media, as silver chloride. It can get isolated from the solution phase by filtration or centrifugation and the substance is determined by weighing or by **gravimetric analysis**.

Precipitation may also be used to effect partial or complete separation of substances. For example, sodium carbonate precipitates calcium from solution as calcium carbonate.

The extent to which a component can be separated from the solution can be determined from the solubility product constant. As a rule, precipitates are not filtered off immediately after they are formed. Most precipitates, except colloids, need a degree of digestion before filtration, as otherwise, some precipitates pass through. When the precipitate separates from the solution, it is not completely pure and may contain impurities. The contamination of the precipitate by substances that are normally soluble in the mother liquor is termed as **co-precipitation**.

Various techniques are employed to reduce contamination by foreign ions. Precipitation from a dilute solution is often effective. The best way to reduce the quantity of foreign ions in the precipitate is to dissolve the precipitate and re-precipitate it. Colloidal particles dispersed in a gas, as flue dust in industrial stacks, can be precipitated by introducing an electric charge opposite to that sustained by the particles.

Pre-plant fertilizer

A pre-plant fertilizer is applied uniformly over a field before planting the crop. It gets incorporated while cultivating or tilling. Where such incorporation is not possible, for example, on perennial forage crops and in no-till cropping systems, the fertilizer may be broadcast on the surface. N, P, K fertilizers are effective when applied at the pre-plant stage. If they are not incorporated, conditions of dry surface soil can reduce the nutrient uptake.

A pre-plant broadcast of fertilizer gives a fairly good result with crops like millet, which are planted in narrow rows. If broadcasting is done after the land is plowed, it gets mixed with the soil. However, although the seedlings get a good start, the broadcast method also stimulates weeds.

Superphosphate is best broadcast prior to final preparation of the seedbed.

Pre-plant nitrate test

To measure the residual soil nitrate-nitrogen (NO_3-N) profile, soil samples are taken from a depth of 60 to 120 cm just before planting or soon after harvest. This is the pre-plant nitrate test **(PPNT)** which acts like one of the **nitrogen availability indices**.

Pre-side dress soil nitrate test

Pre-side dress soil nitrate test, referred to as **PSNT**, is one of the **nitrogen availability indices**. PSNT involves sampling of the soil (from 30 cm depth) before side-dressing and analyzing for nitrate-nitrogen (NO_3-N) which provides a more reliable index of the available soil nitrogen. It is useful for deciding the amount of nitrogen fertilizer to be side-dressed. A major drawback in this procedure is the availability of only a short time (2 to 3 weeks) for completing many important tasks like the collection of soil samples, analyzing these for nitrate-nitrogen (NO_3-N) values, deciding the rate of nitrogen to be applied, and then applying the fertilizer nitrogen. Besides, there is another task of determining the degree of nitrogen stress, by measuring the chlorophyll content of corn leaves using a handheld chlorophyll meter.

Pressmud

Pressmud, also known as **filter process cake**, is a by-product in the sugar industry. It is formed during the vaccum filtration of hot sugar cane juice. It contains about 75% sulphur-rich organic matter and 29% total solid content of which 65% is volatile.

Pressmud is easily biodegradable and is reported to yield biogas 2 to 3 times that of dung. It may be used as a fertilizer or for the reclamation of alkaline soils. It is a dry heterogeneous mass, containing 1.2% nitrogen, 2.1 to 2.5% phosphorus (or 4 to 5% P_2O_5), 2 to 7% potassium (as K_2O), 3 to 5% calcium (as CaO), 250 ppm zinc and 120 ppm copper.

Pressure injection: See Fertilizer placement

Pressure pan

A **plow pan** is also called pressure pan.

Pressure solutions

Nitrogen solutions that contain enough free ammonia to develop a vapor pressure at the storage temperature, necessitating the use of high-pressure equipment for handling, storage and application are called pressure solutions. Liquid ammonia is an example of a pressure solution fertilizer.

Pressurized liquid fertilizer

Commercial fertilizers are available both in solid and liquid forms. A **liquid fertilizer** is also called a **fluid fertilizer**. The main materials used in liquid fertilizers are anhydrous ammonia (pressurized liquid fertilizer), aqua ammonia and non-pressure nitrogen solutions. Among pressurized fertilizers there are low-pressure, medium-pressure and high-pressure types. Low-pressured fertilizers are suitable for direct application, medium-pressured ones are used for ammoniating superphosphates or phosphoric acid and high-pressured ones are used only for ammoniation. For pressurized liquid fertilizers, double-walled vessels with 'a leak warning system' are recommended.

Prilled fertilizer

Prill refers to a pellet or a solid globule of a substance formed by congealing a liquid during an industrial process. The process, known as prilling or granulation, is a combination of spray drying and crystallizing technique used to produce agglomerates.

A fertilizer in the form of small (about 2 to 3 mm diameter), smooth, spherical granules (prills) is called a prilled fertilizer. Its shape results from solidification of the molten droplets of the fertilizer.

The most common industrial method of producing prilled fertilizers is by spraying the molten fertilizer from a height inside a closed tower while a stream of air moves upward. As the drops of the molten fertilizer fall, they cool and solidify. This process produces prills that are smaller than those produced by other processes, and is used mostly for producing urea, ammonium nitrate and some NPK grade fertilizers.

Primary host

A host is an organism or a plant on which other organisms (parasites) live, using up the required nutrition. Some parasites need more than one host to complete their life cycle. The first host is known as the primary host or the **definitive host**.

Primary minerals

A mineral that has not changed its chemical nature since its formation from molten lava is a primary mineral. Rocks composed of primary minerals, upon disintegration, turn into sand and silt. Primary minerals weather chemically and release their elements into the soil solution. Some of the elements released in weathering react to form secondary minerals.

Primary nutrients

Primary nutrients is another term for **macronutrients**. (See also Plant nutrient.)

Primary roots

After the seed begins its physiological process, the first or primary root develops. The primary **root** begins to sprout its own branches, and this generally develops into a root system (Fig.P.37).

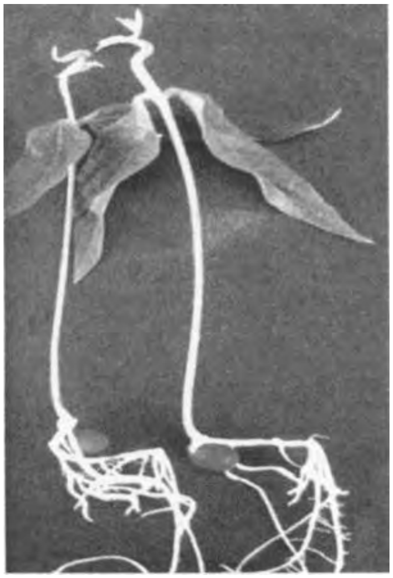


Fig.P.37: Sprouting primary roots of pigeon pea plantlets.

Primary source of phosphorus: See Rock phosphate

Primary standard solution

The solution of a known concentration used in volumetric analysis is called a **standard solution**. Primary standard is one of the two types of standard solutions, the other being the secondary solution. Primary standard is a substance in a 100% pure stable form available for weighing and preparing the standard solutions. Potassium hydrogen phthalate is a primary standard for acid-base titrations.

Primary structure of protein

The linear arrangement of the amino acid residues in a **protein** is termed as the sequence or the primary structure of the protein.

Primary tillage

Tillage is the preparation of land for growing crops. It is done with different mechanical equipments.

Primary tillage involves breaking and loosening of the soil to a depth of 15 to 90 cm using a moldboard plow, disc plow or similar equipment. The objective is to prepare the soil so as to make it workable.

Primary tissues of plant

An **apical meristem** is the region at the tip of each shoot and root of a plant in which cell division occurs continuously to produce new stems and root tissues. The new tissues produced are collectively known as the primary tissues of the plant.

Principle of segregation

The principle or law of segregation, established by Gregor Mendel states that the factors or genes making up pairs are separated from each other prior to the formation of sex cells. In other words, only one factor or gene of each pair goes into a given sperm or egg.

Prismatic structure

Prismatic structure is a unit of soil structure. Its shape is like a prism, in which the vertical axis is much longer than the horizontal one. Its edges are angular and sides are plane. Peds with a columnar structure have the same shape, but have rounded edges. The horizontal section of the aggregates is polygonal.

The shrinkage of moist soil material on drying, causes a multidimensional compression centerd on the numerous loci within the soil mass. When the shrinkage forces are largely resolved in lateral directions, the soil material may contract uniformly with more or less equally spaced centers of the prismatic or columnar peds being formed, bounded by vertical cracks. In the formation of the prismatic structure, the occurrence of uniform shrinkage can lead to consistently spaced and arranged cracks that form the boundaries. Uniform shrinkage occurs if the soil material is homogeneous and the drying is slow.

Prismatic and columnar structures are common in natric horizons because of the enhanced swelling and poor drainage common with sodium saturated clays. In contrast to the prismatic structure, a blocky structure is formed as a result of the combined lateral and vertical shrinkage forces, with neither predominating. Blocky structures are found in the subsurface soils of arid and semi-arid regions and in soils derived from wind-blown loess.

Probability

Probability is the likelihood of a particular event occurring. If there are 'n' equally likely outcomes of an experiment, and 'A' ways in which an event 'e' could occur, the probability of the event 'e' occurring is A/n. For instance, if a die is cast and there are 6 possible outcomes and 3 ways in which an odd number can occur, the probability of an odd number occurring is $3/6 = 1/2$. The probability of an outcome of a certain event is equal to the relative frequency of this outcome among all events of the same kind.

The probability theory is intimately linked with statistics. More advanced probability theories have contributed to the understanding of many vital fields of physics, statistical mechanics and particle behavior in a colloid and molecules in a gas.

The **probability factor** is a correction term in the equation for the rate constant involving the probability of an appropriate orientation of the reactant molecules before reaction. The equation for the rate constant $k = Ae^{-E/RT}$ should involve the probability factor P.

$$k = PZ\,e^{-E/RT}$$

where Z is the number of collisions, E is the activation energy, R is the molar gas constant, T is the absolute temperature and A is the frequency factor. The probability factor has a value of less than or equal to 1 (1 to 10^{-7}), which indicates the chance of a reaction taking place after an activated collision.

Probability factor: See Probability

Problem soil

A soil that suffers from constraints other than the nutrient availability for cultivation is called a problem soil. The constraints include **salinity**, acidity, **sodicity**, **erodibility**, waterlogging and the slope of the land.

Soils are fundamental to the well-being and productivity of agricultural and natural ecosystems. Parameters like soil fertility, potential productivity, resource sustainability and environmental quality indicate the degree of its fitness for a specific use.

The problems of soil are overcome by treating it suitably. For example, an acidic soil is treated with lime. Similarly, sodic soil is treated with gypsum or leached with water. Reclaimed soils are used for crop production. Without such treatments, problem soils are unsuitable for agriculture.

Processed rice

The need to process rice scientifically has been felt because milling and polishing of rice remove all the valuable nutrients contained therein.

Commonly consumed **white rice** is devoid of nutrients like thiamine, niacine, iron, etc. In addition, the age old custom of thoroughly washing the grain before cooking also washes away most of the water-soluble Vitamin B.

Processing of rice, keeping nutrition in mind, is a purely external intervention. **Brown rice**, **instant rice**, **converted rice** and **enriched rice** are some products of processed rice.

Process of coalification

Coalification is the process in which vegetation and other organic matter decompose to form layers of peat, and subsequently get buried deep down in the earth, where under increased pressures and temperatures, the peat gets transformed into coal.

Procurement price

The procurement price is the price at which the government or its agency procures agricultural produce from the farmer.

The government tries to stimulate agricultural production through various economic measures. Subsidies, apart from a guaranteed minimum price for the produce and an insurance coverage, are common in many countries. These measures are meant to encourage the farmer to increase production, in order to meet the domestic demand and create exportable surplus.

Production credit to farmers

Financial assistance given to a farmer for agricultural projects is known as production credit. Commercial banks or governments give such financial assistance to encourage and assist both the farmer and farming. Such loans or credits, either in the form of cash or kind (components or equipments) are repayable over a specified period of time.

Production processes for compound fertilizers

Compound fertilizers account for 15% of fertilizer materials. Unlike commodity type fertilizers, compound fertilizers are formulated to meet the local or regional crop requirements. In addition to containing various ratios of primary nutrients (N, P and K), they contain secondary and micronutrients specific to the crop requirements in that region.

The use of compound fertilizers is driven by the following factors: (a) convenience, (b) crop nutrient needs, (c) government policy, and (d) economics. These are elaborated below.

(a) Convenience: It is more convenient to purchase, transport, store and apply one product than several individual nutrients such as urea, potassium chloride, ammonium phosphate and ammonium nitrate. Free flowing granules of homogeneous compound fertilizers get uniformly distributed. Although many doses of these fertilizers may be required during the growing period, their utility cannot be disputed.

(b) Crop nutrient needs: Compound fertilizers provide nutrients, including secondary and micronutrients, prior to or at the time of planting. The basal dose of a compound fertilizer often needs additional doses of nitrogen to be given to plants or crops. Compound fertilizers, because of their homogeneity, can be uniformly distributed in relatively small quantities, and without the risk of being segregated, a condition that can be detrimental to the crop.

(c) Government policy: In some cases, compound fertilizers are supplied to farmers under subsidized pricing programs. Such policies encourage the use of compound fertilizers.

(d) Economics: The purchase, transportation, storage and application of a compound fertilizer is economically advantageous. Although compound fertilizers, on a nutrient basis, are more expensive than a single nutrient product, they are economically far more preferred, if viewed in totality, that is, the time and effort spent on application. Compound fertilizers are uniquely suited for the fertilization of plantation crops like oil palm and rubber.

The method of granulation has a great impact on the design and operation of the machinery. Hence, knowledge of the mechanism of granule formation is necessary for determining the design features of the granulation process.

Two mechanisms of granule formation are known: agglomeration-type process, and accretion-type process. These are described below.

(I) Agglomeration-type process: **Agglomeration** is the principal mechanism for most granular NPK products in the initial formation of granules and subsequent growth. In the agglomeration-type NPK formulations, 50 to 70% of the raw materials are fed as dry solids. These solids are converted into agglomerates by a combination of mechanical interlocking and cementing. The cementing medium for the granules is derived from salt solutions such as preneutralized slurry or dissolution of a salt on moist surface of the soluble particles. The size, shape, surface texture, strength and solubility of solid particles greatly influence the granulation characteristics of the mixture.

(II) Accretion-type process: Accretion is a process in which layers over layers of a fluid material are applied to a solid particle causing it to grow in size. The slurry-type granulation processes used with **DAP**, **MAP**, **TSP** and some nitro-phosphates are examples of accretion-type granulation processes. This process gives the final granule an 'onionskin' like structure, and is quite different from the agglomeration-type process. In this process, of course, some agglomeration occurs but it is not a significant mechanism.

The recycle-to-product ratio is higher for accretion-type granulation compared to the agglomeration-type process. However, because of the particular temperature and relative humidity, the processing equipment for agglomerated fertilizers may have to be larger, to achieve the same production rate as in the accretion-type process. Granules formed by the accretion-type process are always harder, more spherical and more durable than those formed by the agglomeration-type process. That is, the crushing strength is higher for the accretion-type process than that for the agglomeration-type process.

Chemical and physical parameters for making agglomerated NPKs are the following:

(i) Particle and surface characteristics: The particle size, size distribution and surface characteristics of the solid raw materials determine the mechanical strength of agglomerated NPK granules. For a final product size of 2 to 5 mm, the raw materials should be quite widely distributed within a range of about 0.2 to 3 mm.

(ii) Liquid phase: Cementing of particles is needed to bond the particles into strong agglomerates in addition to processing of the raw materials. The liquid phase is derived from (a) soluble salt solutions added to the granulator, for example, an ammonium phosphate slurry and/or a solution of urea or ammonium nitrate, and (b) dissolution of a small portion of material on the moist surface of the soluble raw material and the recycled particles. The dissolution is caused by the combination of heat and water contained in the above solutions, or steam or water fed to the granulator. The liquid phase, which controls the granulation quality efficiency, forms strong crystal-crystal bonds between the particles.

(iii) Heat of chemical reaction: The amount of heat generated, particularly within the granulator, has a marked effect on the fertilizer materials, the liquid phase formed and granulation characteristics. The most important heat generating chemical reaction in the granulation of NPK fertilizer is neutralization of the acidic materials with ammonia inside the granulator. Experience has shown that if the heat released in the granulator is in the range of about 45,000 to 50,000 kcal/ton of the product, conditions are favorable for optimum granulation.

(iv) Insoluble binders: In some cases, the addition of a small quantity of a finely divided binder powder (like kaolin or attapulgite clay or ground phosphate rock) to the granulating mixture improves the mechanical and crystal bonding. The binder powder helps to fill very small voids between fertilizer particles and also helps to join the particles. Depending on the characteristics of the binder and the materials being granulated, the amount of binder used may need to be approximately 2 to 15% of the total formula weight, so as to be effective. This concept works well for NPK fertilizers that contain a large amount of crystalline ammonium sulphate, potassium chloride, potassium sulphate and/or kieserite and low levels of highly soluble salts or solid binders such as ammonium phosphate slurry or superphosphate, respectively. Finely ground phosphate rocks that contain high levels of iron and aluminum impurities are a very effective binder. They also add a primary nutrient to the product.

(v) Liquid phase control: In the NPK fertilizer granulation, most of the liquid phase is obtained from materials that are introduced at a fixed rate to achieve the final desired product. The resulting liquid phase can be adjusted within specific limits through the choice of raw materials or by controlling free water content and/or composition of the slurry. The NPK granulation by agglomeration is more of an art than a science.

(vi) Acid/ammonia neutralization methods: Neutralization reactions produce heat that contributes to the overall conditions of the liquid phase in the granulator and influences the efficiency of the granulation process. The method of neutralization influences the overall performance of the granulation process. The methods of neutralization are given below.

(a) Direct neutralization in granulator: A direct neutralization in the granulator for the NPK grades containing superphosphate and some nitrogen acts optimally if the amount of ammonia reacted in the granulator does not exceed the equivalent of about 50 kg/ton of the product. In this process, ammonia is distributed beneath the bed using a perforated pipe in the granulator. If sulphuric acid is used, it is also distributed through a spurger beneath the material bed. Rotary drum type granulators are best suited for direct neutralization because the submerged spurgers can be easily positioned beneath the material bed and the reaction contained within a relatively deep bed of materials. With a pug mill or pan-type granulator the positioning is not effective.

(b) Tank-type neutralization: The use of a tank-type neutralizer offers maximum flexibility in managing the acid/ammonia reactions. The latter are most often only partially completed in a tank-type neutralizer which is, therefore, called a preneutralizer. The degree of reaction in the preneutralizer is determined by a number of factors. The production of a fluid slurry for easy transportation or pumping and for uniform distribution on to the rolling bed of the material is the important criteria. The fluidity of the slurry is controlled by the mole ratio of NH_3:H_3PO_4. The selection of the construction material is important when sulphuric acid is used with phosphoric acid in the preneutralizer.

(c) Pipe-type reactors: The tee or pipe reactor replaced the tank-type preneutralizer in the early 70s. The pipe reactor consists of a 5 to 15 m long pipe through which phosphoric acid, ammonia and water are simultaneously added at one end through a pipe configuration resembling a tee. The violent reaction between the acid and ammonia forms a superheated mixture of ammonium phosphate slurry and water vapor. The primary advantages of the pipe reactor over conventional preneutralizers are the elimination of the slurry pump and the piping system in the tee reactor, as also a more concentrated slurry. The tee reactor, which was modified to accept additional flow of sulphuric acid through another pipe inlet located opposite the entry point of phosphoric acid, is called **pipe cross reactor**.

The mixture discharged from the pipe-cross reactor does not need to further react with ammonia in the reactor. Several variations of the pipe-type reactor are used in the plants for NPK, DAP and MAP fertilizers. One of the advantages of the pipe reactor technology in NPK fertilizer production plants is that it enables use of a variety of raw materials, thereby reducing the production costs and eliminating certain 'problem materials'.

A large number of raw materials and process variables must be considered when developing NPK formulations with good granulation characteristics. Considerable skill and an element of art are both required to ensure that a particular formulation will give the desired results.

The processes for manufacturing compound fertilizers are given below.

(i) Steam/water granulation: In the steam/water granulation process, granules are formed by agglomeration. In the granulator (rotary drum or pug mill) steam and/or water or scrubber liquor is added to the weighed solid raw materials to provide sufficient liquid phase and plasticity to cause the dry raw materials to agglomerate into the required size. In some cases, a small amount of ammonia may be added during granulation to react with superphosphate to promote granulation and improve the product quality by increasing the critical relative humidity. The moist and plastic granules are dried and sieved to get the product size. The over-sized and under-sized products are recycled. In some cases, cooling the product in a fluid bedtype cooler is carried out.

(ii) Chemical granulation: The most complex method of preparing a granular NPK fertilizer is by chemical granulation. It is very similar to the steam/water granulation process except that the liquid phase is obtained by reacting ammonia with phosphoric acid, sulphuric acid and/or nitric acid. In a few cases, concentrated urea or ammonium nitrate can also be used. Much of the ammonia-acid reaction is preferred outside the granulator. The granules are formed by agglomeration. The relationship between the consumption of solid and of liquid raw materials is determined by the requirement of the nutrient ratio and solubility, and of the liquid phase; the relationship also depends on the heat of reaction, temperature limitations, the capacity of the process plant equipment and the operating features.

(iii) Prilling: In this process, the NPK mixture is concentrated to approximately 96 to 98% solids before it is introduced to the top of prilling towers through either a nozzle assembly or perforated vessel. The droplets of the molten fertilizer mixture on solidification result into granules of the required size. The NPK granules produced by prilling are smaller than those produced by the other methods.

(iv) Compaction granulation: In compaction granulation, mechanical force is used to form dense particles from fine, non-granular solid materials. The mixture in a correct proportion is continuously fed to a pressure-roll compaction machine to form hard 2 to 3 cm thick and 60 to 100 cm wide sheets. The compaction machine is made up of two horizontally opposed rollers that turn inward toward each other. The rollers are about 100 cm in diameter and wide. Pressure is applied by a hydraulic system in the movable roller shaft (the other is stationary) and bearing assemblies. The compacted sheet material is crushed in a controlled manner to smaller particles. The crushed material is screened to obtain the desired size. The over-sized material is crushed and recycled to screens and the under-sized is returned for compaction. Properties of the raw material, like chemical compatibility, thermal characteristics and plasticity, have great influence on the performance of the process. The pressing force is measured in terms of tons of force per centimeter of the roller width.

Granular fertilizers prepared by compaction are more irregularly shaped compared to those produced by the other granulation processes. This irregular shape may promote caking during storage because of the fines and increased surface area. This unacceptable property can be improved upon by making refinements in the process (like tumbling/abrasion to round off the corners and edges).

(v) Dry mixing and blending: Blending here refers to physical mixing of dry fertilizer materials without any chemical reactions, or change in the particle size. The dry solid blends (often called bulk blends) are usually granular and are sold as finished products, as in the case of MAP, DAP or MOP.

Particle size plays an important role in the preparation of high quality blends. The **size guide number** (**SGN**) is one such information widely used in industry. In practice, a variation of about 25 points from the derived SGN will usually be an acceptable blend.

Another indicator to assist in the selection of materials for making high quality blends is the uniformity index (UI). A UI of 100 would indicate that all particles are of the same size in a sample. In practice, UI of about 50 is common. This means that the size of the smaller particles in the sample is one-half (50%) the size of the largest particles in the sample.

Blending is usually done on a batch basis with the batch size varying from 1 to 3 tons. However, continuous blending is common in countries in Europe and the blending capacity is of 30 to 60 tons per hour. The third option of blending is manual. Sometimes, large, centralized blending plants prove suitable in locations where transport infrastructure is weak. In such cases, it is usually more practical to blend and bag the product near the source of supply, and transport the finished product to distribution points. The NPK granulation processes cannot produce a relatively small quantity of a specific product economically. However, these NPK granulation processes can be used to supply the blender with granular base formulations such as ammoniated SSP fortified with secondary nutrients and micronutrients. These granular base formulations could be used by the blender to uniformly incorporate small quantities of micronutrients throughout the total blend without fear of segregation.

The benefits of granulation and blending can often be optimized by operating both the processes in concert with each other. Such systems offer maximum flexibility in raw material utilization and the ability to produce a large number of nutrient grades to meet the changing demands of the market place.

Productive efficiency: See Efficiency

Productive soil

A soil in which chemical, physical and biological conditions are favorable to the economic production of a crop is known as productive soil. The ability of a soil to grow a crop or allow a cropping system under normal conditions of cultivation is known as **soil productivity**. The productivity depends on natural and acquired fertility, given as the percent optimum yield of the crop or crop sequence on the best soil of the region.

Productivity index of soil

Productivity index (**PI**) is a measure of the productivity of a soil and is given by:

$$\mathrm{PI} = \mathrm{H} \times \mathrm{D} \times \mathrm{P} \times \mathrm{T} \times \mathrm{N(S)} \times \mathrm{O} \times \mathrm{A} \times \mathrm{M}$$

where H is the soil moisture, D is the drainage, P is the effective depth, T is the texture or structure of the soil, N is the base saturation, S is the soluble salt status, O is the organic matter content, A is the cation exchange capacity or the nature of clay, and M is the mineral reserves. (See also Soil productivity index.)

Profiling of soil: See Soil profile

Prokaryotic organism

An organism that has cells but does not have genetic material enclosed inside the cell membrane is called a prokaryotic organism. Prokaryotes include unicellular bacteria, cyanobacteria and actinomycetes. **Eukaryotes** are organisms consisting of cells in which the genetic material is distinctly placed within a nucleus. All organisms other than bacteria are eukaryotes.

There is evidence that prokaryotes appeared approximately 3.5 billion years ago while eucaryotes appeared around 1.5 billion years ago. It is believed that eucaryotic cells probably evolved in symbiotic associations with prokaryotes. (See also Actinomycetes.)

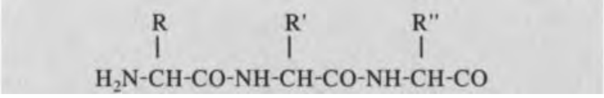
Prolamines

On the basis of their solubility in water, proteins are classified as prolamines, **albumins** and **globulins**. Prolamines are soluble in a mixture of alcohol and water. Prolamines are present in the seeds of cereals.

Protein

Proteins form a large group of organic compounds found in all living organisms. Proteins comprise C, H, O and N (usually 16%) and sometimes S, with molecular weights ranging from 6000 to several millions.

Protein molecules consist of one or several long chains (polypeptides) of amino acids linked in a characteristic sequence. Although hundreds of different amino acids are possible, only 20 are found in appreciable quantities in proteins and these are all α-amino acids. The amino acids are joined by peptide bonds formed between the carboxyl groups and amino groups of neighbouring amino acids as shown below:



$$H_2N\text{-}\overset{\overset{R}{|}}{CH}\text{-}CO\text{-}NH\text{-}\overset{\overset{R'}{|}}{CH}\text{-}CO\text{-}NH\text{-}\overset{\overset{R''}{|}}{CH}\text{-}CO$$

The linear arrangement of the amino acid residues in a protein is termed as the sequence or the **primary structure** of the protein. These polypeptides may undergo coiling or pleating, the nature and extent of which is described as the secondary structure. The three-dimensional shape of the coiled or pleated polypeptides is called the **tertiary structure**. **Quaternary structure** of protein specifies the structural relationship of the component polypeptides.

Proteins are classified broadly as **globular proteins** and fibrous proteins. Globular proteins have compact rounded molecules and are usually water-soluble. Of prime importance in this category are the enzymes which catalyze biochemical reactions. Other globular proteins include antibodies, which combine with foreign substances in the body, carrier proteins such as hemoglobin, storage proteins (e.g., casein in milk and albumin in egg white) and certain hormones (such as insulin).

Fibrous proteins are generally insoluble in water and consist of long, coiled strands or flat sheets which confer strength and elasticity. In this category are keratin and collagen. Actin and myosin are the principal fibrous proteins of the muscle, the interaction of which brings about muscle contraction. Blood clotting involves fibrous proteins called **fibrins**. Fibrins are insoluble proteins found in coagulated blood and are readily digested in gastric juice.

The long peptide chains of proteins, particularly those of fibrous proteins, are held together in a rather well-defined configuration. The backbone is coiled in a regular fashion, forming an extended helix with the result that peptide bonds are brought into close spatial approximation. The stability of the helical configuration is attributed to hydrogen bonds between the peptide bonds.

When heated over 50°C or treated with strong acids or alkalis, proteins lose their specific tertiary structure and form insoluble coagulates. This usually inactivates their biological properties. Proteins can be hydrolyzed to their constituent amino acids and broken down into simpler forms by proteolytic enzymes. They form colloidal solutions and behave chemically as both acids and bases, simultaneously. pH changes, heat, ultraviolet radiation and many organic solvents denature proteins. Such differences in size, solubility and electrical charge are exploited by the methods of separating and purifying proteins.

Simple proteins contain only amino acid chains or polypeptides while conjugated proteins contain polypeptides plus carbohydrates, lipids, etc. On the basis of solubility, proteins can be classified as **albumins** (water-soluble), **globulins** (water insoluble but soluble in salt solutions) and **prolamines** (soluble in alcohol-water mixtures). Prolamines are present in cereal plant seeds.

Proteins, derived from casein and soybean, are used in plastics and adhesives. Special commercially available forms of proteins include textured proteins for food products. Protein hydrolysates and liquid pre-digested proteins are used in medicine.

Protein, primary structure: See Primary structure of protein

Proteolytic enzymes: See Enzyme

Protista: See Protozoa

Proton concentration

Proton concentration is measured as **pH** and is the negative logarithm of hydrogen ion concentration or activity. (See also pH.)

Protozoa

A group of unicellular or acellular microscopic eukaryotic organisms without a true cell wall is called protozoa. They are essentially aquatic and are now classified in the various phyla of the kingdom Protista. They were formerly regarded either as a **phylum of simple animals** or members of the kingdom **Protista**. Protozoa also show many plant-like characteristics.

Most protozoa are **saprotrophs** (living on dead organic matter) but some are parasites, including those causing malaria and sleeping sickness. A few contain chlorophyll and carry out photosynthesis. Like plants, protozoan cells may be flexible or rigid, with an outer pellicle or protective layer. Reproduction is usually asexual, by binary fission, but some protozoa undergo a change of form for sexual reproduction. Their ingestion of fungi and bacteria affects microbial populations and helps rapid recycling of plant nutrients.

Protozoa are as widely distributed as bacteria. Free-living types occur in soil and wet sand as well as in fresh, brackish and salt waters. Protozoa range in size from 1 to 10^6 micrometers. Colonies of protozoa are known as **flagellates**, **ciliates** and sarcodina.

Provitamins

Foods may contain **vitamin** precursors, called provitamins, which change chemically in the body to form actual vitamins.

Proximate analysis of coal

The proximate analysis of coal gives an empirical estimate of the amounts of moisture, ash, volatile matter and fixed carbon present therein.

Pruning of plants

The removal or cutting of unproductive, unwanted or diseased branches or twigs of a plant to optimize on space and nutrient consumption is known as pruning. (Fig.P.38). Pruning is done to fruit trees, tea bushes and rose bushes at a specific time of the year to improve their growth and productivity.

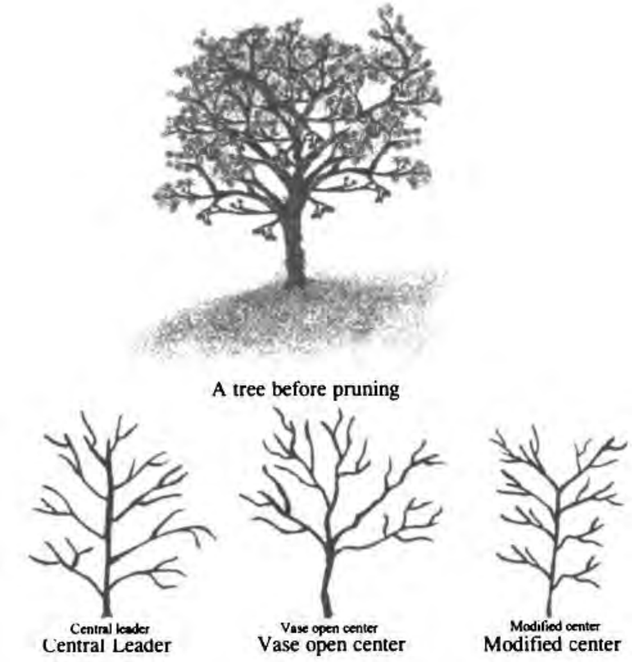


Fig.P.38: Types of pruning. The figure above shows a tree before pruning. The three figures below illustrate the types of pruning.

Pseudomonas

Pseudomonas is a genus of bacteria present in the soil, which converts amino compounds to ammonia and ammonium compounds. *Pseudomonas* belongs to the family of Gram negative, aerobic, non-spore forming, rod-shaped bacteria. Some members respire anaerobically in the presence of nitrates while others produce acids from carbohydrates. None of the Pseudomonaceae family is fermentative or photosynthetic.

Pseudo peat

Peat with poor organic matter is called pseudo peat.

PSM

PSM is short for **phosphate-solubilizing micro-organisms**.

PSNT

PSNT is short for **pre-side dress soil nitrate test**.

Psychoactive drugs: See Psychoactive plants

Psychoactive plants

Plants which contain such compounds that affect the central nervous system of man or animal in various ways, and affect the release of neurotransmitters are called psychoactive plants. These compounds, when extracted and consumed are called **psychoactive drugs**.

The active compounds of such plants are called alkaloids. An **alkaloid** is a class of nitrogenous organic compounds of plant origin and includes many strong drugs and poisons. These compounds have been recognized to have medicinal value but only if administered in the proper dosage. Plant families commonly known to contain alkaloids are the Solanaceae, Rubiaceae and Papaveraceae.

Psychoactive drugs can be classified as stimulants, hallucinogens or depressants. The property of a drug to induce sleep and numb mental awareness is a **depressant**. A drug that alters moods and changes perception of time and space is called a **hallucinogen**. A drug that increases the alertness of the mind, kills appetite and makes the recipient oblivious to fatigue is a **stimulant**. Each of these properties finds its own special use according to the situation. *Cannabis sativa*, commonly known as marijuana, is an example of a hallucinogen. Nicotine, from the tobacco plant is a stimulant. Cocaine, an alkaloid extracted from the cocoa plant, has hallucinogenic effects followed by a feeling of alertness of mind and finally depression.

Puberulent leaf

The surface of a **leaf** provides many characteristics for identification. A leaf with a very fine hair cover is called a puberulent leaf. A leaf with a hairy surface is known as a **pubescent leaf**.

Pubescent leaf: See Puberulent leaf

Puddle tests for soil

The physical and geo-technical properties of a soil are based on its particle size, mineralogical composition, chemical composition and moisture content. The suitability of a given clay can be evaluated on the basis of some simple empirical tests, called puddle tests, which require no equipment and can be performed even by village artisans.

The puddle tests are qualitative but very useful. They are performed as follows: (i) **Pinch test**: The clay is kneaded well and formed into a ball of about 75 mm diameter. The ball is squeezed between the hands until it forms a disc of about 25 mm thickness. If there is no crack in the disc, the clay is considered to have passed the test. (ii) **Tenacity test**: The soil is rolled into a cylinder about 300 mm long and 25 mm in diameter. The cylinder is held up vertically for 15 seconds (holding it by one end and letting the rest hang without support). If the clay supports the cylinder on its own weight, it is taken as having passed the test. (iii) **Elongation test**: A soil cylinder, 300 mm long and 25 mm in diameter is gripped horizontally at the two ends by two hands, leaving about 100 mm unsupported. The cylinder is then stretched until it breaks. The length of the neck formed when it breaks is noted. The longer the neck, the more suitable is the clay.

If the cylinder breaks with little or no stretching, the soil is considered unsuitable. (iv) **Soaking test**: The clay is made into a ball of 50 mm diameter. It is kept in a 600 ml beaker and covered with water. The state of the sample is observed at regular intervals of a few hours, for up to 4 days. If the clay ball does not disintegrate, it is considered suitable. (v) **Free swell test**: This test was designed by Gibbs-Holtz. Free swell is the change in the volume of dry soil expressed as a percentage of the original volume. 10 ml (by volume) of oven dried soil (of 425 μm particle size) is slowly poured in a drizzle into 50 ml of distilled water. It may take anything from a few minutes to a few hours for the soil to settle. The volume of settled soil solids increases (from the original volume of 10 ml), depending upon the swelling capacity of the clays. If the free swell value is more than 100%, it is an indication of the clay being an expanding type. Bentonites show very high free swell values, even up to 2000%. (vi) **Sticky limit**: This test has been designed by **Terzaghi** and **Peck**. Clay is mixed with water in such a way that it becomes plastic and sticks to a dry spatula blade. Then the clay is allowed to dry by exposure to the atmosphere. The moisture content at the point when the tool can no longer pick up the clay is the sticky limit.

Puddling

Puddling is a farm operation of making artificial puddles in a rice field. Such puddles are useful for transplanting rice seedlings. It is done by intensive tillage which makes the earth compact, thus reducing the percolation. Besides rice fields, puddling is used for reducing leakages in reservoirs and canals.

In puddling, the natural soil structure is destroyed by excessive water, intensive tilling or deflocculating agents. It is used in wetland rice fields to reduce percolation and to provide soft soil for transplanting rice seedlings.

The objectives of puddling are to (a) reduce the power required for seedbed preparation, (b) control weeds, (c) incorporate crop residues, (d) produce a soil layer that reduces percolation, and (e) prepare a soil that is suitable for transplanting. Puddled soil or submerged soil undergoes physical, microbiological and chemical changes that are entirely different from those of dry or upland soils. Here, the exchange of air between the atmosphere and the puddled soil is impeded.

Puddled soil develops two zones. The surface layer of 1 to 10 mm thickness absorbs oxygen like a non-flooded upland soil. A second layer is formed in the remaining portion of the puddled soil that is deprived of oxygen. As iron compounds in the soil are reduced, it turns dark grey or blue grey. Efficient nitrogen fertilization of lowland rice must take into consideration these two zones in flooded soils.

The absence of oxygen in the flooded, puddled soil, drastically changes the kinds and number of microbes that decompose crop residues. Decomposition occurs at a much slower rate than in aerated upland soils and toxic end products may result. These include CO_2, CH_4, H_2, N_2 and soluble Fe and Mn salts. To avoid the toxic effects of the compounds, rice fields should be flooded two to three weeks before transplanting. Incorporating crop residues before transplanting also reduces toxic compounds.

Pumped wells and relief wells

Pumped wells and relief wells, which are **sub-surface drainage systems**, are used where there is excessive wetness due to a high water table. Water from wells thus dug can be directly canalized into an irrigation system or to some pre-designated area where water is scarce. Shallow wells are also built to remove seepage spots.

Purchase credit subsidy

Subsidy given to the farmer for the purchase of seeds and implements on credit is called purchase credit subsidy. This is generally provided by the government at concessionary rates. (See also Subsidies in agriculture.)

Pure calcium feldspar

Pure calcium feldspar is another name for **anorthite**. It belongs to the plagioclase subdivision of feldspars.

Pure culture

A medium prepared with specific conditions in terms of the pH, nutrient levels, temperature, oxygen levels, osmotic factors, light, pressure and water content, in which cells or micro-organisms are grown, is known as a **culture**. Cell cultures are prepared in the laboratory for scientific research. The culture for growth of a single species or strain of an organism without contact or association with other living species or strain is known as pure culture (Fig.P.39). For example, in biofertilizer production, a pure culture of a specific bacterial strain (like *Rhizobium*, *Azotobacter*, etc.) is used for mass multiplication. A pure culture is maintained by periodic sub-cultures or by other standard procedures on suitable solid or liquid nutrient media.

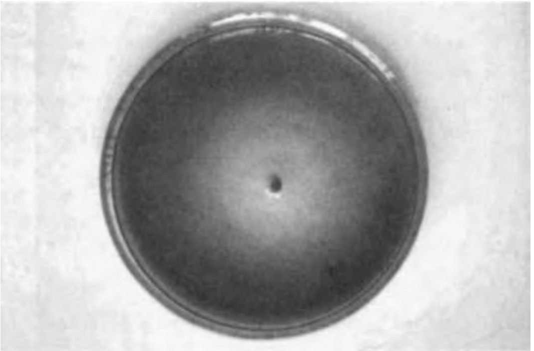


Fig.P.39: Pure culture of a fungus maintained on an agar medium.

The concept of pure culture is important because mostly only one kind of cells of a micro-organism are dealt with at a time in microbiological research. Many techniques have been evolved for the isolation and maintenance of pure cultures.

Pure forest

A forest composed mainly of one species of plants or trees is called pure forest.

Purification

Purification refers to removal of extraneous materials (impurities) from a substance or mixture by one or more separation techniques.

A pure substance is one in which no impurity can be detected by any experimental procedure. Though absolute purity is impossible to attain, a number of standard procedures exist for approaching purification to the extent of 1 part per million (ppm) of impurity or less.

Crystallization, precipitation, distillation, adsorption (various chromatography), extraction, electrophoresis and thermal diffusion are among the widely used fractionation techniques.

Purification of phosphoric acid: See Phosphoric acid production processes

Purity, chemical

A substance is said to be pure when its physical and chemical properties coincide with those previously established and recorded in literature, and when no change in these properties occurs after application of the most selective fractionation techniques. In other words, purity exists when no impurity can be detected by examination.

There are a number of recognized standards of impurity.

Purple bacterium

Purple bacteria belong to the genus *Chromatium*. It is a photolithotrophic sulphur bacterium involved in microbial oxidation of sulphur. This bacterium is active in the rhizosphere and fixes photosynthetic carbon, using sulphide and sulphur compounds as oxidant sinks. (See also *Thiobacillus*.)

Pursel technologies' reactive layer coating process

A range of polymer-coated, controlled-release fertilizers is available for high-value crops to meet the plant requirement of precise nutrient-release control. The release of nutrients can stretch from 1 to 24 months. Three manufacturing processes, namely **Sierra process**, **Chisso Asahi process** and Pursel Technologies' reactive layers coating process are used for producing these polymer-encapsulated, controlled-release fertilizers. (See also Polymer-encapsulated controlled-release fertilizers.)

Putrefaction

Putrefaction refers to the anaerobic decomposition of organic substances, especially the anaerobic breakdown of pertinacious material, under the action of micro-organisms. During putrefaction, gases with foul smell are released, the most important of which is methane (CH_4), along with H_2S, CO_2, NH_3 and polysulphides. This type of decomposition is mainly found in marshy lands. The amino-acid nitrogen of the protein is recycled by incorporating bacteria and fungi in the decomposition process.

Pyrite

Pyrite or **iron pyrite** (FeS_2) is a mineral containing iron and sulphur, and occurs in igneous and metamorphic rocks. It is also found in sedimentary deposits. Pyrite resembles gold in appearance and hence it is also known as **fool's gold**. It is harder than gold, the hardness being 6 to 6.5 on the Mohs' scale. It is the most common and widespread of the sulphide minerals and is used as a source of sulphur for the production of sulphuric acid (H_2SO_4). Under oxidizing conditions, pyrite readily alters to iron sulphates and eventually to limonite, forming gossans, the surface expression for pyrite-rich mineral deposits.

$$2FeS_2+2H_2O+7O_2 \longrightarrow 2FeSO_4+2H_2SO_4$$

$$4FeSO_4+O_2+2H_2SO_4 \xrightarrow{\text{Ferro oxidants}} 2Fe_2(SO_4)_3+2H_2O$$

Soils with excess pyrite become strongly acidic for cultivation. When drained and aerated enough for cultivation, these soils are termed **acid sulphate soils** or Katteklei (cat clays) in Dutch.

The role of sulphur in pyrites is multidimensional. Iron pyrite is a potential source of sulphur for correcting sulphur-deficiency in crops raised on alkaline, calcareous soils. Iron pyrite prevents iron chlorosis in plants and possibly leads to an improvement in the availability of other nutrients such as P, Fe, Mn and Zn. This is because pyrite not only contains these micronutrients as impurities but also enhances the availability of these native forms by increasing acidity. This role of pyrite is of special significance in calcareous soils where lime-induced chlorosis is very common in many crops.

Pyrite can be applied at the rate of 250 kg/ha to correct lime-induced chlorosis, to improve the malleable cane percentage and the yield of sugar cane on calcareous soil.

A symbiotic nitrogen fixation has a special significance in improving soil fertility. Using graded doses of pyrite (0 to 400 kg/ha), the number and dry weight of nodules, as well as grain and straw yield of chickpea increase significantly.

Pyrolysis

Transformation of a compound into one or more other substances by heat alone (i.e. without oxidation) is known as pyrolysis. It is very similar to destructive distillation. Although pyrolysis implies decomposition into smaller fragments, pyrolytic change may also involve isomerization and formation of higher molecular weight compounds. Hydrocarbons subject to pyrolysis give carbon black and hydrogen as in the case of methane at 1300°C.

Thermal cracking of gasoline is used to produce hydrogen for ammonia synthesis. Thermal rearrangements into isomers, thermal polymerizations, and thermal decompositions are all included in the term pyrolysis. But, pyrolysis does not include thermal changes that require catalysts or changes that are initiated by other forms of energy.

An example of inorganic pyrolysis is shown in the following reaction:

$$2NaHCO_3 \longrightarrow Na_2CO_3 + H_2O + CO_2$$

Many pyrolitic reactions involve the production of radicals as intermediates.

One application of pyrolysis is conversion of acetone into ketenes at 700°C. The reaction is

$$CH_3COCH_3 \longrightarrow CH_2{=}C{=}O$$

Pyrolysis of natural gas or methane at about 2000°C and 100 mm of mercury produce a special graphite. Synthetic crude oil can be made by pyrolysis of coal and hydrogenation of the resulting tar. Large scale pyrolysis of cellulosic waste is being conducted for the production of synthetic fuel oils and other products.

PAHs is short for polycyclic aromatic hydrocarbons, and is a type of pollutant.

Pyrolysis gasoline: See Gasoline

Pyrophosphate fulvic acid: See Fulvic acid

Pyrophosphates

The salts of pyrophosphoric acid or diphosphoric acid, with ammonia or sodium or potassium hydroxide are known as pyrophosphates. When phosphoric acid is concentrated above 54% P_2O_5, superphosphoric acid (or pyrophosphoric acid) is formed that contains 30% or more of P_2O_5 in the form of condensed or polyphosphoric acids of general formula $H_{n+2}P_nO_{3n+1}$. Essentially, the production of superphosphoric acid first involves the removal of physical water from the weaker acid [by vacuum concentration of merchant-grade phosphoric acid (54% P_2O_5)], and then the removal of chemical bound water. These steps can be represented as follows:

$$2H_3PO_4 \longrightarrow H_4P_2O_7 + H_2O(g) \text{ (Pyrophosphoric acid)}$$

$$H_3PO_4 + H_4P_2O_7 \longrightarrow H_5P_3O_{10} + H_2O(g) \text{(Tripolyphosphoric acid)}$$

The simplest **polyphosphoric acid** is **pyrophosphoric acid** ($H_4P_2O_7$). Pyrophosphoric acid is dehydrated phosphoric acid. Superphosphoric acids are suitable for the production of clear, liquid fertilizers with micronutrients because of the ability to sequester metal ions. (See Adenosine triphosphate; Ammonium pyrophosphates.)

Pyrophosphoric acid: See Pyrophosphates

Pyrophytic trees

Some trees in the **Savannah** region have a special character that makes them fire-resistant; these trees are called pyrophytic trees. Their special features are high water storage capacity, reduced leaves, a thick bark and thick bud scales. (See also Savannah.)

Pyrrhotite

Pyrrhotite is a sulphide residue which is recovered from sulphides in a process of **sulphuric acid production**.

The Fertilizer Encyclopedia
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Q

Q_{10} of a process

Q_{10} of a process, also known as **Vant Hoff's law**, gives a value that represents the number of times the rate of a chemical, physical or physiological process increases for every 10°C rise in temperature. If the rate enhances two-fold or three-fold, the Q_{10} is 2 or 3.

Generally, the rate of a chemical reaction tends to double for an increase of 10°C. For respiration, Q_{10} is approximately 2 to 3. The influence of temperature on various biological, physical and chemical processes is the value of Q_{10}.

Q_{10} is expressed as:

$$Q_{10} = \frac{K_2}{K_1}$$

where K_2 is the rate at T°C and K_1 is the rate at (T−10)°C.

The Q_{10} value is a linear approximation of what is essentially an exponential relation between the speed of a reaction (the process) and the temperature. The reported values of Q_{10} in literature are often based upon only two data points. Q_{10} may be determined graphically or by a linear regression from a plot of log rate (K) vs temperature (T°C) which should yield a straight line for a single-phase reaction.

It is not always convenient to measure the process rate at intervals of exactly 10°C. The values for Q_{10} can be calculated from measurements at two temperatures T_1 and T_2 using the equation:

$$Q_{10} = \left[\frac{K_2}{K_1}\right]^{\frac{10}{T_2 - T_1}}$$

where $T_2 > T_1$.

Any photosynthetic reaction involves a light phase with a low Q_{10} and a dark phase with a high Q_{10}. Enzyme catalyzed reactions taking place in organisms (over a certain temperature range) have a Q_{10} similar to that of chemical reactions. However, many enzymes become inactivated by denaturation of proteins at temperatures above 40°C, and this is seen by a progressive reduction in the rate of reaction with time. The absorption of oxygen in respiration increases with temperatures of up to 35°C, in which case, Q_{10} is in the range of 2.0 to 2.5. The temperature coefficient is valid only in a certain temperature range. For example, the rate of activation of enzymes by heat and denaturation of proteins can increase 100-fold over a 10°C rise in temperature.

Q/I

Q/I is the short form of **quantity-intensity relationship** or ratio.

Quadratic function model for fertilizer response estimation

Various mathematical models have been developed to estimate fertilizer response. A quadratic function model is commonly used to estimate the response.

$$Y = A + BF + CF^2$$

where Y is the crop yield, F is the fertilizer rate, and A, B and C are the coefficients of response functions, with $B > 0$ and $C < 0$. (See also Physical returns from crops.)

Quaking bog: See Bog

Qualitative analysis

Qualitative analysis, as a means of **chemical analysis**, reveals the nature of individual compounds present in a mixture. Various chemical tests exist for different elements and compounds, and systematic procedures can be used for analyzing the same.

Quality assurance

The concept of quality assurance encompasses a set of activities clearly defined for each step of the process or operation. The sole objective is to ensure perfection in each of the processes, with a view to rendering the final product perfect. The standards of perfection in quality are quantifiable and can be standardized to ensure uniformity of processing.

Quality control relates to a set of activities in operations such as manufacturing, aimed at ensuring that the finished product meets the given specifications. Terms such as quality assurance, quality control and **total quality control** embrace all the technical and managerial aspects of quality and safety of the product during all stages of design, development, specification, manufacturing and usage. Since manufacturers have a legitimate profit objective, they would like to perform the task of quality control as thoroughly as the product demands and preferably at the lowest possible cost.

All this calls for checking the quality at all stages of manufacture, storage and transportation, and making sure that the standardized protocols are rigorously followed at each stage. The same holds true in the case of fertilizers. Even the methods of sampling, analysis, data interpretation, etc. must follow a standardized protocol. Strict quality control procedures must ensure that no unspecified substance is present, lest it jeopardizes the quality of the final product.

Quality control: See Quality assurance

Quality nutrient: See Potash fertilizers

Quality of fertilizers

The quality of any fertilizer is judged mainly by the extent of its compliance with the stipulated physical and chemical properties. Free flowing nature, convenient handling, resistance to caking while in storage and an easy field application are the physical properties indicative of a good quality fertilizer. Sufficient nutrient content and availability to the crop are the chemical properties desirable in a good quality fertilizer.

The quality of a fertilizer is ultimately decided by the agronomic response. In the case of liquid fertilizers, the requirements of properties, such as density, viscosity, crystal (particle) size and type, and sedimentation are important factors. Too dense or too viscous a material makes pouring difficult. Similarly if there are too many sediments and/or large crystals present in a fluid fertilizer preparation, these can block the pipelines, nozzles or orifice meters.

The adopted and developed procedures intended for evaluating the quality of raw materials as well as fertilizer products are under constant review by many organizations, the world over.

Quantification of micronutrient deficiency: See Micronutrients

Quantitative analysis

Quantitative analysis, along with qualitative analysis makes **chemical analysis** complete. Qualitative analysis involves measuring the proportions or quantities of known components in a mixture. Chemical analysis techniques are classified into two main classes – volumetric and gravimetric.

Quantity

Quantity represents the measurable size, weight, amount (or number of units) of a substance. Quantities are arranged in a system of units which involves seven fundamental criteria: length, mass, time, electric current, thermodynamic temperature, amount and luminous intensity.

Fundamental quantities have their own dimensions and units. In mathematical and physical sciences, there are scalars and vectors to describe the quantity. Also, there are extensive and intensive phenomena in statistical thermodynamics, processes on macroscopic and microscopic scales as well as integral and partial area regimes to describe the quantity.

In the case of fertilizers, the quantity of fertilizer required for the growth of a plant is expressed in terms of its weight or volume.

Quantity factor: See Quantity-intensity relationship

Quantity factor of a nutrient

E value is the amount of isotopically exchangeable phosphorus or labile phosphorus present in the soil. The quantity of phosphorus present in a soil solution at a given time is a measure of its intensity. When phosphorus intensity is diminished by withdrawal of phosphorus from the solution, the solid phase phosphorus goes into solution to replenish the loss. The solid phase of phosphorus (or of any nutrient) that acts as a resource is called the quantity factor or **capacity factor** of the nutrient. (See also E value.)

Quantity-intensity relationship

The quantity-intensity relationship reflects the capacity of the soil to buffer the solution against the change in the activity of ion-like potassium. Potassium present in the soil solution and held in an exchangeable state by the soil colloid is readily available. About 0.1 to 2% of the total potassium in the soil is in exchangeable and solution forms.

The exchangeable potassium ion (K^+) in soil colloids is held at three types of exchange sites – the planar position (p), the edge position (e) and the inner position (i) in some clay minerals like illite, vermiculite and chlorite.

Under field conditions, the potassium concentration in the soil solution is buffered more readily by potassium ions in the surface (in the 'p' positions). A high proportion of adsorption by clay minerals results in a high concentration of potassium in the equilibrated soil solution. Potassium is removed by crops and by leaching, but the exchangeable potassium ions play a major role in replenishing the soil solution potassium. Hence, it is important to define the relationship between the exchangeable potassium (Q for quantity) and the activity of potassium in soil solution (I for intensity). The **Q/I** ratio, which gives the quantification of potassium status of the soil, measures the ability of the soil to maintain the intensity of potassium in the soil solution (which is proportional to CEC).

An estimate of the labile soil potassium (held in the p positions) is more easily and reliably done by the Q/I ratio than by the measurement of the exchangeable potassium with 1N ammonium acetate solution.

A higher value of the labile potassium indicates a greater potassium release into the soil, resulting in a larger quantity of the labile potassium. A higher value indicates a good potassium supply or buffering capacity while a lower figure suggests the need for potassium supplementation via suitable fertilizers. Liming, which increases pH, can increase Q/I via the pH-dependent CEC.

When Q/I values are low, small changes in exchangeable potassium produce large differences of K^+ in the soil solution. The buffering capacity of sandy soils is small owing to a relatively smaller fraction of organic matter. In these soils, leaching or rapid plant growth reduces the available potassium rapidly in a few days.

Thus, a relation between the exchangeable potassium and the solution potassium ion is a measure of the availability of the ion (in soils) to the plants. The labile potassium, the rate of release of fixed potassium ions and the diffusion and transport of the potassium ions in the soil solution govern the maintenance of the soil activity ratio against the reduction of potassium ion by root absorption and leaching.

The quantity of phosphorus present in a soil solution at a given time is a measure of its intensity. When the phosphorus intensity is diminished by the withdrawal of phosphorus from the solution, the solid-phase phosphorus goes into solution to replenish the loss. The quantity of the solid-phase phosphorus, acting as a reserve, is called the **quantity factor** or **capacity factor**. This quantity factor refers to both the labile and the non-labile forms of the soil phosphorus.

Quantity of fertilizers, determination of: See Recommended dosage of fertilizers

Quarantine, plant: See Plant quarantine

Quarternary structure

In the context of arrangement of amino acid residues in a **protein**, a quarternary structure specifies the structural relationship of the component polypeptides. (See also Protein.)

Quicklime

Calcium oxide in a calcined form is also called quick lime or **unslaked lime**. (See also Liming materials.)

Quick tissue test

To study nutrient uptake levels and thus the deficiency of nutrients in plants, several simple tests are carried out on plants in the field. For example, a semi-gravimetric analysis of a green plant tissue is done to determine the concentration of soluble nutrients. Since these tests are performed rapidly and are simple to carry out, they are called quick tissue tests or quick tissue analysis.

Quick tissue tests on average around 10 to 15 are commonly conducted for the analysis of N, P and K.

A quick tissue analysis of a plant nutrient is based on the principle that the nutrient concentration of plants is related to the amount of nutrient available in the soil. If the nutrient level in the tissue falls below a critical value, the soil becomes deficient in that element, and this can affect the optimum growth of the plant.

The use of plant tissue analysis in diagnosis and correction is limited by the nutrient concentration calibration data for many plants, their parts and growing conditions.

Whatever the limitations, tissue tests are a useful guide, when tissue samples from both good and poor plants of the same age are taken at the same time, from the same plant part and from the same soil type. This is the most valuable use of plant analysis for the purpose of comparison. (See also Tissue tests.)

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R

Rabbing

Rabbing is a practice followed mainly in the rice-growing areas of the world, where crop residues are plowed back in the soil after harvesting. The practice helps in enriching the soil and discouraging pests.

Rabi

In some parts of the Indian subcontinent, distinct seasons are observed, based on climatic and cropping conditions. The two such seasons, especially in northern India, are ***kharif*** (June to October) and *rabi* (October to April). Crops grown in the *rabi* season are known as *rabi* crops (wheat, barley, oats, chickpea, safflower, etc.) which are grown with the help of irrigation or the moisture conserved in the soil.

Radical

A group of atoms existing alone or in a compound is known as a radical. Strictly speaking, radical denotes an ionic group having a charge, either positive or negative. Radicals found in fertilizers are ammonium (NH_4^+), nitrate (NO_3^-), phosphate ($H_2PO_4^-$, HPO_4^{2-}· PO_4^{3-}), sulphate (SO_4^{2-}), etc. Those important for maintaining the soil pH are hydroxyl (OH^-), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-).

A molecular fragment, having one or more unpaired, usually short lived and highly reactive electrons, is called a free radical. In formulae, free radicals are conveniently indicated by a dot, as $Cl^{\bullet}$ or $CH_3^{\bullet}$. They are formed by ionizing radiation and have a deleterious effect on the tissue. They also act as initiators or intermediates in oxidation, combustion, photolysis and polymerization.

Radicle

The first structure that emerges from the seed during germination is called a radicle. The radicle develops to produce the primary root. In the case of monocots, the radicle first breaks through coleorhiza. This early formation of the root system equips the developing seedling to absorb water for its growth.

Radioactivity

In some elements, atoms are not stable, and they spontaneously emit radiation of various types - a phenomenon Henri Becquerel discovered in 1896. Marie Curie used the term 'radioactivity' to describe the emission of ionizing radiation by some of the heavier elements; it is measured in Becquerels (1 Bq = 1 disintegration/sec.)

Radiation causes damage to biological molecules, and is a health hazard. Radioactive substances emit three types of radiation: (a) Alpha radiation (α) composed of helium (He^{2+}) ions, also called **alpha particles**, (b) Beta radiation (ß) consisting of electrons/positrons emitted by a radioactive substance, also called ß-particles, and (c) Gamma radiation (γ) consisting of highly energized, short wavelength electromagnetic waves resembling x-rays.

The phenomenon of radioactivity is based on the principle that atoms contain still simpler parts and are not indestructible particles. Radioactivity can be induced in many nuclides by bombarding them with neutrons or other particles. The rates of decay of radioactive substances are unaffected by chemical changes, pressure, temperature or electromagnetic fields, and each nuclide has a decay constant or **half-life**. A radioactive nuclide decays to a further radioactive nuclide, followed by a series of transformations which end with the formation of a stable, daughter nucleus.

Radionuclides are unstable elements that disintegrate, emit radiation and form stable elements. There are two main sources of radioactive nuclides associated with fertilizers, which are (a) ^{40}K, a naturally occurring isotope of potassium, and (b) uranium, thorium and their daughter elements present as constituents in phosphate rocks. Potassium contains 0.012% of the radioactive isotope potassium (^{40}K) that emits ß and γ radiations with a half-life of 1.8×10^9 years. Potassium is an essential element for all living beings; an adult body contains 0.2% potassium of its body weight. The amount of potassium in the topsoil varies between 0.2 and 3.3%, giving activity concentrations of about 50 to 1000 Bq/kg soil.

The main concerns related to radioactive nuclides in fertilizers are: (a) increased exposure of workers to the radiation, and (b) their accumulation in soil leading to an increased uptake in food crops.

The radioactivity level in some fertilizers ranges from less than 1,000 to 10,000 Bq/kg weight of fertilizer, depending on the source of the phosphate rock and the content of phosphorus and potassium in the fertilizer. Their accumulation in the top soil and uptake by plants depend upon (a) the input from fertilizers, (b) the duration of the fertilizer application, (c) soil conditions in terms of the pH, moisture, organic matter, clay content, etc., and (d) such factors as soil erosion, leaching, etc.

Assuming an application of 30 kg phosphorus/ha mixed in the top 10 cm and non-removal of uranium from phosphorus fertilizers, uranium accumulates at about 0.25% of the soil, annually. However, if P is incorporated into the deeper soil layers or if uranium is removed at the process site, its accumulation will be low. Long-term data indicates that the risk of radioactivity accumulation in soil arising out of P application is low and does not pose any significant threat to human health.

Radioisotope

An isotopic form of an element that exhibits radioactivity is known as radioisotope. A few elements, such as radium or uranium, have their own naturally occurring radioisotopes. However, a large number of radioisotopes are also produced artificially as these are useful in scientific experiments in industry. This is done by irradiation of stable isotopes with photons or with particles such as neutrons in an accelerator or nuclear reactor. Radioisotopes with a wide range of half-lives and activities are available by these means. The radiation emitted by isotopes may also be used directly for treating diseased areas of the body, sterilizing foodstuffs or controlling insect pests.

Radioactive isotopes, despite the instability of their nuclei, participate in many physical or chemical processes in the same way as any non-radioactive counterparts. Thus, radioisotopes are used as **labels** or tags, to follow an element through a sequence of changes. Carbon (^{14}C) is a commonly used tracer but radioactive forms of iodine and sodium are also used. Many complex biochemical reactions, like photosynthesis, have been examined using tracers. Radioactive enzymes, such as ribonuclease, pepsin and trypsin, are also available for tracer studies.

Most useful applications of tracers are in three fields. (i) In agriculture - by introducing radioactive phosphorus ^{32}P in phosphatic fertilizers to follow its uptake by charting the radioactive regions of the plant. Similarly, the efficiency of different phosphatic fertilizers can be compared using radioactive phosphorus as a tracer element. (ii) In industry - the fate of a catalyst in a chemical plant can be followed by incorporating a radioactive tracer in the catalyst; for example, iridium (^{192}Ir) in a platinum-iridium (Pt-Ir) catalyst. By monitoring the activity of iridium (^{192}Ir), it is possible to determine the rate of the catalyst movement and its direction in the plant. (iii) In medicine - a small quantity of radioisotope of iodine is mixed with an organic dye and injected into the body of the patient. Any tumor strongly absorbs the dye with the radioisotope and emits radiation, which is indicative of the size of the tumor and its location.

Radionuclides: See Radioactivity

Raincoat

A system that keeps the percolating water away from the fertilizer and reduces the leaching of the fertilizer, is called a raincoat. (See also Mulch.)

Rainfall

Rainfall is basically a low-pressure phenomenon of nature. Raindrops range in size of up to 4 mm in diameter. If they are smaller, the rain is called drizzle. Rainfall interests everyone because of its impact on human life. It makes water available for drinking and for crops, and can also lead to floods or soil erosion. What matters most, is the intensity, duration and regularity of the rainfall. **Rainfall intensity** is expressed as the rate of rainfall in cm/hour or day. Light rain is less than 3 mm/hr, moderate rain up to 8 mm/hr and heavy rain more than 8 mm/hr. Other things being equal, erosion of the soil is greater by one rainstorm of high intensity than by several storms of low intensity. The **rainfall duration** is the time during which the rain actually occurs with certain minimum rate or intensity. The total amount of rains during a rainfall event is the rainfall rate multiplied by the duration. The average rainfall intensity for the entire duration of a storm is between the highest and the lowest rainfall intensity. The high intensity portion of a storm period is generally shorter than the low intensity portions.

Rain may result from the melting of snow or hail, as it falls but is commonly formed by direct condensation when a parcel of warm air rises, expands adiabatically, cooling about 1 Kelvin / 100 m. Thus its relative humidity rises until it reaches saturation, when the water vapor begins to condense as droplets, forming clouds. These droplets may coalesce into raindrops, chiefly through turbulence and nucleation by ice particles or by cloud seeding. Moist air may be lifted by convection or forced ascent of air. The gravity of rainfall is measured by a rain guage.

Rainfall in tropical and sub-tropical regions has certain characteristics. In India, for instance, the south-west monsoon is a major rainfall activity in most parts of the country during the June-September period, accounting for about 85% of the annual rainfall in most parts of the country. The remaining 15% is accounted for by the north-east monsoon in some parts of the country. Since rainfall has a dominating influence on crop production in most parts of the world, its study is a matter of perpetual interest.

The important aspect of rainfall is its variability in space (place to place) and time (seasonal, monthly, weekly, daily). There are some optima established on the basis of long period data.

Effective rainfall has a relationship with utilizable rainfall. The time, place, intensity and amounts of rainfall are all involved in this because the rainfall received can be useful, harmful or even disastrous, depending on its intensity and the way it is dealt with. Rainwater can be stored and gainfully utilized for meeting the needs during period of no rains.

Rainfall duration: See Rainfall

Rainfall intensity: See Rainfall

Rain fed agriculture

Growing of crops solely depending on rains or stored soil moisture without resorting to conventional irrigation is known as rain fed agriculture or rain fed farming. This also includes **dry land farming** and dry land agriculture.

Rain forest

Rain forest is an equatorial **forest** which gets more than 200 cm of rains annually.

Rain gauge

Rain gauge is an instrument used to measure the amount of rainfall, and is of different kinds and sizes.

Rainwater is collected in a vessel of area larger than that of the measuring compartment, so that a given depth of water in the latter represents a considerably smaller depth of rainfall (Fig.R.1). A rain gauge, which automatically records the cumulative amount of rainfall in the form of a graph, is called a **rain recording gauge** or **hyetograph**. The place where the rain gauge is kept is called the **rain gauge station**. (See also Precipitation.)

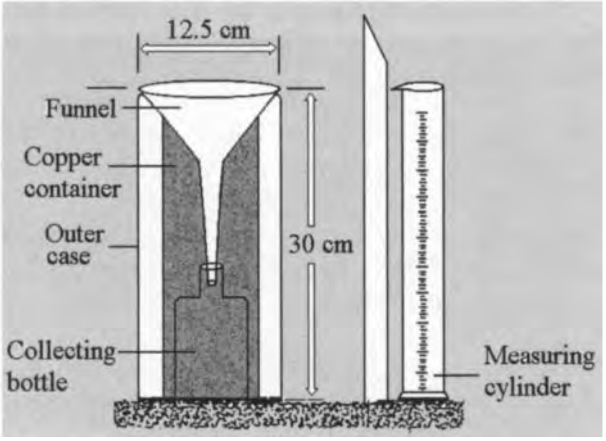

Fig.R.1: Diagrammatic representation of a simple rain gauge.

Rain gauge station: See Rain gauge

Rain harvesting: See Rain trap

Rain recording gauge: See Rain gauge

Rain trap

A kit developed by the U.S. Department of Agriculture to effectively perform **rain harvesting** is called a rain trap. This unit uses low cost plastic or metallic films that can be laid over the ground. Thus, the water can be stored without getting absorbed into the ground. These films are then covered with gravel which protects them from wind and weather. The stored water is then pumped to the desired field.

Rainy day

Rainy day is a day on which more than 2.5 mm of rain is recorded.

Rainy spell

Rainy spell is a period of continuous rainfall for fifteen or more days with more than 2.5 mm rain during each of those days.

Rake

Rake is a garden implement. It has a long handle with a toothed plate attached to one end. It is used for separating small pebbles on the soil surface. It is also used for pulverizing the soil to make a seedbed. They are also used for road maintenance and snow plowing. The term 'rake' is also used in the context of transport of goods by rail. In India, a rake is a full train load of goods like fertilizer. On a broad gauge train, a rake has 75 to 80 wagons and carries about 1800 tons of fertilizer. Jumbo rakes carry 2000 to 2100 tons of fertilizer.

Random sampling

A sample selected at random, in which every individual of the population has an equal chance of being chosen, is random sampling. Since it is impossible to measure all items or possible observations, random sampling is resorted to. As a result, the true quantities, like true average or true median differ from what we get from the random sample. This difference between the two is called **random sampling error**.

Random sampling error: See Random sampling

Rankers

In soil taxonomy, rankers refer to shallow soils on steep slopes similar to lithic inceptisols.

Ranks of coal

The **process of coalification** or coal formation goes through many stages. The various intermediates in the coalification process are called the ranks of coal. **Lignite** or **brown coal** (which is soft and brown with high moisture content) and **sub-bituminous coal** are various ranks of coal.

Coals are classified or ranked according to their fixed-carbon content which increases progressively as they get formed. In the ascending order of the rank, the main types are lignite, sub-bituminous coal, bituminous coal and anthracite.

Rasorite

Rasorite is one of the sources of borax which is produced by re-crystallizing the ores. **Borax** ($Na_2B_4O_7 \cdot 10\,H_2O$) is a source of the boron micronutrient and has many uses.

Rate of returns from fertilizers, economic optimum of

The economic optimum rate of return from fertilizers provides maximum profit and maximum addition to the profit in the given situation as a result of fertilizer use. This rate (F^*) is determined by imposing the condition for profit maximization by setting the first derivative of the response function dy/df equal to zero.

$$F^* = \frac{\left[\frac{P_f}{P_y} - B\right]}{2C}$$

Where P_f and P_y are the prices of the fertilizer and of the crop output respectively, F^* is the fertilizer rate, B and C are the coefficients of the response function in the quadratic function model and Y is the crop yield.

Various mathematical models are used to estimate fertilizer response. A quadratic function model is commonly used to estimate the response to fertilizer application:

$$Y = A + BF + CF^2$$

where Y is the crop yield, F is the fertilizer rate, and A, B and C are the coefficients of response functions ($B > 0$ and $C < 0$).

The main indicators of profitability or physical returns used in the economic evaluation of the fertilizer use are the following: (i) The value to cost ratio (VCR) is the value of the increased crop output as a result of the fertilizer used, divided by the cost of the fertilizer. The VCR changes with the rate of application and is evaluated at optimum rates of fertilizer use. (ii) The magnitude of the profit added by the fertilizer use is expressed in monetary value per unit area, for example, $/ha.

The VCR measures the economic returns of the fertilizer as against the expenditure. It is an important indicator of risk and uncertainty associated with the fertilizer use especially in rain fed agriculture. For a farmer with a dependable irrigation facility and reliable information on weather, a VCR value of 2 is acceptable, whereas VCR of 3 or more is required for a farmer who is faced with an unpredictable weather and a low control over prices.

Ratio of biomass to mineral fertilizers: See Environmental issues related to fertilizer use

Ratoon

Ratoon is the sprouting of the same stalk or shoot of perennial plants like sugar cane. It is a method of cultivation of next crop from regrowth of stubbles of the previous crop after its harvest. This method is called **ratoon cropping**.

Raising a new crop of sugar cane from ratoon is quite common. It saves cost of planting and conserves soil. There is a ratoon stunting disease in sugar cane, caused by an aerobic bacterium. The loss of yield because of the disease was estimated at 5% in Florida, USA.

Ratoon cropping: See Ratoon

Raunkiaer classification of plants: See Chamaephytes

Raw bone meal

From historical times, bones have been used to improve crop efficiency. Bones have a fertilizing effect because they contain 2 to 4% nitrogen and 20 to 25% phosphorus (as P_2O_5). Field trials have demonstrated that animal bones, crushed and steamed under pressure, give maximum fertilizing benefit. The crushed bones should pass through a 2.36 mm mesh, of which not more than 30% should be retained on an 850 micron sieve.

Bone fertilizer is particularly suitable for acidic soils, because with a low pH, the citrate soluble phosphoric acid gets converted to monocalcium phosphate or water-soluble phosphate. In the process, the conversion to monocalcium phosphate decreases the chances of the phosphates getting precipitated as iron or aluminum phosphates. Bone fertilizer is applied to soil before or at the time of sowing, but is not suitable for top dressing application.

Raw bone meal is a by-product of the bone crushing industry, consisting of ground bones without any gelatine or glue. It contains around 4% nitrogen and 22% phosphorus (as P_2O_5). It is essential to have fine bone meal, since the finer the material, the easier its availability to plants.

Home gardeners generously use bone meal on their flowers, shrubs and lawns because it can be used widely without the fear of salt induced damage.

Raw material and feed stock, fertilizer: See Fertilizer raw materials and feed stock

Raytheon isothermal reactor process in phosphoric acid production process: See Phosphoric acid production processes

Raytheon process for MAP-DAP production: See Monoammonium and diammonium production processes

Reaction product

A newly formed product or compound that does not undergo any further change in a reaction is called a reaction product. Its concentration in a reaction increases or remains constant. In a stoichiometric equation, the products are usually indicated on the right hand side and their stoichiometric coefficients are considered positive. The final reaction product is formed either directly in a chemical transformation of the reactants or via unstable intermediates.

In organic chemistry, a simple isolated reaction is rather rare. Apart from the principal reaction leading to the main product, undesirable side reactions occur, giving rise to side products, the number of which is indicative of the inefficiency of the process. Therefore, it is necessary to adjust the reaction conditions in order to get an optimum yield of the desired product.

New chemical compounds are formed as a result of the reaction of the fertilizer nutrient with soil constituents. For example, a soluble phosphorus fertilizer reacts with Al, Fe and Ca compounds in soil and the reaction products then serve as a source of phosphorus for plants.

Reactions of micronutrients with fertilizers: See Micronutrient fertilizer production processes

Reclaiming saline soils

Problem soils may be categorized as either being saline or sodic. Saline soils are characterized as those with a saturation extract conductivity of 4.0 deciSiemens per meter or more and an SAR (sodium adsorption ratio) less than 13. This type of soil may be compared with normal soils, which have an electrical conductivity (EC) < 4 and SAR < 13.

In common parlance, saline soil contains amounts of soluble salts sufficient to adversely affect its productivity. Saline salts hinder plant growth and this is a major area of concern.

Reclaiming such soils involves setting up effective internal drainage and leaching out salts by adequate amounts of low-salt irrigation water, such that the salts move downward and away from the root zone. But, soil dispersion problems occur with different levels of exchangeable sodium concentration (even as low as 10% exchangeable sodium), as well as the type of soil. For example, montmorillonites are most easily dispersed, but kaolinites are quite stable. Colloidal dispersal creates impermeability, hindering the process of leaching by water.

The determination of the salt quantity to be removed influences the method of leaching. For instance about 45 centimeters of ponded water removes most of the salts for up to 35 centimeters of depth. Some salts require more water for them to be moved or adsorbed on the soil particles.

Another effective method for reclaiming saline salts is the use of organic mulch, like wood waste, plant cuttings, etc. This is an especially useful tool in rain-fed or water-scarce regions. Mulch slows down water evaporation, thus brings down the rate of salt moving to the surface.

An important aspect of reclaiming saline soils is the establishment of salt-collecting pits or tanks to ensure that these salts do not accumulate in neighbouring areas.

Reclamation of sodic soil

Soils lose productivity due to changing patterns of irrigation, waterlogging, salt accumulation, etc. Soil productivity is restored by reclaiming the soil. Excess soluble salts or sodium from alkali soils are removed by applying gypsum. Similarly, lime is added to acid soils to reclaim them. Plants in salt-affected soils may not wilt but often exhibit symptoms similar to those of stress (drought) conditions.

To reclaim saline soils, excess salt is removed by scraping, flushing, leaching, etc.

Reclamation of sodic soils aims at reducing the exchangeable sodium so that it does not degrade the physical properties of the soil and interfere with the plant growth. In sodic soils, the exchangeable sodium is so high that water alone does not leach out the sodium. The sodium must be exchanged by another cation and then leached downward and out of the root zone.

Calcium is often used to replace sodium in sodic soils. Of all the calcium compounds, calcium sulphate is considered the best and the cheapest. A number of soil amendments like the use of gypsum, calcium chloride, elemental sulphur, sulphuric acid, lime-sulphur, iron sulphide, iron pyrites, sulphates of aluminum and iron, etc. are used to reclaim sodic soils. Even hydrochloric acid, available as a by-product from the alkali industry, is considered as an amendment.

The gypsum (hydrated calcium sulphate) requirement (GR) is the amount of gypsum necessary to be added to reclaim the soil, using a soil bulk density of 1.34 g/cc for an average soil, and is given by:

$$GR = \frac{\text{Metric tons of gypsum}}{\text{Hectare of soil to some fixed depth (30 cm)}}$$

Or

$$GR = 4.50 \times (Na_x)$$

where GR is the gypsum required per hectare to 30 cm depth and Na_x is the centimoles/kg of exchangeable sodium to be replaced by calcium from the added gypsum.

Crops differ considerably in their sensitivity to sodicity. In general, grain legumes are very sensitive while cereals, cotton, sugar cane and forage legumes (such as *Trifolium alexandrium* and *Melilotus parviflora*) are less sensitive to sodic soil. Grasses like Bermuda grass, Rhodes grass, Para grass, Karnal grass, barley, rice, alfalfa, green manuring legume dhaincha and sugar beet are fairly tolerant to the conditions of sodicity.

Recommended dosage of fertilizers

Fertilizers should be used as per the dose recommended for a crop and according to its nutrient management plan. The recommended doses and plans are specific to the field, its cropping history and soil analysis.

Many factors have, therefore, to be considered for estimating the fertilizer rate for a particular crop. The parameters are nutrient availability and residual nutrients in the soil from past cropping, local soil and climatic conditions, etc.

Some recommendations have evolved. For example, the fertilizer recommendation for irrigated wheat crop is roughly 80 to 120 kg N/ha, 40 to 60 kg P_2O_5/ha and 40 kg K_2O/ha, whereas for the late-sown irrigated wheat crop, the dose recommended is somewhat lower: 60 to 80 kg N/ha, 30 to 40 kg P_2O_5/ha and 20 to 25 kg K_2O/ha. The fine tuning of the fertilizer dose is done according to the soil test results.

However, when the soil and climatic conditions vary widely in a region, the same quantity of a fertilizer cannot be prescribed as an optimum dose for the same crop, without consulting the local agricultural department. The amount of fertilizer to be applied depends on the concentration of the required nutrient in that fertilizer. The chemical composition of some fertilizers is shown in Table-R.1.

Table-R.1: Fertilizers and their chemical compositions.

Name of Fertilizer	Percentage of nutrients				
	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Sulphur (S)	Calcium (Ca)
Nitrogen					
Urea	46	–	–	–	–
Ammonium sulphate	20.6	–	–	24	–
Ammonium chloride	25	–	–	–	–
Ammonium sulphate nitrate	26	–	–	15	–
Calcium ammonium nitrate	25	–	–	–	8
Ammonium nitrate	33	–	–	–	–

Phosphorus					
Single super-Phosphate	–	16	–	–	12
Triple super-Phosphate	–	45	–	2	13
Dicalcium Phosphate	–	52	–	–	29
Rock Phosphate	–	20 to 30	–	–	–
Potassium					
Murate of Potash	–	–	60	–	–
Potassium Sulphate	–	–	50	18	–
Compound					
Mono ammonium phosphate	11	48	–	–	–
Diammonium phosphate	18	46	–	–	–
Ammonium phosphate sulphate	16	20	–	15	–
Urea ammonium phosphate	28	28	–	–	–
Nitrophosphate	20	20	–	–	–
Nitro phosphate	15	15	15	–	–
Ammonium nitrate phosphate	18	18	9	–	–
Complex					
Different kinds of grade fertilizers	17	17	17		
	10	20	20	–	–
	10	26	26	–	–

Once the composition of a fertilizer is known, the **quantity of fertilizer** to be applied to a crop as per the recommended fertilizer dose can be calculated, using the multiplication or **conversion factors** given in Table-R.2. It is also possible to know the amount of nutrients supplied by the quantity of the fertilizer applied, using the multiplication factors.

For example, if a crop needs 50 kg of nitrogen, then according to the multiplication factor, 107.15 (2.143 × 50) kg urea is required; similarly, 236 (50 × 4.72) kg ammonium sulphate is required to meet the nitrogen requirement of that crop. On the other hand, if a crop is fertilized with 120 kg of urea, then the fertilizer supplies 56.04 (120 × 0.467) kg nitrogen. Similarly, the requirement of other fertilizers can be determined by using the **multiplication factor**.

Recovery of ammonium sulphate from industrial byproduct liquors

Several methods are used for ammonium sulphate manufacture, depending on the availability of raw material and local conditions.

Ammonium sulphate is also recovered from the waste streams of caprolactum, acrylonitrile and certain other processes first by concentrating the liquor to around 35% ammonium sulphate. The ammonium sulphate is recovered from the slurry by centrifuging and drying. The process, which is uneconomical because of low concentrations of ammonium sulphate, produces around 1.8 to 4.0 tons of ammonium sulphate per ton of caprolactum.

Recovery of potassium sulphate by the Italkia Pasquasia potassium sulphate process: See Potassium sulphate production processes

Recovery of potassium sulphate from natural complex salts: See Potassium sulphate production processes

Recycle ratio of fertilizer

Recycling is a process by which any waste material is made reusable. Putting organic waste back to the soil is a means of recycling the nutrients removed by the crops. In

Table-R.2: Conversion factors for nutrient concentration in fertilizers.

A	B	C	D	E
Fertilizer	Conversion factor	Nutrient (A × B to get amount of nutrient)	Conversion factor	Fertilizer (C×D to get quantity of fertilizer)
Urea	0.467	N	2.143	Urea
Ammonium sulphate	0.212	N	4.72	Ammonium sulphate
Ammonium nitrate	0.350	N	2.857	Ammonium nitrate
Phosphorus pentoxide	0.436	P	2.292	Phosphorus pentoxide
Dicalcium phosphate	0.233	P	4.292	Dicalcium phosphate
Potassium oxide	0.830	K	1.205	Potassium oxide
Potassium chloride	0.632	K_2O	1.583	Potassium chloride
Ammonium sulphate	0.243	S	4.121	Ammonium sulphate
Magnesium oxide	0.603	Mg	1.658	Magnesium oxide
Calcium sulphate	0.294	Ca	3.397	Calcium sulphate

Source: "Rice Nutrient Disorders and Nutrient Management", 2000. Potash & Phosphate Institute, Norcross, G.A. With permission.

industrial processes, the practice of returning a reaction product to the beginning of the process sequence is known as recycling. With recycling, compounds that have so far not reacted, react increasing the conversion efficiency.

Once the product passes through the granulator, in a fertilizer granulation process, a certain quantity of particles lies outside the desired region of the grain-size spectrum (the off-size material) and must be run-through again. This is recycling of fertilizer. For a given mixture and temperature, optimal granulation takes place only within a narrow range of the solid to liquid ratio. The quantity of recycled fines depends not only on the chemical properties of the material but also on the water content of the slurry and the granulation device used. Recycling is also needed to generate nuclei for the granulation condition in the granulator.

The mass ratio of the recycled fertilizer material to the final product is often referred to as the recycle ratio of the fertilizer. For example, 20% granulation efficiency implies a recycle ratio of 4:1 (not considering the other losses). It is important to know the recycle ratio in the granulation process.

There is concern over the earth's deteriorating environment. In this situation, recycling has emerged as an effective method for cutting down on pollution and conserving important natural resources. It has also become an increasingly vital source of material for modern industry.

Red earth

Red earth, a term of German origin, refers to **red soils**. Leached, red, deep, clayey soils of the humid tropics, having low silica, are examples of red earth. Red earth has coarser grains than black soils. The clay component is more obvious in the sub-surface soil than the top soil. The subsoil is compacted and not permeable to water.

Formed mainly from granite rocks, red soils are highly variable in depth and show a well developed profile. These vary in color, texture and fertility. The fertile variety is deep colored, rich in potassium, but poor in nitrogen, phosphorus and humus.

Redox potential

Reactions between two substances where **reduction** and **oxidation** happen simultaneously are **redox reactions** (reduction and oxidation reactions). They are reactions where one or more electrons from one chemical is/are transferred to the other chemical.

Many important chemical reactions involve oxidation-reduction. Most reactions used for energy production are redox reactions.

The oxidation of sugars, fats and proteins in human bodies, provides the energy necessary for life. Combustion reactions, involving both the processes of oxidation and reduction provide most of the energy for human activity.

Redox potential quantitatively expresses the oxidizing or reducing power of a system. It expresses the possibility of a substance to be oxidized or reduced according to the relative ability of that substance to undergo either of these reactions.

Although every reaction taking place at an electrode has to be an oxidation or reduction reaction, the term redox electrode refers to the electrode used to assess the potential in a system in which both oxidized and reduced states are present in the solution; for example, Fe^{2+} and Fe^{3+}, Sn^{2+} and Sn^{4+}. For such systems an inert metal like platinum is used to make electrical contacts. Depending on the direction of the current, oxidation or reduction takes place at the electrodes. The term redox potential refers to the potentials of these electrodes.

The standard redox potential is related to the redox potential of the system by the equation:

$$E = E^0 + \left(\frac{RT}{nF}\right) \; ln \; \frac{[\text{oxidized state}]}{[\text{reduced state}]}$$

where E is the electrode potential, E^0 is the standard electrode potential, R is the universal gas constant (8.314 J /K / mole), T is the temperature in K, n is the number of electrons involved in the reaction, and F is Faraday, 96500 coulombs.

The tendency of a substance to donate or accept electrons is expressed by the standard oxidation-reduction potential, that is, the potential difference measured between a half-reaction and a platinum electrode in equilibrium with hydrogen gas at a pressure of 1 atmosphere in a solution with hydrogen at 1M concentration.

$$Fe^{2+} \longrightarrow Fe^{3+} + e$$

Redox potential data can be used for measuring pH, for studying chemical equilibrium and also for redox titration in volumetric analysis.

Redox potential is an important consideration for flooded paddy fields. It gives the status of iron present in the solution. The redox potential normally varies from minus 300 millivolts (mv) in a highly reduced soil to plus 800 mv in well-aerated soil. As the reduced conditions intensify, the soil micro-organisms start using the available oxygen in the soil in the form of salts. The sequence in which the decomposition takes place is the nitrate, manganese dioxide, iron oxide, sulphate, and finally, organic compounds. This is in the order of decreasing redox potential of the ions. Redox potentials help in understanding the easy reduction of the nitrates compared to the sulphates.

Redox reactions: See Redox potential

Red soils

Red soils originate from felsic and mafic parent material and from granite rock. These soils are prone to intense weathering. Red soils are seen in tropical, temperate or semi-arid regions with humid and warm conditions, heavy rainfall and good drainage. These soils develop under deciduous forests with very little organic matter. They are commonly found over convex landforms.

Such weathered soils are low in bases and are not fertile. The red color is due to the presence of unhydrated iron oxides, and the occasional presence of manganese dioxide and partially hydrated iron oxides (Fig.R.2). Such soils also usually have aluminum and silica, besides iron. Red soils are commonly neutral to acidic, devoid of carbonates and deficient in nitrogen, phosphorus and calcium. They are common in alfisols. These red soils are found in China, and many parts of India, Kenya, Bangladesh, Thailand, etc.

Fig.R.2: Red soils - the red color is due to presence of iron oxides.

Reduced tillage

Reduced tillage or **conservation tillage** refers to fewer tillage operations compared to conventional methods, and helps to conserve soil and/or water.

In a reduced tillage system, the primary tillage operation is performed in conjunction with a special planting procedure in order to reduce or eliminate secondary tillage operations.

Reducing agent

In a chemical reaction, the chemical that loses or supplies electrons is called the reducing agent.

$$2Na_{(solid)} + Cl_2{}_{(gas)} \longrightarrow 2NaCl_{(solid)}$$

Here, the sodium atom is the reducing agent and has lost an electron (Na^+) and the chlorine atom has gained an electron (Cl^-). Sodium is oxidized and chlorine is reduced. This is the ability of the substance to deoxidize or change the element from a higher to a lower valence. In the denitrification process, a variety of bacteria reduce nitrate to nitrogen. The bacteria are the reducing agents. Devardas' alloy is also used to reduce the nitrate to ammonia in the estimation of nitrates. (See also Oxidation.)

Reducing-balance method: See Fixed costs

Reducing power

The energy driving power of ATP (adenosine triphosphate) and $NADPH_2$ (nicotinamide adenine dinucleotide phosphate), needed for reducing carbon dioxide to carbohydrate by plants, is called the reducing power or **assimilatory power**.

Reduction

Reduction involves a reaction in which an atom or ion gains electrons. It may also be referred to as **electronation** as is shown in the following example:

$$2Hg^{2+} + 2e^- \longrightarrow Hg_2^{2+};$$
$$Cl + e^- \longrightarrow Cl^-$$

In terms of the oxidation number, the term reduction applies to any chemical change involving a decrease in the oxidation number. Reduction may occur by way of (a) acceptance of one or more electrons by an atom as shown above, (b) removal of oxygen from the compound, and/or (c) addition of hydrogen to a compound. A reducing agent is a substance that brings about reduction as also supplies electrons. It contains an atom which shows an increase in the oxidation number.

The process of denitrification is the reduction of nitrate to nitrogen and nitrous oxide. It is done by a variety of bacteria. Some substances are reduced more easily than others. For instance, nitrate is reduced more easily than sulphate. **Reduction intensity** is a measure of the ease with which oxidation-reduction reactions take place and is dependent on the redox potential of the reaction.

Reduction intensity: See Reduction

Reference curve

In the instrumental methods of analyses of fertilizers, such as in colorimetry, a standard graph is drawn with known concentrations of the ions and the intensity of color or absorption. This graph of concentration against absorption at a fixed wave length, which is known as a reference curve or calibration graph, is used for estimating the concentration of the unknown material.

Reformed gasoline: See Gasoline

Refugia technique for IPM

Integrated pest management (IPM) includes a range of activities, considered as good agricultural practices, aimed at achieving a specific goal of plant protection without disturbing the surrounding ecosystems. One of the techniques used is refugia technique in which pest control is achieved by maintaining the controlled presence of predator insects in the same area. Insects which prey on a specific pest are allowed to grow in a fixed area in the field so that the threat from the pests is automatically controlled. Maggots, which attack cabbage plantations, are generally kept under control with a certain species of *Bacillus* parasite.

Regeneration

Regeneration refers to the regrowing of a lost or damaged part of an organism. In plants, this includes the production of dormant buds and adventitious organs. The term is comprehensive and covers a wide range of restorative activities in a variety of organisms. The capacity for regeneration varies greatly among different groups of organisms. As a rule, the structures formed as a result of regeneration are duplicates of the original structure and possess all their functional characteristics. All living organisms possess some power to regenerate, but its extent varies.

Regeneration is also the restoration of a material to its original condition after it has undergone chemical modification necessary for manufacturing purposes. The most common instance is of cellulose for rayon production. The wood pulp used must first be converted to a solution by reaction with sodium hydroxide and carbon disulphide. In this form (cellulose xanthate) it can be extruded through spinnerets. After this operation, it is generated to cellulose by passing through acid (viscose process). Collagen can be regenerated by acid treatment after it has been purified for use in food products by alkaline solution.

Replenishing the sodium ions of a **zeolite** or similar ion-exchange agent by treatment with sodium chloride solution is also known as regeneration. Molecular sieves are regenerated by heat removal of the water (about 200°C) followed by treatment with an inert gas.

Regosols

Regosols are one of the 30 soil groups in the FAO/UNESCO classification system of soils.

Regosols are defined as the soils with very limited soil development and are characterized by (a) a shallow, medium-to-fine texture, good to imperfect drainage or unconsolidated parent material which may be of alluvial origin, (b) an absence of gleyic properties within 50 cm of the surface, (c) lack of salic properties, (d) exclusion of materials that show fluvic properties, and (e) the lack of a diagnostic soil horizon (layer) formation, other than an ochric or umbric A-horizon, due to relatively unstable dry or cold climatic conditions that can destroy the soil profile zonation.

Regosols are common over a wide range of ecological conditions, in all climate zones and altitudes. However, they occur mainly in arid areas, dry tropics and in mountainous regions, (mostly in land of level to rolling topography) occupying about 260 million hectares.

A low to moderate development of regosols occurs in shrubs and a low development occurs under trees, dryland grasses and wetland grasses. Regosols are frequently associated with leptosols and arenosols.

Regosols are classified into 6 subclasses as follows: (i) Gelic regosols are the regosols having **permafrost** within 200 cm of the surface. (ii) Umbric regosols have an umbric A-horizon. (iii) Gypsiric regosols are those that are gypsiferous regosols at least between 20 and 50 cm from the surface. (iv) Calcaric regosols are calcareous from 20 to 50 cm from surface. (v) Dystric regosols have a base saturation (by 1M NH_4OAc at pH 7.0) of less than 50% at least from 20 to 50 cm from the surface. (vi) Eutric regosols are other regosols distinct from those mentioned above.

Regression analysis

Regression means 'stepping back toward the average'. Regression analysis in statistics is a mathematical measure of the average relationship between two or more variables in terms of the original units of the data.

In this mathematical analysis there are two types of variables: dependent variables and independent variables. **Dependent variable** is the one, the value of which is influenced or is to be predicted. The variable which influences the values or is used for prediction is an **independent variable**. Regression analysis can only organize data already available under a particular set of conditions and have little predictive value under other conditions.

Relative density

Relative density is another name for **specific gravity**.

Relative growth rate: See Leaf area index

Relative humidity

The atmospheric water vapor content is expressed in many ways, namely, relative humidity, absolute humidity, humidity mixing rates and specific humidity.

Relative humidity (RH) represents the amount of water held in the atmosphere at any temperature relative to the maximum amount that the atmosphere can hold at the same temperature. It is expressed as a percent of the saturation humidity measured at the same temperature.

The relative humidity of atmosphere varies from very low in deserts to very high in humid climates. Unlike atmospheric air, the relative humidity of soil air is always almost between 99% and 100%.

Relative humidity is a useful index of dryness or dampness for determining the extent of evaporation or absorption of moisture. (See also Hygroscopicity.)

Relative standard deviation: See Standard deviation

Relative translocation

Translocation is the transport of substances from one part of a system to another. In soils, translocation is the movement of clays or soluble salts, along with water. In plants, the translocation is seen in the movement of a dissolved substance across a cell membrane.

Relative translocation in plants is the mobility of a substance in two media, across the root cortex and into the xylem which carries them by mass flow to the shoot. The nutrient load dissolved in the xylem fluid consists mostly of ions but also some organic materials made in the roots; for example, amino acids. Upon their delivery to the growing shoot tissues, the nutrients are reabsorbed from the xylem fluid, and assimilated.

Relay cropping

Relay cropping involves sowing a new crop before harvesting the first crop in between the rows of the standing crop. Relay cropping makes better use of the 'time-temperature' window which is the amount of heat available to grow crops in a particular season.

Relay cropping is practiced to make use of the 'left-over' growing degree days to produce another (second) crop. For example, a season from April to October has 1600 growing degree days, and growing of wheat in that season requires only 1200 growing degree days; the 'left-over' is 400 growing degree days. This additional heat is used to grow another beneficial crop. Italian rye grass, inter-seeded with corn in the spring, is an excellent example of relay cropping.

The Italian rye grass is a good forage crop and is inter-seeded when the corn is in a 3 to 6 leaf stage. It does not compete with corn at that stage. The growth of the rye grass is suspended once the canopy of the corn crop closes. After the corn is harvested, the rye grass begins to grow again to produce excellent forage for livestock, using the surplus soil nitrogen left over after the corn harvest.

Relay cropping also benefits the environment by reducing the loss of a significant amount of nitrogen that would otherwise have been lost through leaching and/or volatilization.

Reliability, a measure of

A measure of reliability is reflected in the extent of deviation of the observed value from the expected value. The more the deviation, the less the reliability, generally. This measure of reliability also depends on the precision with which the experiment is conducted.

Remote sensing

Remote sensing involves data collection and analysis of the earth's surface features through aerial photography either from an aircraft or a satellite using special cameras and imaging systems. The remote sensing technique employs cameras, infrared detectors, multi-spectral scanners, microwave receptors and radar systems to capture information from a distance. Remote sensing uses the visual, infra-red and microwave portions of the electro magnetic spectrum.

Major limitations of aerial photography come mainly from the spectral sensitivity of the films, spectral resolution of the photographic filters and the logistics involved therein. These limitations have been overcome by newer non-photographic techniques put on board the orbiting satellite. Satellite imaging provides earth-related information, in a very short time, which is not achievable by conventional aerial photography. Satellite systems can provide repetitive coverage of very large areas with good spatial resolution. It can take tens of thousands of photographs, for many years, using conventional aerial photography. The interpretation of satellite images allows for, among other things, the assessment of crop conditions, and the facility to locate and size up weather systems.

Aerial photography and field surveys are used for studies of population densities in livestock and wildlife, forest inventories, movement of ocean currents, land use pattern, chemical and physical characteristics of soils, plant diseases, insect infestations and crop production.

Infra-red (IR) aerial crop photography is a reliable means for following crop yields. The interpretation of the pictures is based on the fact that healthy green plants, for instance, reflect a large amount of IR light, whereas nutritionally deficient, diseased, drought-stressed plants under the influence of pesticides and insecticides do not reflect IR light. Inadequate drainage and uneven use of fertilizers and herbicides can also be sensed remotely from satellites.

Some of the problems in using remote sensing techniques for assessing the quality and quantity of crops relate to (a) small land holdings with small cropped fields, (b) fixed crops like sorghum, red gram, wheat and ground nut, (c) crops like wheat and barley which may create confusion in identification, (d) different cultural practices, (e) large variation in sowing dates, (f) large areas under rain-fed conditions with poor growth, and (g) cloud cover during the June-October ***Kharif*** season.

Rendzina

Rendzina is one of the 106 soil units as described by the FAO-UNESCO legend. It is an intra-zonal calcimorphic soil with an AC profile formed on a calcareous parent material, with an A horizon. The horizon is dark in color with a crumb structure, and is rich in organic matter and carbonates. There is also high biological activity in the A_1 horizon. The active lime content is high and the pH is 8 or more.

The natural vegetation of rendzina soils is shrubs, but meadows are also present as a consequence of human activity. There exist **black forest rendzinas** (very rich in humus), **white rendzinas** (very rich in carbonates) and **brown rendzinas** (low carbonate content).

Rendzina constitutes a soil unit in which the mollic A horizon is contained in, or located immediately above, the calcareous material, with a calcium carbonate content greater than 40%, without diagnostic features of vertisols or high salinity.

Repellents

A substance which does not mix or blend with another substance because of its incongruent physico-chemical nature is called a repellent. All hydrophobic materials (like oils, fats and waxes) have water-repellent properties. Silicone resin coating, that keeps water from penetrating masonry, is another example of repellents.

Repellents protect humans and domestic animals, as well as plants or products, from pests and insects. Repellents, which may be gases (olfactory), liquids or solids (gustatory), make food or the environment unattractive or offensive to insects. Standard repellents for mosquitoes, ticks, etc., are citronella oil, dimethyl phthalate and n-butylmerityl oxide oxalate. Copper naphthenate and lime/sulphur mixtures protect vegetation against rabbits and deer. Copper acetate and formic acid, mixed with ground asbestos, is a shark repellent. Bird repellents are prepared with due consideration to taste, which often varies widely from one type of bird to another.

Insect repellents, which must not be toxic, are used against crawling insects. For example, creosote lines and dinitro-o-cresol barriers are used against migrating chinch bugs; pentachlorophenol and trichloro-benzene soil barriers are used against subterranean termites and sticky bands around tree trunks to protect against gypsy moth larvae. There are also repellents to prevent insects from feeding on plants. For example, Bordeaux mixture prevents the feeding of leaf hoppers, flea beetles and psyllids on plants; fly and mosquito repellents are used to lessen the attack of blood-sucking insects, mites and ticks; logs are treated with pentachlorophenol to prevent an attack of bark beetles, whereas mothproofing treatment is resorted to for protecting woollen goods from moths and carpet beetles.

Replacement sampling

The selection of small groups of entities to represent a large number of entities is known, in statistics, as sampling. In replacement sampling, each individual sample chosen is replaced before the next selection is made. Although this makes the population equivalent to an infinite one, it creates an artificial situation because mostly, real sampling is neither feasible nor possible.

In replacement sampling, a sampled item is again included in the population (aggregate), with the possibility of its being sampled again. This is usually undesirable because it creates loss of efficiency but often it is unavoidable due to practical considerations or the nature of the infinite population. (See also Sample.)

Reproduction

Reproduction is the process by which an organism produces offsprings, an ability that is a unique characteristic of plants and animals. There are two kinds of reproduction: sexual and asexual.

In sexual reproduction, special cells containing half the normal number of chromosomes called gametes, are involved.

At the molecular level, the most important aspect of reproduction is the ability of the chromosome to duplicate itself. The production of haploid cells is made possible by a process called meiosis and is necessary to prevent doubling of the chromosome numbers with each generation in sexually reproducing individuals. The advantage of sexual reproduction is that the bringing together of the genes derived from two individuals produces variation in each generation enabling the population to change and adapt to changing environmental conditions.

In asexual reproduction, parts of an organism split off to form new individuals. The process is found in some animals but is more common in plants. Some examples are the fission of single-celled plants, the budding of yeasts, the fragmentation of filamentous algae, spore production in bacteria, algae and fungi and the production of vegetative organs in flowering plants (bulbs, rhizomes and tubers).

Reserve acidity

Soil pH is indicative of the soil acidity or basicity. The acidity arises from (a) acids released during decomposition of the organic matter in the soil, (b) the leaching of exchangeable bases through percolation and drainage water, and (c) use of fertilizers like ammonium sulphate.

There are two types of acidities – reserve acidity or **exchangeable acidity** and **potential acidity**. The pH of the soil solution gives an idea of the **active acidity** and the stored reserve acidity. The hydrogen ion (H$^+$) and aluminum ion (Al^{3+}), which are in an exchangeable form on the soil exchange complex, are called reserve acidity or exchangeable acidity. The behavior of acid soils is similar to that of weak acids which have greater potential acidity than active acidity. Hence, there is no sharp end point in the titration of acid soils with bases.

Adsorbed ions of hydrogen (H$^+$) and aluminum (Al^{3+}) are released into soil solution and become active when the acidity of the soil solution is reduced by liming or by any other amendment. Thus, hydrogen ions (H$^+$), removed from the soil solution alone, are replaced by the reserve acidity. The degree of resistance to change in the hydrogen ion (H$^+$) concentration (that is, the soil solution pH) is the buffering capacity of that soil. For instance, if enough liming material is added to neutralize the hydrogen ion concentration in the soil solution, the equilibrium shifts to the right, so that more hydrogen ions are released from the exchange complex. Thus, until enough lime is added to use up the reserve acidity, the pH would rise only slightly.

$$\underset{\text{(reserve acidity)}}{\text{Adsorbed H}^+\text{ and Al}^{3+}} \longleftarrow \quad \longrightarrow \underset{\text{(active acidity)}}{\text{Solution H}^+\text{ and Al}^{3+}}$$

Reserve acidity values are useful in predicting the amount of lime needed to neutralize soil acidity.

Reserved potassium

Non-exchangeable or fixed or reserved potassium is not bonded covalently within the crystal structure of the soil mineral particles. It is held between adjacent tetrahedral layers of micas, vermiculites and inter-grade clay minerals. The greater the clay content, greater the fixed potassium. Weathering of micas releases potassium in soils. Micas have their entire negative charge satisfied by potassium; the release of potassium results in the formation of secondary clay minerals such as illite and vermiculite with accompanying gain of water and swelling of lattice. With the release, potassium changes from a non-exchangeable form to an exchangeable form. Depletion of potassium from a soil solution, by plants or by leaching, lowers the potassium concentration in the solution and induces the liberation of fixed potassium. This reserve potassium in soils is generally measured by extracting the soil with boiling nitric acid.

Reservoirs

Water in a dam or any other collected water body forms a water reservoir. It may be a highly porous and permeable mass of rock that is able to hold or transmit water. (Fig.R.3).

Fig.R.3: Check dams act as water reservoirs, where water can be used for irrigation purpose. Courtesy: Dr. Vrishali Deosthali, Department of Geology, University of Pune, India.

Reservoirs are most often man-made lakes, made by building dams across rivers and streams or by dredging a basin into a flat stretch of land. Water towers and water holding tanks atop buildings are also reservoirs. Water from man-made or natural lakes and reservoirs usually meet the domestic needs in cities and towns. Such water is also used to irrigate land. Water is drawn through pipes, and in some cases, pumped hundreds of kilometers away.

Residual effect of fertilizers

A portion of nutrients supplied to plants through fertilizers and manures, unused by the plants during the season and becoming available in the subsequent season for the next crops, is known as the residual effect of that fertilizer or manure.

The residual effect of fertilizers or manures is seen after at least one year of its application. The effect of this unutilized residue, in the remnants of the soil, has to be carefully assessed for correction before a fresh dose of macro or micronutrient is added.

The residual effect is more important for phosphorus, sulphur and micronutrients. (See also Carryover effect of fertilizer.)

Residual material

Unconsolidated and partly-weathered mineral material, accumulated by the disintegration of consolidated rock is termed as residual material. Chalk decalcified clay, which is the main residue of dissolution of calcium carbonate, is an example of a residual material.

Residual protective fungicide

Residual protective fungicides do not penetrate the plant tissues but perform a protective function. These fungicides form a protective barrier on the plant surface and prevent fungus from entering the host, thereby inhibiting spore germination or mycelial growth. These are multisite or multisided inhibitors.

Inorganic sulphur and copper compounds are examples of this class of fungicides.

Residual sodium carbonate

The excess of carbonate plus bicarbonate over calcium plus magnesium in water is residual sodium carbonate (**RSC**).

$$\text{RSC (meq/l)} = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Irrigation water is considered safe if its RSC is <1.25 and unsafe if RSC is >2.5.

Resilient energy, loss of : See Hysteresis

Resistance, active

Active resistance results from host reactions occurring in response to the presence of a pathogen or its metabolites. The formation of phytoalexins, thickening of cell walls, suberization, etc. are the examples of active resistance.

Resistance block method for estimation of soil moisture

Resistance block method is used for rapid and frequent estimation of soil moisture contents at many depths. The principle involved in the estimation is that electrical conductivity decreases with a decrease in soil moisture. A gypsum block containing two electrodes at a fixed distance is buried in soil and the conductivity across the electrodes is measured with a modified Wheatstone bridge. With calibration, the moisture percent from field capacity to wilting point can readily be determined. Nylon and fiberglass blocks have replaced gypsum blocks as they do not deteriorate in soil. Soluble salts in water, form an electrical current as ions carry electrons. The conductivity or resistance reading for various moisture contents must be calibrated for each soil block that would be used. Calibration of blocks should be redone periodically because the salt content of the soil may change, or blocks may deteriorate (in the case of gypsum).

Resistance of conductor: See Ohm

Resistance, passive

Passive resistance does not entail any defensive reaction of the host to the presence of a pathogen. It may result from physical and chemical attributes of the host, which prevent infection, or from an absence of quantities which stimulate or facilitate infection.

Respiration

When living organisms take oxygen or energy and give out carbon dioxide, it is called respiration. It is a metabolic process in plants and animals in which organic substances are broken up into simpler products. While it happens, energy stored in the molecules, like adenosine triphosphate (ATP) is released, and subsequently used up in other metabolic processes.

In respiration, chemical oxidation breaks down carbohydrates and fats to release energy. Most plants and animals take in oxygen by way of respiration and give out carbon dioxide as an end product. The exchange of oxygen and carbon dioxide between the body tissues and the environment is called **external respiration**. In animals, respiration (exchange of gases) takes place at respiratory organs (lungs) assisted by respiratory movements (breathing). In plants, oxygen enters through the pores on the plant surface and diffuses through the tissues via intercellular spaces or dissolved tissue fluids.

At the cellular level, respiration is known as **internal** or **tissue respiration** operating in two stages. In the first stage, glucose is broken down to pyruvate (**glycolysis**), which does not require oxygen and represents anaerobic respiration. In the second stage, pyruvate is broken down by a series of reactions into carbon dioxide and water and the process is known as **Krebs cycle**. This is the main energy-yielding stage which requires oxygen. The processes of glycolysis and Krebs cycle are common to all plants and animals that respire aerobically.

Respiration makes available to the cell the stored energy which is transferred to the energy-carrying molecules, such as adenosine triphosphate (ATP), in the form of carbohydrates which meet the energy needs of the cell.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy (36 ATP)}$$

Respiration that requires oxygen is known as **aerobic respiration**. The one that proceeds even in the absence of oxygen is called **anaerobic respiration** or **fermentation**. A complete oxidation of glucose requires the presence of oxygen, as found in some yeast, bacteria and in muscle tissue, and is known as aerobic respiration.

When oxygen is not available, pyruvic acid is converted to ethanol and carbon dioxide by yeast. The only energy yield from this alcoholic fermentation is two ATP molecules produced during glycolysis.

Respiratory index is the number of milligrams of carbon dioxide released from one gram of dry plant material at 10°C. The **respiratory ratio** or **respiratory quotient (RQ)** is the ratio of the volume of carbon dioxide released to the volume of oxygen absorbed in the respiratory process.

$$RQ = \frac{\text{Vol. } CO_2}{\text{Vol. } O_2}$$

This ratio indicates the type of the substrate oxidized. The ratio is 1 for carbohydrates, < 1 for fats, and > 1 for organic acids.

The oxygen uptake of an organism is measured using a **respirometer** (Fig.R.4). A simple respirometer consists of a chamber (in which the organism is placed) connected to a manometer. Carbon dioxide is chemically removed from the chamber, so that only the oxygen uptake is measured. In humans, the oxygen consumption is measured by a spirometer which can also be used to measure the depth and frequency of breathing.

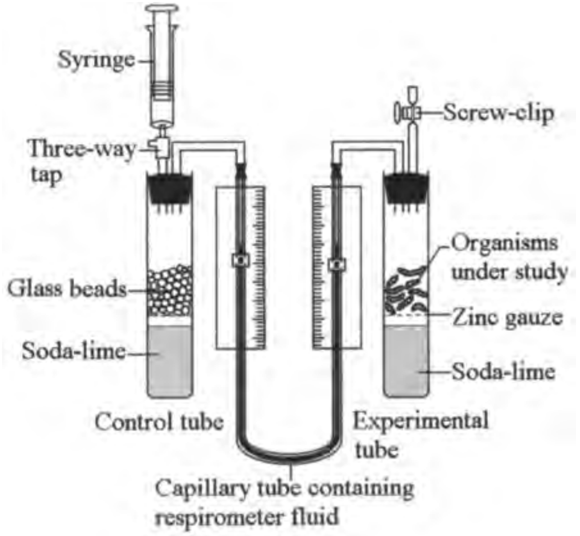

Fig.R.4: Diagrammatic representation of a respirometer used in measuring oxygen uptake by organisms.

Respirator

Respirator is a facemask equipped with filters to remove poisonous gases, dust particles, etc. from air.

Respiratory chain: See Heme

Respiratory index: See Respiration

Respiratory quotient: See Respiration

Respiratory ratio: See Respiration

Respirometer: See Respiration

Response curve

The reaction of a plant to the applied fertilizer is known as response. The response can be positive or negative. An increase in the plant growth leading to higher yields is an indication of a positive response. It is usually measured in percentage, kg/ha or kg crop per kg of fertilizer used.

The graph showing the response of a plant to the fertilizer used, in the form of yield or changes in growth, is called the response curve. The response curve should be developed before screening **genotypes**. In developing a response curve, a large range of concentrations should be covered to obtain a quadratic response, using more than one cultivar.

Response curves differ among soils because of the differences in the nutrient levels, releases, buffering and the plant performance for reasons other than nutrition. Responses also differ among plant species and varieties because of the differences in their requirements and abilities to extract nutrients. The response of one nutrient can be altered by correcting another deficiency or limiting condition. In general, things that increase the growth of a plant also increase its nutrient response and nutrient requirement. Different plant characteristics need not respond in the same way to the applied fertilizer. For sugar cane and sugar beet, for instance, nitrogen fertilizer is withheld during crop maturation in order to raise the sugar concentration and make the milling as well as the extraction cheaper.

Response function

In fertilizer terminology, the response function represents a relationship between the addition of a nutrient (X) and the yield of the product (Y) and is expressed by a number of algebraic equations or functions. Some of these are:

Linear response	$Y = a_1 + b_1X$
Quadratic response	$Y = a_2 + b_2X + c_2X^2$
Mitscherlich equation	$Y = a_3(1-10^{-cX})$
Power function / **Cobb-Douglas equation**	$Y = a_4X^6$
Exponential / logarithmic curve	$Y = a_5e^{bX}$

where a_1, a_2, a_3, a_4, a_5, b, b_1, b_2, c and c_2 are constants.

Similarly, numerous equations or functions have been used to describe the relationship between plant growth and nutrient input. As the variables in the formulae are not independent variables, the constants do change. Factors other than nutrient interactions (such as environmental factors) affect the shape of the curves. An understanding of these interactions with the crop growth factors is necessary to identify the management practices for the soil and the crop.

Response rate

The response rate or **fertilizer efficiency** is indicated by an increase in the crop output relative to the nutrient input. It is determined by the plant root system, the fertilizer-water interaction and fertilizer management techniques.

The initial response rate may be 30 to 70% for the added nitrogen, 10 to 30% for phosphorus and 50 to 80% for potassium. A cereal with a faster growing or more extensive root system, has a better competitive advantage over the associated legume. For nitrogen, legumes generally compete poorly with grass species.

Fertilizers should be applied only if the crop responds positively. Certain crops need larger amounts of a particular nutrient than others do. Legumes require large amounts of phosphorus whereas grains require proportionately more nitrogen. Here, the crop variety is also important; for example, some of the more recently developed varieties respond better to higher doses of fertilizer than the traditional varieties.

Response yardstick

A change in the ratio of crop output to the unit nutrient input on a macro scale is the response yardstick. Its knowledge is often required by economists and statisticians for comparative analyses.

Soils, in their native state, are normally responsive to nitrogen and phosphorus. Many also respond to potassium and other nutrients. As fertilizers are added, the status of phosphorus and potassium status increases; in turn, the yield response to nitrogen may increase because of the higher phosphorus and potassium fertility of the soil. For example, 100 kg phosphorus per hectare may be an agronomically optimum amount initially, but for the next 20 years, phosphorus may be needed only for replenishing the removed phosphorus.

Farmers normally have a specific area of land for crop plantation. For economic analysis, fertilizer use is monitored on the basis of per hectare of the land used. The addition of the first few kilograms of the fertilizer may have the largest effect on the yield, but this quantity may be inadequate after a few years because of the law of diminishing returns. The variability of climate and other factors make it difficult to evolve a simple response curve for a given field fertility.

There are various mathematical models or algebraic equations for estimating the fertilizer response. A **quadratic function model** is commonly used to estimate the fertilizer response functions that represent agricultural output increasing at a decreasing rate, as a result of the increased fertilizer application rates. The model is written as:

$$Y = A + BF + CF^2$$

where Y is the crop yield, F is the fertilizer rate, and A, B and C are the coefficients of the response functions that are usually estimated from the ordinary least square method and experimental data. The actual yield for a given year can be affected by many other factors, such as weather, diseases, insects, weeds, etc.

Retardant

A catalyst that slows down or arrests a chemical reaction is called a retardant. Such substances are also called **negative catalysts**. For example, acetanilide retards decomposition of hydrogen peroxide, and salicylic acid prevents pre-vulcanization of rubber.

Retention capacity of soil

The intrinsic capacity of a soil to retain water after it is well moistened and drained in a natural way, is called the retention capacity of the soil. Water held in the soil and prevented from moving downwards by friction or retained around the particles by other bonding forces is in equilibrium with the soil atmosphere. The quantity of water retained in the soil depends on the soil type and structure. While large pores allow water to drain off by gravitational flow, small pores retain water by capillary forces. Generally, clayey soils can store large amounts of water, but large amounts of the plant-available-water are found in silt-loams and other high-silt soils.

Retention price of fertilizer

The retention price of a fertilizer is its minimum selling price by which the government ensures a certain rate of return to the industry. To stimulate and sustain the growth of food production and high returns in a situation when crop prices cannot be raised, fertilizer subsidies are given to farmers to retain the viability of the agricultural industry.

Retro argillic

Retro argillic is a subtype of **argillic horizon** found in oxisols. After cultivation, this subtype horizon is exposed to compaction. Parameters such as the increased clay content, high bulk density, low CEC, very low silt to clay ratio, and very low amounts of weatherable minerals are relevant and need to be observed.

Retting

Retting refers to soaking of fibrous plant materials in water to facilitate the separation of the fibers from the stalks for further processing in a post-harvest operation. Jute, flax and hemp are examples of such fibrous materials.

Reverse of mineralization: See Mineralization, ammonium form

Reversible aggregation of particles

Flocculation is a process in which colloid particles come together, forming large lumps. Reversible aggregation of particles means that the forces holding the particles together are weak and a simple agitation can break the lumps into their original state.

Reversible reaction and phenomenon

A chemical reaction which proceeds first to the right and then to the left when the ambient conditions are changed, is known as reversible reaction. The product of the first reaction decomposes to the original components as a result of different temperature and pressure conditions. An example is:

$$H_2O + CO_2 \rightleftharpoons \underset{\text{Carbonic acid}}{H_2CO_3}$$

in which carbonic acid reverts to water and carbon dioxide. Similarly, ammonium chloride decomposes on heating to ammonia and hydrogen chloride which recombine on cooling.

$$NH_4Cl \underset{\text{Cooling}}{\overset{\Delta}{\rightleftharpoons}} NH_3 + HCl$$

A colloidal system such as a gel or suspension can be changed back to its original liquid form by heating, addition of water or by other methods. For example, evaporated egg white can be restored by addition of water.

Reversion

Reversion is a process in which an element in the soil is converted from a highly soluble or a rapidly assimilable state to a non-assimilable or poorly assimilable state. The ions, having thus undergone retrogression, remain either fixed in the crystal lattice of clays or blocked in insoluble crystalline forms, practically lost to the plants. This also occurs in fertilizer mixtures where mixing norms of the ingredients are not followed.

When a water-soluble phosphate fertilizer, such as superphosphate or ammonium phosphate, is applied to soil, it reacts with Ca, Fe or Al ions in the soil solution immediately after dissolution, and precipitates as insoluble phosphates or gets adsorbed on the surface of the clay particles. This process is known as reversion of phosphate or fixation of phosphate and the compounds formed are known as **phosphate reaction products**.

Phosphates formed by the process of reversion are called **reverted phosphates**. Thus, the water-soluble and citrate-soluble phosphate compounds [$Ca(H_2PO_4)_2$ and $CaHPO_4$] are accordingly converted to $Ca_3(PO_4)_2$ when incorporated into the soil. Similarly, soils acidic in nature, and rich in aluminum and iron, transform the phosphates into insoluble phosphates of aluminum and iron.

The monocalcium phosphate fertilizer in neutral or calcareous soils is transformed into insoluble bi-calcium and tri-calcium forms while in acid soil it converts into insoluble aluminum or ferric phosphate. A moderate increase in pH of acid soils and of fresh organic matter favors stabilization of the fixed phosphorus and increased assimilability.

When a potash fertilizer is added to the soil, especially in unsaturated conditions, potassium ions in the adsorption complex move to the inside of the crystal lattice of clays. This underlines the need to readjust the fertilizer dose depending upon the losses and gains.

Reverted phosphate: See Reversion

RGR

RGR is short for **relative growth rate**.

RHA

RHA is short for **rice hull ash**.

Rhenania

Rhenania is a thermally produced phosphate fertilizer. It is made by calcining a mixture of phosphate rock, sodium carbonate and silica in a rotary kiln at 1250°C. Sodium carbonate is used to yield $CaNaPO_4$ and silica is used to form Ca_2SiO_4. The product is found to be substantially more effective than superphosphate on several acid tropical soils.

Rhenania phosphate is the commercial name for the fertilizer manufactured by fusing basic slag with rock phosphate. It contains 17% total phosphorus, 16% of which is citrate-soluble and 5% is water-soluble phosphorus. It is also called **pelophos**.

Rhenania phosphate: See Rhenania

Rheology

Rheology is the study of deformation and flow of matter. The flow characteristics of liquid fertilizers should be suitable for the uniform distribution of the fertilizer. If the rheological properties (such as viscosity and its changes with temperature and concentration of the dissolved salts in foliar sprays) of the liquid fertilizer are favorable, the fertilizer spreads uniformly.

Liquids are characterized by their ability to flow, a property dependent largely on their viscosity and sometimes on the rate of shear. A Newtonian liquid flows immediately on the application of force, the flow rate being directly proportional to the force applied. Water, gasoline and motor oils used in tractors are examples of Newtonian liquids. Non-Newtonian liquids exhibit an abnormal flow response to force because their viscosity is dependent on the rate of shear. Some do not flow until the force exerted is greater than a certain value, called the yield point. And in the case of clay, this property is called the **yield point of clays**.

Some clays, like bentonite suspended in water, liquify when agitated and become a gel when at rest. This phenomenon is known as **thixotropy**. Thixotropy is also displayed by paints and printing inks which flow on application of slight pressure, such as by brushing or rolling. This property of clay is used in oil well drilling fluids. In some highly concentrated suspensions, the rate of increase of strain decreases with an increased shear. This phenomenon is known as **dilatancy**.

Rheopexy

Gels get converted into a paste form by mechanical force. This property is known as the rheopexy of gels.

Rhizobacteria

Bacteria present in the **rhizosphere** of a soil are called rhizobacteria. They first infect the root hairs and subsequently enter the nodule cells to produce methemoglobin. The latter is an oxygen-carrying pigment (also called **leghemoglobin**) that makes the environment anaerobic, which is necessary for nitrogen fixation. The plant roots supply the nutrients necessary for the bacteria.

Rhizobia

The bacteria rhizobia belong to the genus *Rhizobium* and have many strains. They are unicellular with a rod-like shape and a width less than 2 µm. Rhizobia respire aerobically and derive food (carbon source) and energy from organic matter, which makes them **chemoheterotrophic**. In their symbiotic association with leguminous plants, rhizobia enter the root hairs, multiply in the roots, and form root nodules. Legumes provide the carbon source (monosaccharides and disaccharides) for the bacteria, which in turn fix the atmospheric nitrogen for plants. The nitrogen-fixing capacity of rhizobia makes them a very important biofertilizer, although all strains do not fix nitrogen to the same extent.

Rhizobia are Gram-negative bacteria with two distinct growth patterns, namely, the **fast-growing** and the **slow-growing**. The fast-growing variety consumes disaccharides and produces acid on the medium (yeast manitol-agar) and doubles every two to four hours. This group includes ***Rhizobium trifolii*, *R. minosarum*** and ***R. phaseoli*** all of which can be called ***R. leguminosarum***. Another strain, *R. meliloti*, is also fast-growing.

The fast-growing, acid-producing species mainly form nodules on the roots of the pea group of legumes, and are commonly known as **medic rhizobia, clover rhizobia, pea rhizobia** and **bean rhizobia**.

Slow-growing strains, identified as ***Bradyrhizobium***, consume pentose and produce alkali on the medium and double every six to twelve hours. Slow-growing rhizobia have polar or sub-polar flagellate bacterial strains. The slow-growing group includes *Bradyrhizobium japonicum*, which grows on nodulating soybean, lotus, vigna and cicer types of legumes. Lupini rhizobia are a common strain of slow-growing *Rhizobium* bacteria. There are countless strains of this bacterium, a few thousands of which are maintained in culture collections. Strains are distinguished by growth characteristics, immunological reactions, and host specificity. Fixation rates up to 500 to 600 kg/ha/year have been estimated.

The production of ***Rhizobium* biofertilizer** involves four steps which are (a) isolation, (b) authentication and strain selection, (c) preparation of mother culture, and (d) mass production. The desirable temperature for growth is 28 to 30°C and aeration at the rate of 5 liters air/hour. A *Rhizobium* biofertilizer increases the yield by 10 to 35%.

For its effective application, water and sugar, or gum arabic is mixed with a biofertilizer to form a **inoculum** slurry. Seeds are mixed in this slurry, spread on a plastic sheet and dried in the shade. The coated seeds are further treated with fungicide after a gap of at least 24 hours and are then ready for sowing.

Nitrogen produced by the symbiosis of legume and *Rhizobium* varies with the kind of legume. The contribution of nitrogen can be summarized as follows: green gram and black gram, groundnut, pea, soybean and cowpea get nitrogen on the lower scale (in the range 50 to 85 kg/ha), whereas chickpea, lentil and clover get nitrogen in the range of 80 to 150 kg/ha. Alfalfa and pigeon pea seem to benefit the most in that they get nitrogen in the range of 100 to 200 kg/ha.

Carrier-based or agar-based *Rhizobium* biofertilizer is available in two forms - as broth or dried culture. New forms like pelleting, *Rhizobium* pastes and freeze-dried inoculants have also been developed.

Seven species of rhizobia are generally recognized and are known as **cross-inoculation groups**, based on the ability of *Rhizobium* isolates to form nodules on the roots of limited species of legumes. The cross-inoculation groups of rhizobia are listed in Table-R.3.

Table-R.3: Cross-inoculation groups of rhizobia.

Species	Legume type	Cross inoculation group
Bradyrhizobium japonicum	*Glycine*	Soybean group
R. leguminosarum	*Pisum, Vicia, Lens*	Pea group
R. lupini	*Lupinus, Orinthopus*	Lupini group
R. meliloti	*Medicago, Melilotus, Trigonella*	Alfalfa group
R. phaseoli	*Phaseolus*	Bean group
R. trifolii	*Trifolium*	Clover group
Rhizobium sp.	*Vigna, Arachis*	Cowpea group

Rhizobium

Rhizobium is a genus of root nodule bacteria which fix atmospheric nitrogen. It is found in the root nodules of leguminous plants. (See also Rhizobia.)

***Rhizobium* bacteria, fast-growing**: See Fast-growing *Rhizobium* bacteria

***Rhizobium* bacteria, slow-growing**: See Slow-growing *Rhizobium* bacteria

***Rhizobium* biofertilizer**: See Rhizobia

Rhizobium inoculation

The application of *Rhizobium* culture in any form to seeds is known as *Rhizobium* inoculation. Symbiotic heterotrophic bacteria, specific to the crop to be grown, are added or inoculated in a dried and powdered form to the crop seed to ensure that nitrogen-fixing organisms are present. Bacteria from the genus *Rhizobium* are best known for symbiotic association. Agar-based cultures are the quickest way to inoculate plants in small experiments. The surface growth of *Rhizobium* on agar is scraped with a needle or scalpel and suspended in water, which is then sprinkled on the seeds before sowing.

Carrier-based cultures are mixed with a minimum amount of water to form a slurry. To this is added 10% sugar or 40% gum arabic, and the slurry is poured on the seeds to coat them. The coated seeds are allowed to dry in the shade before sowing (Fig.R.5).

In the USA and Australia, **seed pellets** are often used to establish legumes in acid soils or to avoid hazards of pesticides or fertilizers. In India, however, the **pelleting** of seeds with lime and gypsum is done for soybean in problematic soils. The applied rates are about 5 g of inoculum/kg seed (or 1 part inoculum: 200 parts seed). An alternative technique to encourage nodulation is to heavily apply a peat granule-mixed inoculum which trickles down into the soil as the seed is planted.

Different bacterial species inoculate different legumes. For instance, species that inoculate lupines do not inoculate lespedezas or trifolii. Some bacterial species can, however, react symbiotically with several similar legumes.

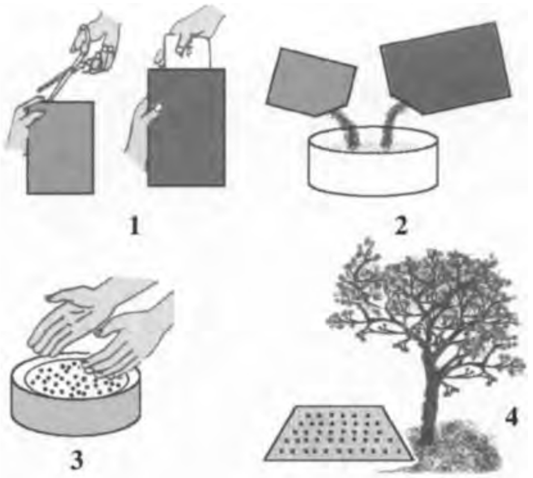

Fig.R.5: Steps in the treatment of seeds with biofertilizer are. (1) opening packet of inoculum and sticker, (2) preparing the slurry, (3) mixing with seed, and (4) drying under shade. The inoculated seeds are then ready for sowing.

Rhizobium leguminosarum

Rhizobium leguminosarum is one of the species of *Rhizobium*, belonging to the pea group of seven cross-inoculation groups. It forms nodules on the roots of legume types such as *Pisum, Vicia* and lens, which include peas, broad beans, lentils and vetch. *R. leguminosarum* is a fast-growing, acid forming species of the pea group. Bacteroids in nodules are mostly X-, Y-, star- and club-shaped.

Rhizobium meliloti

Rhizobium meliloti causes nodule formation on species of *Melilotus* (sweet clover), *Medicago* (alfalfa) and *Trigonella* (fenugreek). These bacteria are club-shaped and branched. They grow fast on the yeast extract media.

Rhizobium minosarum

Rhizobium minosarum is a fast growing bacterium and belongs to the group *R. leguminosarum*. (See also Rhizobia.)

Rhizobium phaseoli

Rhizobium phaseoli, a fast-growing strain of the *Rhizobium* bacteria, causes nodule formation on temperate species of *Phaseolus*. Bacteroids found in nodules are usually rod-shaped and often vacuolated with a few branched forms.

Rhizobium sp.

Rhizobium sp. is a species of the genus *Rhizobium*. The bacteria, commonly known as cowpea rhizobia, have the ability to fix atmospheric nitrogen. As a crop inoculating group they represent the cowpea group. They form nodules on the legume type, such as *Vigna* and *Arachis*.

Rhizobium trifolii

Rhizobium trifolii, a fast-growing strain of the *Rhizobium* bacteria, causes nodule formation on *Trifolium* spp.

Bacteroids in nodules are pear-shaped, swollen, vacuolated and rarely, X and Y shaped.

Rhizoflora

The microflora growing in the rhizophere is called rhizoflora.

Rhizoid

Rhizoid is a short hypha, which attaches a fungus to the substrate to collect nutrients (Fig.R.6). It is one of the groups of delicate, colorless, hair-like outgrowths, found in certain algae and the gametophyte generation of bryophytes and ferns.

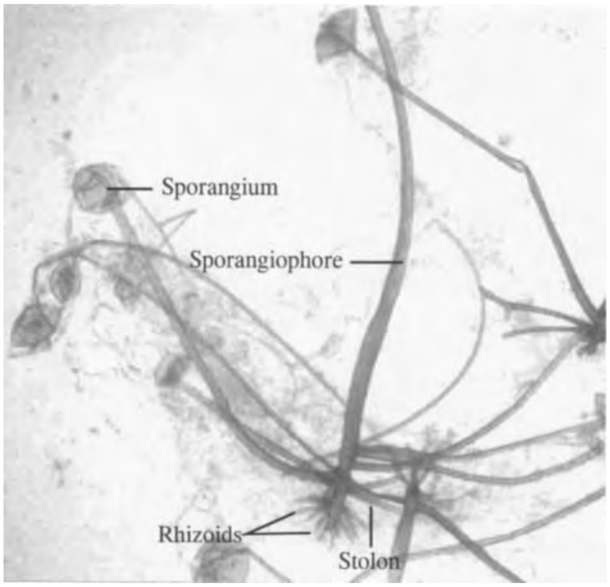

Fig.R.6: Rhizopus stotonifer, fungus bearing rhizoids.

Rhizoids anchor the plant to the substrate and absorb water and mineral salts.

Rhizome

Rhizome is a swollen, horizontal underground stem which enables the plant to survive from one growing season to the next. Rhizome also helps to propagate the plant vegetatively in some species. It lasts for several years and new shoots appear each spring from the axils of the scale leaves. Buds found at the nodes can give rise to new plants (Fig.R.7).

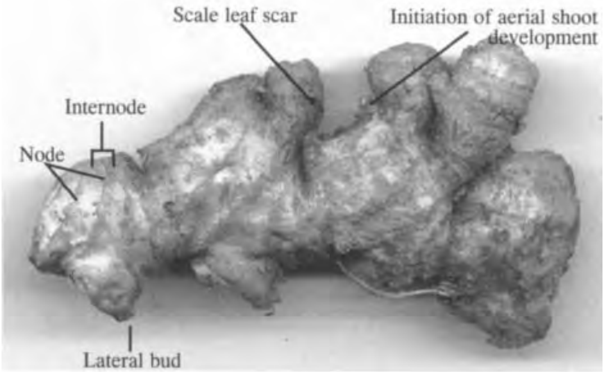

Fig.R.7: Rhizome (Zingiber officinale), a modified underground stem.

In some cases, rhizome may also be a food storage organ. It may be thin and wiry as in couch grass, or fleshy and swollen as in iris and ginger. Compact upright underground stems such as in rhubarb, strawberry and primrose are often called **root stocks**.

Rhizoplane

The external surface of plant roots, together with closely-adhering soil particles, is known as rhizoplane. The microbial density in this area is such that a veritable mantle of bacteria surrounds the roots.

Rhizoplast

Rhizoplast is the connecting strand between the nucleus and blepharoplast.

Rhizosphere

The soil volume adjacent to the plant root surface is called the rhizosphere (Fig.R.8). It is the cylindrical space extending a millimeter or so from the root surface. It exhibits significant chemical and microbial activity, quite different from the rest of the soil. In the process of penetrating the soil, the roots compress the surrounding soil and increase its bulk density. For example, fine sand is observed to increase the density from 1.4 to 1.5 gm cm^{-3} and clay increases the bulk density from 1.2 to 1.3 gm cm^{-3}.

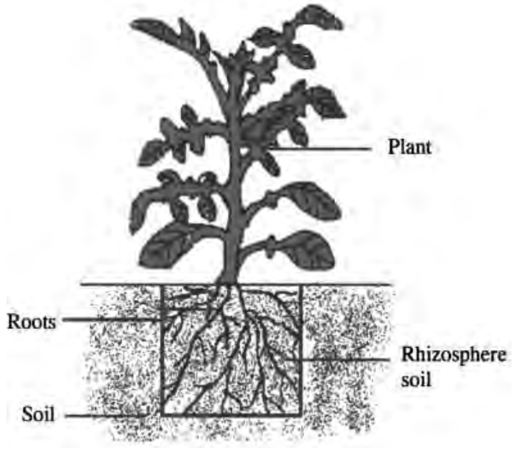

Fig.R.8: Soil adhering to the roots is called rhizosphere soil.

The rhizosphere generally has greater organic matter owing to the destruction of the root cap cells and fine roots, and secretion of mucilage in and around the root system. Mucilage also leads to the formation of micro aggregates by cohesion of soil particles. It helps to keep the moisture in the rhizosphere intact despite the increased demand for water near the root. **Root mucilage**, containing 99.9% water, has a water potential of -7 kPa. The microbial population in this area is conditioned, both quantitatively and qualitatively.

Microbial populations are normally at least ten times denser in the rhizosphere than in the rest of the soil. Rhizosphere microbes ordinarily account for much of the soil's heterotrophic activity, decomposing and assimilating dead plant cell exudates.

The activity in the rhizosphere is two-way. The exudates from the plant roots are used by the microbes and the roots take up nutrients from the rhizosphere. The nitrogen-fixing symbiotic bacteria live and grow here. Leguminous plants support higher rhizosphere populations compared to non-legumes. The stimulation of micro-organismic growth in the rhizosphere results chiefly from the liberation of organic substances by the growing plant. The process of nutrient uptake starts in the rhizosphere. Convective flow and diffusion are the two mechanisms for the movement of nutrients. When a plant dies, the microbial population reverts to the level of the surrounding soil.

Some of the rhizospheric bacteria are known to produce gummy coatings that help them stick to the root cells and glue the soil particles together. In this way, they contribute to the development of a granular soil structure in the root zone. There is evidence that rhizospheric organisms can help mobilize plant nutrients such as iron, copper and zinc by producing chelating agents. Others suppress root pathogens.

Rhone-Poulenc phosphoric acid reaction system:

See Phosphoric acid production processes

R horizon

Soil, made mostly of minerals, is divided into horizontal layers, each uniquely identified by distinct characteristics. R horizon is one of the identified master horizons of soil, which represents parent materials. The symbol R is reserved for hard bedrock such as granite, sandstone and limestone. (See also Soil horizons.)

Ribonuclease

Ribonuclease is an enzyme, which causes splitting of ribonucleic acid. Pancreatic ribonuclease, for example, cleaves only phosphodiester bonds that are linked to pyrimidine 3' phosphates. It is a critical regulator of life processes in the cell. The enzyme, when synthesized, is composed of 124 amino acid residues. It is one of the few proteins for which the sequence of amino acids has been elucidated.

Ribonucleic acid

Ribonucleic acid (**RNA**) is a generic term for a group of natural polymers, consisting of long chains of alternating phosphate and D-ribose units, with bases adenine, guanine, cytosine and uracil bonded to the 1 position of the ribose. Ribonucleic acid is universally present in living cells and has a functional genetic specificity due to the sequence of bases along the polyribonucleotide chain.

The following four types of RNA are known:

(i) **Messenger RNA**: It is synthesized in the living cell by the action of an enzyme that carries out the polymerization of ribonucleotides on a DNA template region which carries the information for the primary sequence of amino acids in a structural protein. It is a ribonucleotide copy of the deoxynucleotide sequences in the primary genetic material.

(ii) **Ribosomal RNA**: It exists as a part of a functional limit within living cells, called the **ribosome**, a particle containing protein and ribosomal RNA in roughly 1:2 parts by weight, having a particle weight of about 8 million. **Messenger RNA** combines with ribosomes to form polysomes containing ribosome units, usually 5, complexed to the messenger RNA molecule. This aggregate structure is the active template for protein synthesis.

(iii) **Transfer RNA**: It is the smallest and best characterized RNA. Its molecules contain about 80 nucleotides per chain. There are at least twenty separate kinds, correspondingly related to each of the 20 amino acids naturally occurring in proteins. Transfer RNA must have at least two kinds of specificity. (i) It must recognize (or be recognized by) the proper amino acid activating enzyme so that the proper amino acid will be transferred to its free 2' or 3' -OH group. (ii) It must be recognized as the proper triplet on the messenger RNA-ribosome aggregate. Having these properties, transfer RNA accepts or forms an intermediate transfer RNA amino acid that finds its way to the polysome, complexes at a triplet coding for the activated amino acid, and allows transfer of the amino acid into peptide linkage.

(iv) **Viral RNA**: It is isolated from bacterial viruses, and animals and may be considered as a polycistronic messenger RNA. It has a molecular weight of 1 to 2 million. Generally, there is one molecule of RNA per infective virus particle. The RNA of RNA virus can be separated from its protein component and is also infective, bringing about the formation of complete virus.

Ribosomal RNA: See Ribonucleic acid

Ribosome

Ribosome, a ribonucleoprotein, is the smallest organized structure found in cell cytoplasm.

Ribosome occurs in all cells including algae, bacteria, fungi and protozoa. It is the site of protein synthesis. The cells contain 45 to 60% of ribonucleic acid, the balance being proteins.

Ribosome crystals appear as sheets of black dots, each sheet containing hundreds of ribosomes in recurring groups of four under an electron microscope. The ribosomes in higher organisms (with a total mass of 4,000,000 daltons) are a one-third to a one-half larger than ribosomes in bacteria and other micro-organisms.

Ribosomes play an important role in protein synthesis. A part of the deoxyribonucleic acid (DNA) in the nucleus serves as a template for the synthesis of a messenger RNA molecule, whose sequence of nucleotides is complementary with that of the DNA.

Rice

Rice (*Oryza sativa*) is probably the single most consumed food grain in the world. It has been in existence for the last 7000 years. Rice, an annual, is multi-stalked plant which grows to around a meter (Fig.R.9). The grains, borne by a panicle, are surrounded by bracts. Air columns in the stalk enable the diffusion of air through the stem down to the roots. The process of threshing and winnowing, followed by milling and polishing, converts the harvest into the marketable product that people commonly consume.

Fig.R.9: Rice field. Rice is considered the most consumed foodgrain in the world.

Since rice is the native of South-East Asia, it is best suited to a watery ecosystem and is mostly grown in flooded fields. Rice plants are able to resist decay even while they remain submerged for long periods. This happens by the help of the stems that are both elongated and perforated, helping the plants to photosynthesize and transport oxygen to the roots.

Over thousands of years of its existence, rice has adapted itself to survive different situations, like drought, floods, nutrient stress, etc. Rice is categorized according to the environment in which it grows. Thus, rice is grown in rainfed lowland, deepwater, tidal wetland, rainfed upland and irrigated land areas. Upland rice is the rice cultivated on lands without ponding.

Rice is grown on 155 million hectares of land across 100 countries. Consumption of rice increases by an average of 2% every year. Asia produces 92% of the total rice, accounting for 90% of the harvested area. However, there is still a shortage of the grain in the world. While Australia has achieved the highest rice yield (10 tons per hectare). Asia manages only 3.9 tons per hectare. One of the reasons is that in Asia, there are about 250 million tiny land holdings dedicated to rice, making large scale agricultural practices difficult to adopt.

Rice is a good source of thiamine and niacin (both Vitamin B). It also provides iron, phosphorus and magnesium. It has higher levels of amino acid and lysine compared to other cereal grains.

Rice is also categorized on the basis of the nature and treatment of the grain, that is, size, variety and processing. Accordingly, there is **long grain rice**, **medium grain rice**, **short grain rice** (according to size) Arborio, jasmine, black rice, fermented red rice, parboiled rice, aromatic rice, glutinous rice, etc. (according to variety) and **enriched rice**, **converted rice**, **instant white rice**, etc. (based on processing methods). The nutrient value decreases when processes like mechanized milling and polishing are used. The unprocessed rice is called **brown rice** (the dehulled whole grain) which is more nutritious compared to **white rice** which is refined and processed.

Optimal levels of rice production are achieved by a balanced and appropriate addition of sulphur, iron and zinc, apart from NPK. Rice needs 14.7 to 16 kg of nitrogen per ton of grain yield (with a grain to straw ratio of 60 to 40), 6 to 6.4 kg of phosphorus (as P_2O_5) per ton of grain (a grain to straw ratio of around 70 to 30) and 17 to 19 kg of potassium (K_2O) per ton of grain (with a grain to straw ratio of around 12 to 88). A deficiency of any of these nutrients affects rice yield. The nutrient doses depend on the severity of the deficiency and the nature of the soil. For instance, 10 to 40 kg of sulphur can be supplied to a hectare depending on the deficiency. Similarly, zinc is supplied either directly to the soil (10 to 25 kg of $ZnSO_4 \cdot H_2O$ or 20 to 40 kg of $ZnSO_4$ are applied per ha on the soil surface) or by dipping the roots of seedlings in a zinc fertilizer solution. Iron deficiency is generally corrected by chelates, foliar application or by soil application of 100 to 300 kg ferrous sulphate per hectare.

In view of the growing demand of rice across the world, increasing the yield of rice per hectare is imperative. Research involving genetic engineering, biotechnology and other innovations is being carried out in many research centers around the world on international, national and regional levels to achieve the objective of higher rice yields. International Rice Research Institute (IRRI), Philippines is one of the major research centers for rice.

Methods for increasing the efficiency of rice cultivation include (a) developing rice plants that are resistant to pests and pathogens, (b) modifying the life cycle of rice by delaying the process of crop senescence and inducing early flowering, so that more produce is generated, (c) increasing the dependence on micro-organisms or organic matter for bio-fertilizers instead of chemical fertilizers, (d) increasing the productivity per unit of land, so that more land is not locked under rice cropping, (e) developing genetically modified varieties which can improve the nutritional value of rice, like increasing the content of iron and vitamin A, (f) making the biotechnology revolution spread to the developing world, (g) finding solutions to conflicting issues of financial liability and technology exchange, among the possessors of germplasm, research organisers and international promoter institutions, (h) controlling weeds which are sometimes considered the biggest enemy of the rice crop, and (i) encouraging **organic rice farming** using the principle of **polycultural farming of rice**. Organic system of farming emphasizes use of environmentally safe, eco-friendly methods of cultivation.

Like all crops, rice is attacked by several diseases. The yield of rice is affected all over the world by many bacterial and fungal diseases. These pathogens attack various parts of the plant such as the leaf, stem, panicle, blossom, etc. Although the severity and extent of damage varies with the geographic location or the variety of rice, the major diseases are bacterial leaf blight, **leaf blast**,

stem rot, bacterial leaf streak, sheath blight, seedling blight, brown leaf spot, kernel smut, sheath spot, etc. In addition to these, there are many other diseases which are specific to certain locations and seasons.

Increasing the yield and preventing or fighting diseases have been the main objectives of rice growers both in the past and today. Different methods have been prescribed in ancient literature, to increase yield and prevent diseases in rice. In the period 321 to 296 BC, the Indian treastise on Economics "*Arthasastra*" explained how rice could be planned and fungal diseases prevented, adding inputs like fish manure, etc., and by observing the monsoon. Ancient Chinese and Japanese manuscripts prescribe use of ducks in rice farming to control insects and nourish the crop.

Rice-azolla-fish culture

Rice-azolla-fish culture is a farming system developed and used in China. In this system of farming, rice, azolla and fish grow simultaneously in the same field. This system improves the yield of both fish and the rice.

Rice classification

There are some popular varieties of rice that are cultivated, the choice being based on traditionally accepted taste, robustness of the variety, etc. The number of rice varieties may run in hundreds, though most of them are limited to specific areas and patronized by specific cultures.

Rice is categorized on the basis of (a) the size of its grain, (b) the flavor or the variety, and (c) the processing method adopted. The classification based on the size gives three different categories, namely the **long grain**, the **medium grain** and the **short grain**.

Based on the variety, there are many types such as Thai Jasmine rice, Black rice, fermented red rice (China), Basmati rice and par boiled rice (India), **Arborio**, aromatic, **glutinous rice**, etc.

Acknowledging that rice is processed by different methods to achieve maximum nutrient retention, there is **enriched rice**, **converted rice**, **instant rice**, **white rice** and **brown rice**.

Rice farming with ducks

An innovation in organic rice cultivation is the use of ducks. A thousand year old journal in China recommends the use of ducks in rice paddies. Japan is known to have used it for over 500 years.

Ducks are released in the field where rice is cultivated. The flooded field provides enough water, snails, insects and weeds for the ducks to live in. Rice plants provide hiding places for ducks.

Ducks provide many advantages to a rice farmer. They eat weeds in the field, thus taking care of weed menace. Weeding takes up a substantial amount of time, especially when weedicides are not applied as a part of organic farming. Ducks also eat insects among the crop. They eat snails which are a threat to the crop. Their droppings provide nourishment to the growing crop. By moving through the fields, they prevent sediments from settling too much at the bottom of the paddies.

Finally, it is believed that rice suffers some level of stress, due to ducks, which is good for rice growth. Ducks form a part of diet, which is yet another advantage, providing nourishment to the farmer's family and adding to the farmer's income. Care has to be taken that the ducks do not get preyed upon by dogs, wolves, etc. A simple barbed wire around a duck-rice farm can solve the problem.

Duck farming is gaining in popularity in many countries like Taiwan, Korea, Indonesia, Vietnam, Cambodia and Philippines, besides China and Japan. In Tanzania, an experiment with ducks resulted in increased yields of rice, and also increased nutrition level in the people.

Rice hull: See Rice hull ash

Rice hull ash

Rice hull ash (**RHA**) is the result of burning rice hull, a residue of the rice plant. Rice hull ash may be produced in an open field or by using it in a hull-fired stove.

Rice hull is a natural, renewable by-product of rice production. On burning, hull produces blackish grey ash, which is non-crystalline silica and hence, a natural silica fertilizer. RHA may be produced and stored for incorporation into a seedbed at the rate of 0.5 to 1 kg RHA/m^2, before sowing the rice seed.

The seedlings are observed to become healthy, tough, disease-resistant and capable of producing a better yield.

Rice, major diseases of

Like any other crop, rice crop is prone to bacterial and fungal attacks which are a major threat to its yield. These pathogens affect various parts of the plant such as the leaf, stem, panicle and blossom.

The severity and extent of damage varies with the geographic location or the variety of rice, or both. Newer strains of pathogens keep emerging, making it very difficult to control the spread of the infection.

Diseases such as bacterial leaf blight and leaf blast grow at epidemic proportions. These invade large areas of rice fields in Asia. Stem rot, bacterial leaf streak, sheath blight, seedling blight, brown leaf spot, kernel smut, sheath spot, etc are some other diseases which are harmful but not epidemic in nature. In addition to these, there are many others which are specific to certain locations and certain seasons.

The productivity of rice cultivation is challenged by the bacterium *Xanthomonas oryzae* pv. *oryza*. This causes bacterial leaf blight. This disease spreads in almost all Asian countries, affecting yields upto as much as 80% in the affected areas.

The leaf develops yellow watery lesions at its margins. The lesions run parallel to the leaf and may cover the whole leaf. The bacterial ooze may be observed in the way water turns murky when a portion of the leaf is soaked in it. The leaf subsequently dries up, turning the lesions greyish-white.

Scientists have been successful in incorporating resistance traits in modern rice varieties. They inoculated varieties of wild rice from many Asian countries like India (*Oryza malampuzhaensis*), China (*Oryza rufipogon*), the Philippines, Nepal, etc. with hundreds of strains (over 1200 known strains) of the bacterium, leading to the identification of over 25 genes that are resistant to many of the strains of the disease. Xa21 and Xa23(t) are two such prominent genes. Research continues to develop lines of rice varieties that will have resistance genes to fight the maximum number of strains of bacterial leaf blight.

Bacterial leaf blight spreads with irrigation water, windblown rain, infected trimming tools, over-fertilization and warm temperature (around 30°C). Humidity also favors the disease.

The use of resistant varieties of rice and effective bactericide / antibiotic like streptocycline can control the spread of the disease. In some areas, rolling of stubble to bring about rapid decay is also found to control the disease.

Rice leaf blast is caused by *Piricularia griesa* (*Magnaporthe griesa* or *Piricularia oryzae*). **Leaf blast in rice**, a widespread fungal disease, is responsible for crop losses of up to 50% in affected areas. It affects the rice crop yield in both flooded and non-flooded areas. The plant is affected in two steps – the leaf and the panicle. Thus, this disease is also commonly known as **panicle blast** and **rotten neck** because the fungus prevents the maturation of the rice grain and breaks the seed head of the rice plant.

The fungus produces spores rapidly after creating lesions on leaves, nodes, panicles, etc. These lesions are elongated with pointed ends, grey centers and reddish-brown margins. The fungus penetrates the plant cuticle and rapidly fills the cell. In about 5 days, the visible manifestations occur on the leaf and stem. Conditions favorable to the spread of the disease are humidity and temperature of around 25°C. Crops suffering from drought stress are also prone to this fungal attack.

Some of the ways to control or prevent the infection are by destroying the infected crop residues, avoiding overuse of N fertilizers, early planting, proper flood management and the use of resistant varieties. Some fungicides (like pyroquilon) are effective, but their prescription differs with local conditions.

A recent breakthrough in the control of blast was carried out by the IRRI (International Rice Research Institute, Manila) and a Chinese institution, which involves planting a modern cultivar in two rows, followed by different types of improved local cultivars in the next couple of rows. Such an interspersing of cultivars has curtailed the spread of the disease to some extent.

Besides rice, this fungus affects around 50 species of grass. Controlling loss of crops is a constant challenge because newer strains emerge rapidly.

Another disease seen in rice is the **stem rot**, caused by the fungus, *Sclerotium oryzae* on circular or irregular areas in rice fields. The plant is attacked near the water line during the early reproductive stages, by causing black lesions that are rectangular with angular borders. These lesions grow in size and the fungus enters the stem, thereby weakening it. By the time the harvest comes, the infestation would have already taken its toll resulting in lodging and causing the death of the plant. Stem rot may be managed by crop rotation, varying the flood levels, using only the necessary amounts of nitrogen, etc.

Rice nutrient needs and deficiency

The rice plant needs several nutrients for its healthy growth. They are nitrogen, potassium, phosphorus, sulphur, zinc and iron. A deficiency of any of these causes a fall in yield. It is, therefore, crucial to identify the deficiency and take steps to correct it.

Nitrogen is an essential plant nutrient responsible for rapid plant growth, grain yield and quality. Since most soils are deficient in nitrogen, the need to add nitrogen is felt. Its deficiency shows up in stunted plants with small yellowish green leaves and a low yield due to fewer panicles per unit area.

It is critical to match the actual crop demand of nitrogen with a nitrogen fertilizer. Nitrogen may be applied either through inorganic or organic fertilization. Over-fertilization can attract fungal and bacterial attacks, and can cause harm to the environment.

Being highly mobile within the plant and the soil, nitrogen may be supplied through ammonium sulphate (21% N, 24% S), urea (46% N), diammonium phosphate (18% N, 45% P_2O_5), **farmyard manure**, **compost**, etc. **Azolla**, in association with anabaena, can fix nitrogen in ammoniacal form that becomes available to the plant. The legume **sesbania** (*Sesbania cannabina* and *Sesbania rostrata*) can also fix nitrogen. Both azolla and sesbania can be used as green manure. **Organic rice farming** is becoming an increasingly acceptable way of cultivating rice.

Urea-diammonium briquettes, placed deep under the plants help to provide adequate supplies of nitrogen and phosphorus to the seedlings, without allowing for nitrogen and phosphorus losses through volatilization, leaching, etc.

Potassium is required in adequate quantities along with balanced supplies of other nutrients to ensure a healthy crop response to potash fertilization. Potassium aids in the growth of the plant and the roots, prevents lodging and increases resistance to pathogen attack. Potassium is deficient in coarse-textured soils, upland soils, sandy soils, acid sulphate soils, organic soils and over-cultivated soils. Fertilizer potassium should be applied before the last soil puddling, prior to transplanting. A top dressing of potash within a fortnight of direct seeding is also recommended.

Stunted dark green plants with yellowish brown leaf margins and/or older leaves with necrotic tips and margins are indications of potassium deficiency.

Muriate of potash (MOP) with 50% K or 60% of K_2O is a commonly used source of potassium. **Rice straw** is also incorporated leading to a supply of 14.0 kg of K per ton of straw. Another supplement of potassium is azolla which contains 0.3 to 0.6% of K by dry weight.

Phosphorus is an essential plant nutrient and aids in root development, early flowering and ripening. It is mobile in the plant, but not in the soil.

Phosphorus is deficient in sandy soils (with a low organic matter content) volcanic ash soil, saline/alkaline/calcareous soil, acid upland soil and acid sulphate soils. Phosphorus availability is enhanced under anaerobic conditions.

Plant growth is stunted when phosphorus is deficient. The plant grows with erect leaves and thin stems. Deficiency can be controlled by applying all the phosphorus before the last soil puddling, prior to transplanting. It can alternatively be top dressed 10 to 15 days after direct seeding. The commonly used phosphate fertilizers are those containing P_2O_5 or its equivalents.

Sulphur is essential for chlorophyll production and is required to produce amino acids (like cystein or methionine) in plants. Sulphur mobility is high in plants (but not as much as N) but limited in the soil. Sulphur deficiency is occasional and may be seen in leached sandy soils and weathered soils rich in iron oxides.

Since sulphur limits plant growth, a deficiency is seen in the yellowing of young leaves on pale green plants. Sulphur may be supplied as ammonium sulphate (24% S), single superphosphate (12% S) and **gypsum** (17.5% S), in such a way that 10 to 40 kg of S is supplied to a hectare of a field, depending on the severity of the deficiency.

When soil is low on zinc and if conditions such as flooding are prevalent, the plant uptake of zinc suffers. Occasionally, the deficiency is seen in the form of stunted plants with dusty brown spots on the upper leaves, higher levels of empty grains and delayed maturity. Neutral and calcareous soils, peat soils, saline soils, highly weathered soils, sandy soils and old acid sulphate soils with small amounts of K, Mg and Ca are generally deficient in Zn.

To correct Zn deficiency, 10 to 25 kg of $ZnSO_4 \cdot H_2O$ or 20 to 40 kg of $ZnSO_4$ is applied per ha on the soil surface. Alternatively, roots of seedlings are dipped in a 2 to 4% ZnO suspension before planting. Soluble zinc sulphate (23 to 36% Zn) and soluble zinc chloride (48.5% Zn) are also used.

The application is done on the soil surface after last puddling and levelling in the main field, or on the nursery beds a week before seedlings are sown. In alkaline soil, zinc may be applied to each crop. Allowing the soil to dry up reduces zinc deficiency.

Iron is required for electron transport in photosynthesis. But iron is not mobile in either plant or soil. Flooded, slightly acid soils are generally not deficient in iron, but neutral, calcareous and alkaline upland soils are commonly deficient in iron.

Soil application of 100 to 300 kg ferrous sulphate per ha of soil or a foliar application of 2 to 3% ferrous sulphate solution or iron chelates can be used 2 to 3 times bi-weekly at the start of tilling the soil. Solid $FeSO_4$ may also be broadcast next to rice rows.

Deficiency symptoms are the interveinal yellowing and chlorosis of emerging leaves. Iron deficiency also causes a fall in yield and dry matter. (See also Organic rice farming; Rice.)

Rice – polycultural farming methods: See Polycultural farming methods of rice

Rice – prescriptions from the past

A revisit to ancient scriptures reveals many interesting observations, practices and prescriptions which hold good in some situations even in today's world. The following are a few highlights of such ancient wisdom.

The Indian treatise on Economics "*Arthasastra*" written in the period between 321 and 296 BC, explains how rice cultivation could be planned and fungal diseases prevented, by observing the monsoon. It documents many varieties of rice. The *Arthasastra* has documented methods of preventing fungal diseases by leaving the seeds out at night to allow them to soak in the morning dew and then exposing them to the sun for seven consecutive days and nights. This was found to be an effective method to control bacterial and fungal pathogens. This practice is common in some parts of India even today where chemical pesticides are not used. The same procedure is carried out for wheat too, to control the smut disease, and could meet the stipulated practices of modern organic rice farming.

Another major organic farming instruction to rice growers, as depicted in *Arthasastra* is the use of fish manure. The method involves release of minute fish in the flooded rice field when the seedlings start to mature, followed by the addition of *snuhi* (*Euphorbia neriifolia*) plants, some of the species of which contain ingenol-esters. This toxic compound kills the fish, releasing nitrogen, phosphorus and calcium from the fish to the crop.

Ayurveda, the ancient science of medicine which originated in India more than 4000 years ago, mentions, among various other things, rice varieties and their effects on human health. For instance, the *Raktashali* (red), *Mahashali* (large and fragrant), *Panduka* (yellowish), *Turnaka* (quick maturity) all have properties of being tasty, sticky, nourishing, semen augmenting, diuretic, and slight flatulence causing. These observations may have the potential to help scientists to formulate nutritive diets for specific, health problems.

Another innovation in organic rice cultivation is **rice farming with ducks**. A thousand year old journal in

China recommends the use of ducks in rice fields. Japan is known to have used it for over 500 years. This method could also be used in today's farming.

Rice, processed: See Processed rice

Rice straw

Rice straw is one of the two residues of the rice plant, the other being **rice hull**.

Straw is considered an important source of potassium and silica and is used as an organic nutritional supplement. It is also a good organic matter.

Rice straw is generally incorporated into the soil while plowing. In large quantities of 2 tons/hectare, rice straw can supply around 20 kg of K/ha and around 100 kg of silica/ha.

Ridge and furrow

The ridge and furrow is a tillage practice advocated in rain-fed farming areas where crops are grown on beds and the soil is worked very carefully to produce fine tilth. Though grain crops can be sown on the flat land after plowing and harrowing, a heavy rainfall causes soil erosion until the planted crops are able to cover the soil. The ridging or mounding is done as a conservation measure to prevent soil erosion and is effective when the ridges are made to collect and confine water in the furrows (Fig.R.10). The ridge and furrow practice is particularly important in low rainfall areas and on silt soils where ridges are clustered to minimize the run-off. On poorly drained soils, ridges are spaced wide apart to permit drainage.

Fig.R.10: Ridge and furrow practice is commonly used in low rainfall areas.

Depending on the agronomic requirements, three configurations are distinguished, which are (a) pointed ridges, usually 45 to 75 cm apart, (b) broad ridges, with furrows 75 to 150 cm apart, and (c) truncated ridges or graded furrows with variable furrow spacing.

Rill erosion

Erosion occurs from run-off water flowing with sufficient volume and velocity. The result is the uneven removal of the land surface, and is called rill erosion. Rills are small ditches or channels made in the soil or rock by running water. But since they are only a few centimeters deep, they offer no obstacle to tillage operations. A large rill may be too wide or deep to fill by normal cultivation, in which case it is called a **gully**. When most of the soil is transported by rills, the erosion is rill erosion and when it is done by gullies it is called **gully erosion**.

Risk optimum

Economic optimum in crop production mainly considers fertilizer cost. The rationale is that the additional yield (income), upon applying a unit of fertilizer should exceed the cost of the fertilizer. Risk optimum is a special case of economic optimum, when the price of the produce is unknown. The risks taken to achieve the optimum returns in crop production can be said to be the risk optimum. The true economic optimum is not known until after the harvest, while fertilizers must be applied at an early growth stage. To minimize the risk, the purchased inputs can be minimized or the estimated total nitrogen required can be split into several smaller applications adjusted to crop and market conditions.

River pebble phosphate

River pebble phosphate is a low grade phosphate ore and is one of the four kinds of phosphate rock. The phosphorus content of river pebble phosphate rocks vary from 2 to 21%.

RMSD

RMSD is short for **root mean square deviation**.

RNA

RNA is short for **ribonucleic acid**.

Rock phosphate

Rock phosphate is a natural mineral found as a geological deposit on a large scale in the form of sedimentary rocks containing various amounts of calcium phosphates. Once ground, it is used as a phosphatic fertilizer, called **phosphorite** or **mineral phosphate**, or as a primary source of phosphorus.

Rock phosphate deposits are found in many countries, such as the USA, Russia, Tunisia, Malaysia, Sri Lanka, Israel, Jordan, etc. India alone is estimated to have about 140 million tons of rock phosphate deposits, most of which are however, of low grade and with substantial impurities unsuitable for the production of phosphate fertilizers.

A large part of mined rock phosphate is used to manufacture single superphosphate, triple superphosphate, tri-calcium phosphate and calcium metaphosphate. Finely ground rock phosphate can be applied directly to the soil if it is strongly acidic, as it has a high humus content. It is, however, not recommended for neutral or alkaline soils where acid-treated rock phosphate (like superphosphate) is used. The material should optimally be in the mesh size of 60 to 100.

Powdered rock phosphate is free-flowing and is easily amenable to handling and storage. Crops like rubber, tea, coffee, apples and fruit plantations of oranges are suitable for direct application of rock phosphate.

The most predominant mineral of phosphate is **francolite** which is **calcium carbonate-fluorapatite** of formula $[Ca_5(PO_4,CO_3)_3(F,OH)]$. Four kinds of phosphate rocks are recognized: **hard rock phosphate**, **soft rock phosphate**, **land pebble phosphate** and **river pebble phosphate**, with the phosphorus content varying from 2 to 21%.

Most of the phosphorus in the phosphate rock is in an apatite form. There is, therefore, no water-soluble phosphorus. The citrate solubility can vary from 5 to 17% of the total phosphorus, depending on the chemical nature of the rock and the size to which it is ground. The efficiency of the ground rock phosphate can be increased by (a) mixing rock phosphate with soluble phosphorus and fertilizers, (b) mixing rock phosphate with elemental sulphur or sulphur-producing compounds, and (c) using phosphate solubilizing micro-organisms.

Over 90% of the rock phosphate production, starting with high-grade rock phosphate without impurities, is used in acidulating factories to produce superphosphate and phosphoric acid. Less than 8% of rock phosphate is used directly as soil fertilizer and about 2% as animal and poultry feed.

Rock phosphate-coated urea

Rock phosphate-coated urea, containing 36% nitrogen and 5% phosphorus (as P_2O_5) gives a range of products with the capability for slow release of nitrogen into the soil. This type of urea, which contains 80% urea, 15% rock phosphate and 5% oil, dissolves about 5% in one day, around 27% in 7 days and the rest in 25 to 30 days in soil water.

Rock phosphate-coated urea costs 10 to 15% more than prilled urea.

Rock wool

Rock wool is used as a potting medium and is produced by spinning volcanic basalt rock in blast furnaces. (See also Growth media, plants.)

Rogues

Rogues or **off-type plants** are undesirable plants growing in a field of morphologically uniform plants. They are removed to ensure the production of a high quality and uniform pedigree seed. Removing rogues is called roguing.

Rogues arise due to genetic changes within cultivars from inter-crossing or mechanical mixtures. Roguing is required both in the field of parental seed production and in the seeds for commercial hybrid use. The removal of off-type plants in both the male and female parental rows is desirable to maintain genetic purity.

Roguing involves removal of the entire plant, (especially when the plants are small) to prevent secondary tillers from arising. A source of inoculum and the subsequent disease spread may be reduced by roguing infected plants before they release their spores in the seed fields.

The beauty of all hybrid seed production lies in the high purity seed achieved by careful roguing, harvesting, seed conditioning and selection, and isolation of the field. In this, the seed grower's responsibility is to ensure removal of all off-type plants in the seed field before they produce the pollen. In wheat sown in conventional narrow rows, roguing is less practical; however, roguing is essential for male-fertile plants in a male sterile parent.

Root

Root, which is a part of every plant, grows mostly beneath the soil surface. It anchors the plant in the soil and absorbs water and mineral salts or nutrients.

Roots also serve the purpose in the synthesis of growth substances, in partitioning and redistributing the stored photosynthate and as a site for the nitrate reductase activity in some species. Water and nutrients enter the root through minute root hairs at the tip of each root. Roots need oxygen to function and plants growing in swamps have special provisions to supply it, like in the case of aerial roots of mangroves.

The **radicle** (embryonic root, Fig.R.11) may give rise either to a tap root system with a simple main root from which lateral roots develop, or a fibrous root system with many roots of equal size (Fig.R.12). The longest roots are usually as long as the height of the tree but the majority of roots are only a few feet long.

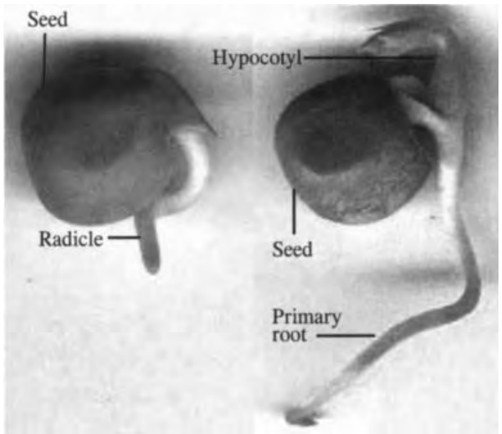

Fig.R.11: Primary root radicle developed from a seed during germination.

The apical meristem at the root tip gives rise to a protective sheath, root cap and primary root tissues. The vascular tissues usually form the central core which distinguishes the roots from the stems wherein the vascular tissue often forms a ring. The **root hairs** develop just behind the root tip from the epidermis and generally increase the surface area of the roots to facilitate the absorption of water and minerals. Beyond the root hairs, lateral roots develop. In a typical cereal crop, roots constitute 30 to 50% of the total plant mass, whereas in a forest their mass would be several times larger.

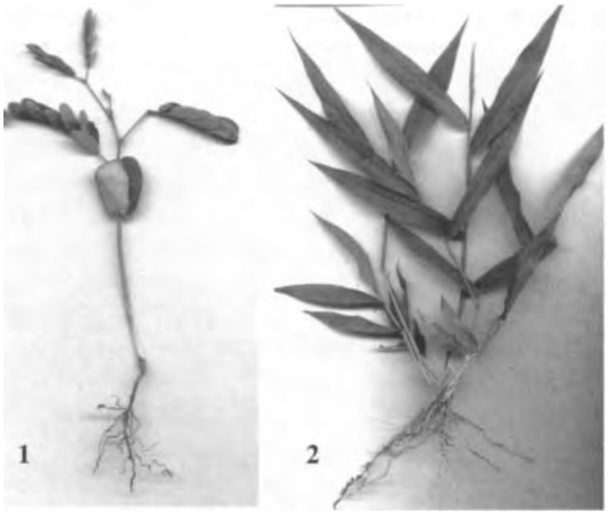

Fig.R.12: Types of roots. 1. Tap root system in Jacaranda mimisifolia. 2. Fibrous root system in a grass variety.

Sometimes, roots are modified as a defense mechanism. For example, carrots are swollen with food to survive the winter. Orchids have absorptive aerial roots that absorb moisture from the air while plants such as ivy have short clasping roots for climbing. The roots of leguminous plants like beans and peas contain root nodules for nitrogen fixation. The roots of parasitic plants, such as mistletoe and dodder, absorb food from other plants. The other modifications supporting the plant include prop roots, stilt roots and buttress roots.

Two sets of roots normally support the growth of cereal plants. **Seminal**, **primary** or **seedling roots** are produced from the seed at germination. The central permanent or **adventitious roots** arise from crown internodes just below the surface of the soil (Fig.R.13). The same crown internodes are also the place of origin of the shoots as well as of the above-ground parts. The growth of roots contributes to the development of the granular structure in topsoils. The granular structure of soil probably results from several processes involving root penetration, addition of organic matter from the root cap, soil compression, root exudates, production of gums by microbes and desiccation of the soil as the root absorbs water.

Seeding depth can influence the depth of the seminal roots rising from the seed. Seeding should not be so deep that the primary shoot or plumule cannot emerge. Deep seeding does not increase the depth of the secondary, coronal or adventitious root system. Seminal roots are often regarded as serving the plant until the adventitious or secondary roots are established. In wheat, seminal roots support the main stem of the plant and may function till the plant matures. In corn, seminal roots degenerate six weeks after germination. Adventitious or coronal roots initially tend to grow horizontally before turning downward. Inter row cultivation may cut these developing roots, reduce the uptake of the nutrient and water and lower the yield.

Fig.R.13: Adventitious roots of banyan tree.

The majority of the root system in cereal crops consists of fine fibrous roots which retain the same diameter throughout their length. In corn, the adventitious roots arise from the internodes - also known as **brace** or **anchor roots** - and hold the plant in an upright position.

Two major types of root systems are found in flowering plants - **taproots** and **fibrous roots**. Taproots have one large main root with small lateral or branch roots. Taproots can be enlarged for storage, as in carrots, turnips and beets. Fibrous roots are highly branched and lack a central main root.

Root cap is a cone-shaped structure that covers the root tip (like a cap) and develops as a result of cell division by a meristem at the root apex. It protects the root tip as it grows through the soil particles. The cells are constantly worn out by friction and are replaced by meristems. They enable the roots to penetrate the soil without injury to the growing plant.

Plant roots push out such substances as organic acids, sugars and soluble plant components into the soil, which are called **root exudates**. These are important in enhancing microbial activity in the rhizosphere. Exudation is affected by plant species, environmental conditions and foliar sprays. Root exudates help in disease resistance, spore germination and nutrient dissolution for easy absorbance by plants. Root exudates, also called **root mucilage**, consist of 99.9% water, with a water potential of about –7 kPa. It helps in returning moisture into the soil around the roots. Agricultural soils which generally remain deficient in water become moist because of the root mucilage. A clay-mucilage combination is observed to hold more moisture than clay alone.

The number or the length of the roots within a given soil volume divided by the soil volume is called the **root density**. Root systems differ in total length, depth of penetration, lateral spread and root density. They also differ in form, thickness, degree of branching and development of mycorrhizae as well as in their growth rate and persistence.

The arrangement of roots in the space within the soil, especially the vertical root density profile, is termed the **root distribution**. A young or small root is known as the **rootlet**.

The root also hosts bacteria, fungi and other micro-organisms that live in its cortex. Some of these are harmless, others are parasitic and still others are symbiotic with the plant, helping it to acquire nutrients. Overall, the root and rhizhosphere environments support much of the soil's total microbial and biochemical activity.

Root cap: See Root

Root crops

Root crops, also called roots, are some biennial plants. They develop swollen edible roots as food reserves, commonly in the form of sugar (Fig.R.14). Mangle, turnip, swede and fodder beet are examples of root crops.

Root crops (such as sugar beet and carrot) are grown mainly as cash crops. The 'tops' or foliage of root crops (except for carrots and mangles) are valuable fodder for farm animals like sheep and pigs. Root crops are often grown in rotation, or between cereal crops.

Fig.R.14: Carrot and beet are examples of root crops.

Root density: See Root

Root distribution: See Root

Root exudates

The substances that are pushed out by the plant roots into the rhizosphere are called root exudates. Exudates or **root mucilage** include organic acids, sugars and soluble plant components. (See also Rhizosphere; Root.)

Root hairs

The small thread-like extensions or growth from the roots of a plant are called root hairs (Fig.R.15). These single cells at the root surface with thin walls and large surface area are required for the absorption of nutrients and water from the soil. Ions (like H^+) attached to the surface of the root hairs are exchanged with those on the surface of the clays and organic matter in soils.

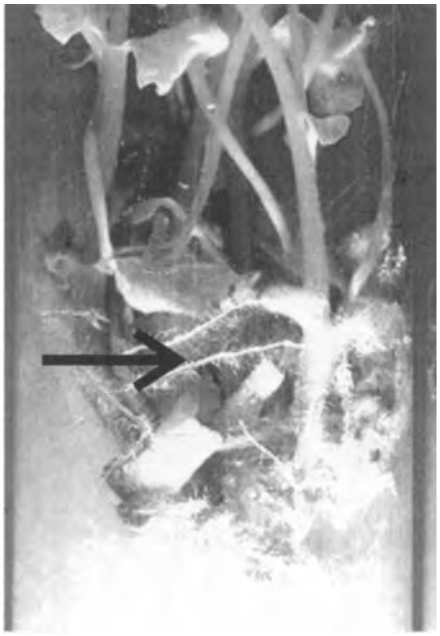

Fig.R.15: Root hairs (indicated by arrow) of Mentha arvensis grown in an artificial medium.

The ability of the roots to absorb nutrients and water from the soil depends on their morphological and physiological characteristics, such as the root radius, root length, root hair, root density and the ratio of the root surface to shoot weight.

Root interception

Root interception is one of the mechanisms for nutrient absorption in plants. The growing roots push the soil particles aside and come in direct contact with nutrients. Nutrient absorption by the roots depends on their morphology, volume in the soil and nutrient concentration in the soil void volume. Root interception, which accounts for about 1% or less of the nutrients absorbed, can be enhanced by mycorrhizae especially when the plants are growing in infertile soil.

The root surface available for ion absorption is a function of the surface area. Root density varies with soil properties, species and management practices. On average, the soil volume occupied by the roots of food crops is around 0.7 to 0.9%. The only nutrient which can be supplied completely by interception is calcium, although the process may provide a significant part of the requirement of Mg, Zn and Mn.

Rootlet

A young or small root is known as a rootlet.

Root mean square deviation

Root mean square deviation (RSMD) is the square of the mean of the sum of the squares of the differences between the values and the mean of the values. RMSD is of particular importance in situations falling in normal distribution curves. The minimum value of the root mean square deviation occurs when the origin coincides with the arithmetic mean, when it is called **standard deviation**.

Root morphology

Root morphology is the study of the form, shape and structure of roots. Most roots have similar structure, although the sizes vary. The root structure of crop plants includes root hairs, epidermis, cortex, endodermis and stele (Fig.R.16). Stele contains pericycle, xylem, phloem and pith (when present). Ions absorbed by root hairs move through the epidermis, cortex, endodermis, pericycle, and finally come to the xylem, and in turn, translocate to the shoot. The phloem supplies photosynthate from the shoot to the root.

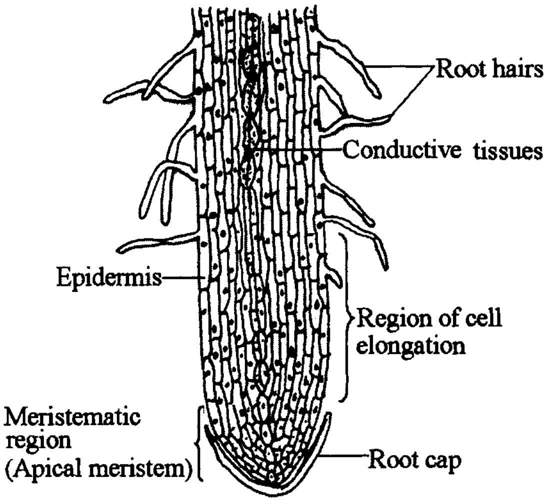

Fig.R.16: Structure of root.

The solute moves to the stele (across the cortex) in two parallel pathways: one passing through the extra cellular space or **apoplast** (cell wall and inter cellular spaces) and the other passing from cell to cell in the **symplast** through the plasmodesmata, which bypasses the vacuoles.

Root mucilage

Root mucilage is another term for **root exudates**. (See also Root.)

Root nodules

Root nodules are tumor-like swellings on the roots of certain plants. Symbiotic bacteria (such as rhizobia and actinomycetes) form nodules on plant roots. Nodules are sites for nitrogen fixation. The bacteria first infect the root hairs and then through several cells, form a covering on the root. (Fig.R.17). The number of covering cells increases rapidly. Bacteria enter the nodule cells and form enclosing membranes to produce the oxygen-carrying pigment, called **leghemoglobin**. For actual fixation of nitrogen an anaerobic condition is required, which the hemoglobin helps to create. Rhizobia infect only the family Leguminosae (like beans, clover, peas, lucerne), whereas actinomycetes infect at least seven different botanical families, such as Betulaceae, Myricaceae and Elaegnaceae. The mere presence of nodules on the roots does not necessarily indicate nitrogen fixation. Some mature nodules are large, elongated, often clustered on the roots and have pink centers (**effective nodules for nitrogen fixation**); the pink color is due to leghemoglobin indicating the occurrence of nitrogen fixation. There is a large number of **ineffective nodules** which may have white or pale green centers. Root nodules are scattered over the entire root system.

Fig.R.17: Nodules on soybean roots.

Root stocks

A plant on to which another variety is grafted is a root stock. Stem cuttings or buds from a desirable cultivar are joined (grafted) to the base of another tree (Fig.R.18). The cutting (or bud), called the **scion**, becomes the upper portion of the new tree, while the root stock or stock of the second tree becomes the root system of the graft combination. Grafting can create thousands of identical copies of a variety which will continue to produce yields with desired characteristics.

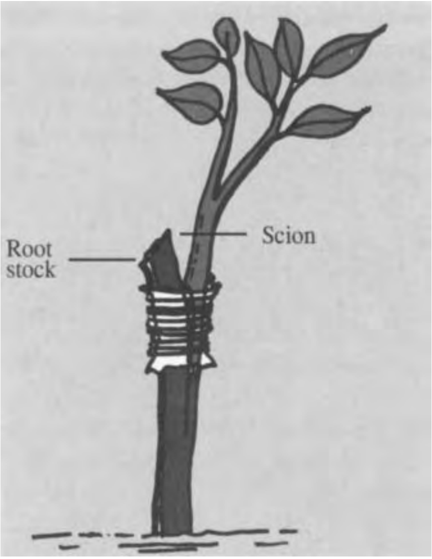

Fig.R.18: Root stocks are used in grafting for producing new trees, as in the case of apples.

Root succulents

Root succulents are modified roots which develop over a period of time to survive in unfavorable conditions. Such plants are **xerophytes** or dry land plants. They have a large, underground water storage organ with short-lived stems and leaves appearing above the ground. Examples of such roots are *Oxalis* sp.

Root sucker

The root sucker is a shoot coming from the root of a plant. Synthetic growth regulators, like indoleacetic acid and indolebutyric acid, are commonly used to induce rooting of the plant. The **sucker** is a young plantlet which grows from the basal nodes of another plant of the same species like banana and tobacco. It has root initials and can establish easily as an independent plant when detached and replanted.

Root vegetables

Root vegetable crops, which include carrot, beetroot and Jerusalem artichoke, are classified based on the specific parts of the plant. They have small seeds but are planted directly because transplanting adversely affects the quality of the roots. (See also Horticulture.)

Root zone

The volume of the soil in which active roots grow during the life of a crop is known as the root zone. It is generally 50 to100 cm deep, depending on the crop and soil type, and is also known as the **soil water belt**.

Crops differ a great deal insofar as the development of their root system is concerned. A single crop shows variations in the number of roots developed, depending on the environment and differences in their genetic makeup. As some nutrient elements do not move very far in the soil, the extent of the root system determines whether the plant acquires enough of these vital nutrients. If the root growth is shallow, plants may show deficiency symptoms despite a good supply of nutrients in the soil. It is a good practice to examine if any deficiency symptom in the roots is due to restricted root growth. Dry surface conditions may also limit nutrient uptake even if most nutrients are available in that zone; this condition is called **positional unavailability**.

Rope wick

Rope wick is an applicator for herbicides in which the herbicide in solution moves by capillary action to an applying surface (commonly a rope or fabric) where it is wiped into the weed cleaves.

RoP process for partially acidulated phosphate rock

RoP (short for **run-off pile**) process for **partially acidulated phosphate rock (PAPR)** involves treating of phosphate rock with a portion of stoichiometric quantity of the acid to increase the water soluble phosphorus in the fertilizer.

ROP-TSP

ROP is short for **run-off pile triple superphosphate (TSP)**

Rosette: See Rosetting

Rosetting

Rosette is a rose-like cluster of plant parts (e.g., the leaves of a plant) or markings which resemble a rose.

Rosetting refers to a severe reduction of internodes in the vertical axis of leaves without proportionate reduction in the size of leaves. It is a kind of stunting and is difficult to detect unless normal plants exist nearby for comparison. Nutrient deficiencies of zinc (in apples and pecans) and copper may cause rosetting.

Rotap

Rotap is a rotary type sieving apparatus designed by W. S. Tyler to determine the percentage of various particle sizes in a powder.

Sieves of various pore sizes are placed in a vertical column and arranged on the rotary sieve shaker in a descending order, the biggest pore size being kept at the top and the smallest pore size at the bottom. The bottom sieve is fitted with a pan. A soil sample (~ 50 g for a sieve of 20 cm diameter) is kept on the top sieve, which is covered with a pan and the whole stack of sieves is fitted on a rotary sieve shaker, and bolted. The entire assembly is vibrated by an electric motor for about 20 minutes, causing both circular and tapping motion. The important feature of rotap is that both speed and stroke are fixed and not adjustable. The rotap is equipped to handle 1 to 13 sieves at a time and equipped with a timer to terminate automatically after a predetermined time. The samples from various sieves are collected and weighed.

Rotary drum-type method for determination of abrasion resistance

Fertilizer granules, with unique characteristics like porosity, shape, crystal surface, moisture content, chemical composition and method of production, should be strong enough to withstand handling and storage conditions. The granules should ideally have a high resistance to crushing and impact. **Abrasion resistance of a granule** is the resistance to formatting dust, fines and fractures.

The rotary drum-type method measures the percent dust and fines created by subjecting a sample to abrasive action (Fig.R.19). A pre-screened sample is weighed and placed in a drum with an abrading medium. The drum is rotated at a specified speed for a predetermined period. After separating the abrading medium, the sample is mechanically sieved to separate the dust, fines and fractured granules.

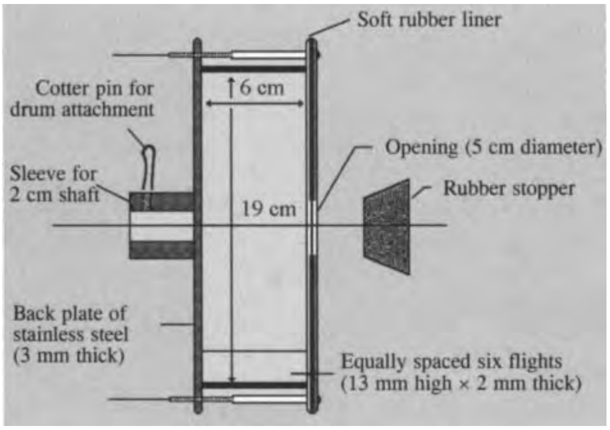

Fig.R.19: Cross-sectional view of a rotary drum used in abrasion resistance test.

Rotary shaker in biofertilizer production

A rotary shaker gives a circular motion with adjustable speed to the flasks it holds (Fig.R.20). Biofertilizer production uses rotary-shakers as the culture flasks need to be agitated for aeration. The number of flasks can be more than 100 in large rotary shakers. Double-decked shakers are also available.

Fig.R.20: A doubled-decked rotary shaker.

Rotation of crop

Rotation refers to the practice of growing different crops on the same land in a regular, recurring sequence. The most important reason for this practice is to hinder weeds, nematodes, soil-borne pathogens and other pests from reaching and damaging population levels. (See also Crop rotation.)

Rotten neck

Rotten neck is another name for **leaf blast in rice**. (See also Rice, major diseases of.)

Rotting

Rotting is the decomposition of organic matter by the chemical action of bacteria or fungi. Besides natural rotting, the soaking of fibrous plant material (like jute, flax hemp or coconut husk) in water, to facilitate the separation of fibers from the stalk, amounts to man-made rotting. These cut plants are allowed to rot in slow-moving or standing water for 10 to 12 days at 30 to 35°C. The fiber is then hand-separated from the main stem, washed and dried, yielding 1.0 to 1.8 ton per hectare of processed and dried fibers. By weight, 5% of freshly harvested stalks are dry fiber.

Rough rice

Rice grain, enclosed in the hull consisting of the lemma and palea, is called rough rice or **paddy**. It varies in size, shape, color and length of awn on the lemma.

Roundworm: See Nematodes; Nemagation

Row crops

Row crops are crops planted or sown in rows of uniform spacing throughout the field, facilitating any other cultivation between the rows for weed control. Root crops, potato and cabbage belong to the category of row crops for which the width of the row is about a meter. This width was established on the basis of space needed for a draft horse to pull scuffles or a cultivator to pass through without damaging the plants.

Row placement

Row placement is one of the two types of band placements, of fertilizers, the other being the **hill placement**. In row placement, fertilizers are applied on one or both sides of the row. This is suitable for sugar cane, potato, maize, tobacco, cotton, cereals and vegetables. More applications are possible with row placement than with hill placement.

RSC

RSC is short for **residual sodium carbonate**.

RSD

RSD is short for **relative standard deviation**.

Rubber

Rubber is a naturally occurring elastic substance. It is found in the latex of many plant species belonging to about 311 genera. Rubber quickly restores itself to its original size after it has been stretched or compressed. The yield or stretch of the vulcanized material ranges from a few hundred to over 1000 percent.

Natural rubber is obtained from many plants and commercially from *Havea brasiliensis*, a tree native to Brazil. The tree is now grown in the tropical regions of Asia, Africa and America. *Havea* is propagated through seeds and by adopting vegetative methods. Planting is done in specially prepared nursery beds. The soil is dug up and mixed with fertilizers. The germinated seeds are planted with a spacing of 30 cm × 30 cm. The seedlings are grown in the nursery till they attain a diameter of 20 to 25 mm above the collar.

The seedlings are usually transplanted in June-July into pits made in the field about 4.5 m apart to accommodate a stand of about 500 plants per hectare. Sometimes the seeds are sown *in situ* in the fields.

Rubber trees should be regularly manured with balanced fertilizer mixtures from the time of planting to the age of economic production for ensuring maximum production. The recommended dose varies according to the age of the plant. During the first year of planting, a single dose of 225 g of a 10:10:4:1.5 NPKMg mixture is applied to each plant. The dosage increases to 900 g and 100 g in two split doses during the second and third years respectively. From the fourth year till the plants in the area become ready for tapping, the application of 900 g of the mixture per plant in two split doses, one in April-May and the other in September-October is recommended. For trees under tapping, an NPK 10:10:10 mixture at the rate of 900 g per tree is applied annually during April-May.

Latex is obtained from the bark of the rubber tree by tapping. Tapping is a process of controlled wounding, during which thin shavings of the bark are removed to induce the flow of latex. Normally a rubber tree can be tapped economically for 25 to 30 years. A slanted cut is made in the bark and the milky fluid latex, occurring in the inner bark, is tapped off. The latex, an aqueous colloid of rubber and other particles, is coagulated with dilute acid and creped or sheeted and smoked. Natural rubber is a polymer of isoprene. Its elasticity is due to the chains being randomly coiled but tending to straighten when the rubber is stretched.

Though known since the sixth century, it was only after Goodyear invented the process of vulcanization that its use became very popular. Synthetic rubbers, especially those produced since World Wars I and II, are long chain polymers and elastomers belonging to copolymers of the type of butadiene/styrene, butadiene/nitrile, ethylene/propylene, polymers of chloroprene (neoprene rubber), butadiene, isobutylene, silicones, polyurethanes, polysulphide rubber and chlorosulphonated polyethylenes. Some latexes (both synthetic and natural) are used as adhesives and for making rubber coatings, rubber thread and foam rubber. Most, however, are coagulated and the rubber is treated with vulcanization and other reinforcing agents including antioxidants and fillers before being used in tyres, shoes, rainwear, belts, insulation and many other applications.

Run-off

On a sloping terrain, rainwater can run-off, or can flow down the slope of the soil surface. Water loss caused by the run-off, especially when the rainfall is heavy, is due to the low water-absorbing capacity of the soil and the absence of vegetation (Fig.R.21). Field studies show that early maturing *kharif* crops can substantially reduce run-off. *Kharif* crops, now finding favor with cultivators, include green gram, black gram and maize, followed by safflower and wheat.

There is a threshold level of precipitation, beyond which run-off is produced. Below the threshold level, the precipitation may simply evaporate or seep in the soil. Techniques are available to improve the **run-off efficiency**, defined as the yield expressed in percent of the total precipitation on the catchment. The improvement in percentage is achieved by covering the catchment surface with silicone compounds, concrete, aluminum foil, butyl rubber sheet, plastic sheet, paraffin wax, asphalt, polyvinyl fluoride, etc. The choice of the material depends on considerations of costs, durability, etc. For example, plastics are susceptible to damage by wind, sunlight, livestock and pests. Soil grading and compaction is a simple and inexpensive method to improve the run-off which causes soil erosion. The longer and greater the slope, greater is the velocity and erosive power of the run-off.

The **run-off rate**, in the case of soil erosion, can be calculated from the equation:

Fig.R.21: Run-off of water down the slope due to heavy rainfall erodes the soil.

$$Q = \frac{CIA}{360}$$

where Q is the run-off rate in m^3/sec, C is the run-off coefficient, I is the rainfall intensity in mm/ha and A is the catchment area in hectares.

The ratio of the volume of run-off in a watershed area during rains to the volume of rains received during that period is known as the **run-off coefficient**.

Surface run-off is the water that runs over the soil surface to reach the nearest stream channel. Rainfall is one of the important climatic factors for surface run-off and soil erosion. The application of some highly-soluble nitrogenous fertilizers, especially urea and nitrate, may be lost by surface run-off. Losses may be greater from ammonium nitrate (5% of the applied nitrogen) than from urea (1 to 3%).

One way of minimizing the run-off is a careful and rational management of crop residues. The land surface receives water either from rain or from surrounding upland areas. The downward movement of excess water through the soil profile is not easy in the case of impermeable soils. If the run-off is in thin sheets, it is called sheet flow and the erosion it produces is **sheet erosion**. If the raindrops fall on the soil speedily, the soil aggregates are splashed away. This erosion is called **splash erosion**.

Sometimes, excess water is applied to a field during irrigation, and surface drainage ditches are used to dispose of the excess water.

Run-off coefficient: See Run-off

Run-off efficiency: See Run-off

Run-off pile products

Products that are taken from the production piles without consideration toward the particle size are known as run-off pile products. Hence, such products consist of particles of many different sizes, i.e., from very fine powders to coarse, pebble-like particles. The coarse particles are friable and hand-crushable. Typical examples of fertilizers sold as run-off pile materials are some forms of single superphosphate and monoammonium phosphate.

Run-off-pile TSP: See Triple superphosphate production processes

Run-off rate: See Run-off

Rural compost

Diverse organic materials generally obtained from rural areas are cattle dung, cattle urine, crop residues or farm wastes (such as weeds, straw, chaff, leaves, sugar cane waste, groundnut husks, etc). Compost produced by partial fermentation of these materials is termed rural compost. The addition of 40 to 50 kg per ton of calcium nitrate to the above mentioned material promotes rapid compost formation and organic matter decomposition. The average nutrient content varies from 0.5% to 1.0% for nitrogen, around 0.2% for phosphorus and 0.5% for potassium.

Rust diseases, wheat: See Wheat

The Fertilizer Encyclopedia
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Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

S

Sacrificial protection

Sacrificial protection is the preferential corrosion of a metal coating for the sake of protecting the substrate metal. For example, when zinc is in contact with a more noble (less reactive) metal in the electromotive series, such as steel, a galvanic cell is created in which electric current flows in the presence of an electrolyte. Atmospherically contaminated moisture constitutes the electrolyte. Under these conditions, the zinc coating, rather than the steel is affected. Thus, galvanic protection is sometimes called sacrificial protection.

Preventive methods of corrosion include applying a protective layer of paint, varnish or electroplating. The use of zinc or aluminum during galvanizing works on this principle. (See also Cathodic protection.)

SAI process for non-granular monoammonium phosphate: See Scottish agricultural industries process for non-granular monoammonium phosphate

Salic horizon

A mineral horizon formed by the accumulation of the salts of sodium, calcium or magnesium which are soluble in cold water, is called the salic horizon. These diagnostic subsurface horizons are usually found in arid and semi-arid climates. A salic horizon is 15 cm thick (or more) and contains at least 2% salts. A salic horizon does not favor plant growth.

Saline alkali soil

An alkaline soil containing harmful soluble salts as well as exchangeable sodium, in such quantities as to hinder plant growth is called saline alkali soil. Saline alkali soils are identified as having an exchangeable sodium percentage of more than 15, an electrical conductivity of the saturation extract more than 4 dS/meter (at about 25°C) and a pH of around 8. Saline soils are a result of two processes of **salinization** and **alkalization**.

Soluble salts indicate the salt content in the soil solution. A high degree of exchangeable sodium indicates high amounts of sodium, making the soil sodic in nature. Thus, these soils are also known as **saline sodic soils**. A high content of both salt and sodium keeps the humus soil particles flocculated and immobile.

Reclaiming such soils is more difficult than reclaiming **saline soils** mainly because the treatment of the exchangeable sodium can be undertaken only after other soluble salts are leached. In fact, leaching may lead to Na being hydrolyzed, and in turn, an increase in pH.

Saline alkali soils are variously called **white alkali** (if soluble salts are in large proportion) because of the color of the salts, and **black alkali** (if Na salts are higher in proportion than other soluble salts) because of the color of the dispensed humus.

Saline seep

Saline seep is a process in which salt accumulates when water moves through a soil. Seep develops when the percolating water reaches an impermeable dense clay, moves laterally down the slope and rises to the surface by capillary action. The evaporating surface water leaves behind salts and renders the soil non-productive. To reduce salt seepage, deep-rooted crops are used in rotation (with minimum summer fallow) and intensive cropping is undertaken so that soil water in the seeps is used up. Deep-rooted alfalfa on 80% of recharge areas hinders seep formation owing to inadequate water.

The development of saline seep is due, among other things, to frequent fallowing during periods of above-normal rainfall on sandy soils that have a low water retention capacity. Any practice that increases water infiltration (such as constructing ponds to collect run-off water) increases saline seep.

Saline seep can be controlled by restricting the amount of stagnated surplus water. The following practices control saline seep: (a) reduction of fallowing frequency, (b) increased use of fertilizers, and (c) growth of deep rooted perennial crops (such as alfalfa) to remove soil water. Additionally, when alfalfa grows and dries out the soil, wheat plantation may be initiated.

Saline sodic soil: See Saline alkali soils

Saline soil: See Salinity

Saline water

Depending on its salt content and ionic composition, irrigation water can be **good quality water**, **marginal quality water**, saline water or **sodic water**. The total salt content (g/l or ppm) or the electrical conductivity (dS/m) may give a general indication of the water quality (the conductivity dS is given in deciSiemens and m is meter).

Saline water has electrical conductivity of >4 dS/m, sodium adsorption ratio of <10, and no residual sodium carbonate content. Whether a specific lot of water is usable by the plants or not depends on the extent of plant growth, the amount of leaching permitted during irrigation and the extent to which the soil is allowed to dry before the next round of irrigation. A high sodium concentration in water is undesirable since sodium adsorbs onto the soil cation exchange site, causing soil aggregates to break into smaller pieces, soil pores to seal and soil to become impermeable. The salts affect plants by increasing the osmotic pressure of water, making the plant exert more energy to absorb the soil water. Salt concentration of even less than one percent (by weight) can affect plant growth.

Crops are broadly divided, according to their tolerance to salinity into different categories. Table-S.1 shows the expected yield decrement for certain crops due to salinity of irrigation water when surface irrigation method is used.

Table-S.1: Salt tolerance values of selected crops, grasses and trees.

Crop	Salt tolerance threshold (dS/m)	50% yield (dS/m)
Sensitive		
Alfalfa	2.0	8.8
Beet, red	4.0	9.6
Berseem	1.5	10.3
Corn	1.7	5.9
Cowpea	1.3	4.9
Date palm	4.0	17.9
Lettuce	1.3	5.2
Onion	1.2	4.3
Peanut	3.2	4.9
Rice	3.0	7.2
Sesbania	2.3	9.4
Spinach	2.0	8.6
Sugar cane	1.7	9.8
Tomato	2.5	7.6
Tolerant		
Asparagus	4.1	29.0
Bermuda grass	6.9	14.7
Cotton	7.7	17.0
Sorghum	6.8	15.0
Soybean	5.0	7.5
Squash	4.7	9.9
Sugar beet	7.0	15.0
Wheat	6.0	13.0
Very tolerant		
Barley	8.0	18.0
Guayule	15	19

(Source: Ayers and Westcot, 1985. Adapted with permission from "Soil Salinity and Water Quality", 1996, by R. Chhabra. Oxford and IBH Publishing Co. Pvt. Ltd.)

Sensitive crops require irrigation water with electrical conductivity (EC_w) less than 0.7 dS/m. Relatively tolerant crops withstand up to 3 dS/m. Water with EC_w higher than 3 dS/m should not be used for irrigation, except with appropriate amendment.

Salinity

A saline solution is a liquid impregnated with, or containing salt(s). Salinity of saturated soil extracts is determined by its electrical conductivity (EC), expressed as deciSimens per meter (dS/m).

Soils containing large quantities of soluble salts and exchangeable sodium that interfere with the growth of most crop plants are known as **saline sodic soil**.

Saline soil is a soil, the saturation water extract of which has an electrical conductivity of more than 4 dS/meter and an exchangeable sodium concentration less than 15% (or sodium adsorption ratio less than 13).

Salinity and **sodicity** of soils are two unfavorable conditions for plant growth. Correct identification of the problem is necessary for its correct reclamation. Saline soil is a non-sodic soil containing many soluble salts (that may not be tolerated by plants) and having an EC < 4 dS/m.

Dominant ions under saline conditions are calcium (Ca^{++}), magnesium (Mg^{++}), chloride (Cl^-), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). A high salt concentration in soils increases the water-holding capacity of the soil particles. This makes it increasingly difficult for plants to use the water. Another feature of salinity is the toxicity of one or more ions of the salt. Plants suffering from salt damage may show leaf scorching, indicating toxicity of sodium or chloride; leaves may become yellow prematurely, wither and drop. Often, such plants look dull and dark and grow stunted.

Salt affected soils are classified according to the soluble salt concentration in the extracted soil solution and the percent exchangeable sodium. The limiting line between a saline soil and a non-saline one is at 4 dS/m electrical conductivity for water extracts from a saturated soil paste. This EC limit has recently been reduced to 2 dS/m.

Saline soils contain salts which are much more soluble than calcium sulphate. They tend to be sodic because of the presence of excess sodium salts (over other salts). However, all saline soils are not sodic if they also contain calcium, magnesium and other salts. When water evaporates, the soil salt solution becomes highly concentrated. This is seen in semi-arid basins with limited drainage, where irrigation often adds more salt than it removes.

Saline soils are relatively easier to reclaim for crop production, if adequate amounts of water with low salt is available, internal and surface drainage are feasible, and salt disposal areas are available.

Salinization

The process of enrichment of soil with soluble salts such as chlorides, sulphates and carbonates of Na, Ca and Mg is known as salinization, which takes place in semi-arid and arid regions, and in coastal and low-lying areas where clay content is high and low permeability reduces leaching.

Sulphides and chlorides are among dominant salts, whereas nitrates and borates are not very common in salinization. Salty water, blown inland from the ocean accumulates in the landscape depressions and renders the soil unproductive. Salinization is controlled by applying water in excess of the crop need.

Salinization dominated by sodium is known as **alkalization** which leads to the collapse of soil structure and soil compaction, and raises the pH above 8. The application of gypsum or calcium salts, followed by leaching, reduces the effect of salinization.

Salt affected soil

A soil that contains soluble salts or exchangeable sodium or both, is considered salt-affected. Such soils occupy an estimated 952 million hectares, which is about 7% of the world's land area. Due to salinization, 1.25 million hectares of irrigated land becomes unproductive every year.

Salt affected soils adversely affect the growth of most crops. Salts hinder plant growth due to the toxicity of most of them, making plants exert more energy to absorb organic solutes. Soluble salts make it difficult for plants to absorb water from saline soils. The high exchangeable percentage of sodium in the soil (over 15% sodic soil) disperses the clay and humus and makes the soil slowly permeable (or impermeable) to water. In addition, excess sodium is toxic to plants especially when calcium concentration is low.

Rainfall on permeable soils removes soluble salts by leaching, which is why most salty soils occur in arid regions or in poorly drained soils of sub-humid regions.

Salted soils are classified on the basis of (a) the total soluble salt content, and (b) the **exchangeable sodium percentage (ESP)** or sodium adsorption ratio (SAR). Exchangeable sodium percentage of the soil is the percent exchangeable sodium among the total soil exchangeable cations of all types in the soil samples. **Sodium adsorption ratio (SAR)** is an estimate of the exchangeable sodium percentage of soil or what it becomes, if the sampled soil water remains in that soil for a long time.

By using the concept of electrical conductivity (EC), total soluble salts in the soil sample are estimated. A weighed soil sample is converted into a saturated paste with a known quantity of liquid, and the conductivity of the liquid is measured in deciSiemens (dS). Normal and sodic soils have an EC of less than 4 dS/m, whereas saline and saline sodic soils have an EC of more than 4dS/m. As far as the sodium adsorption ratio is concerned, normal and saline soils have an SAR of less than 13, whereas sodic and saline sodic have an SAR of more than 13.

Reclaiming salt-affected soils involves drainage, replacing excessive exchangeable sodium and leaching out soluble salts. The experience in Punjab (India) has shown that it is possible to reclaim salt-affected soils by the scientific management of soil, water and crop. Plants that readily accumulate common salt ions are called **halophytes**, and are commonly found in deserts and shorelines. They protect saline lands from erosion and feed wildlife. Crops with a degree of halophyte behavior include beet, date palm, jojoba and barley. However, most crop plants accumulate organic solutes and regulate their osmotic potential. (See also Salinity.)

Saltation

Saltation, the most important form of wind movement, is the lifting and bouncing of soil particles (of about 0.1 to 0.5 mm in diameter) making them rise into the air (about 20 to 30 cm) and fall back to the ground around 100 cm away. This lifting effect is caused by wind blowing close to the surface. When the soil bounces back, it loosens nearby particles, and the process continues. Saltation leads to creep and suspension.

There are two other forms of wind force, namely creep and suspension. The movement of wind causes air pollution, poor visibility and serious damage to plants. Saltation is also known as **vaultation**.

Salt balance

Salt balance represents a relation between dissolved salts in irrigation water carried to an area and the quantities of dissolved salts removed by drainage water from the same area. The overall salt balance (SB) can be defined in terms of various processes that contribute to the salt inflow and outflow, and the local changes in soil salt concentration. The **overall salt balance** (SB) is given by:

$$SB=(DC)_{rain}+(DC)_{IW}+(DC)_{ground}+S_{dissol}-(DC)_{DW}-S_{prec}-S_{crop}$$

where DC is the product of the water depth (D) and salt concentration (C) for rain, irrigation water (IW), ground water and drainage water (DW), S_{dissol} is the salt term for dissolution, S_{prec} stands for precipitation and S_{crop} for crop uptake. Assuming negligible contributions from dissolution, precipitation, crop removal and ground water effects, we have:

$$SB = (C_{IW}\cdot D_{IW})-(C_{DW}\cdot D_{DW})$$

At steady state $SB=0$

Therefore, $C_{IW}\,D_{IW} = C_{DW}\cdot D_{DW}$

To maintain the salt balance, the amount of salt added during irrigation must be equal to that which is drained. **Salinization** will occur if $SB > 0$, that is $C_{IW}\cdot D_{IW} > C_{DW}\cdot D_{DW}$. Since irrigation waters continuously add salts, leaching out these salts by adding more water becomes necessary (or critical). This intervention maintains the salt balance. This additional water is called the **leaching requirement** (LR) and is given by:

$$LR = \frac{E_{iw}}{E_{dw}}$$

where E_{iw} is the electrical conductivity of irrigation water and E_{dw} is the electrical conductivity of drainage water or soil water extract at which a decrease in yield is obtained.

Salt effect

When fertilizers are placed properly, say a couple of centimeters from the seed, normal germination and early growth of the plant are expected. However, if the seed and fertilizer are placed together, germination may be delayed or prevented by a phenomenon known as salt effect. This happens because fertilizers are basically soluble salts and when they are dissolved in the soil solution, they increase the osmotic pressure of the soil solution which inhibits water absorption by seeds and roots. Potassium chloride and ammonium nitrate delay or prevent germination. Superphosphate has much less solubility by comparison and has little or no effect on seed germination.

Salt fertilizer

Salt fertilizer refers to the use of sodium chloride as a fertilizer applied 2 to 3 weeks prior to sowing. Salt fertilizers increase the yields of such crops as sugar beet, coconuts, carrots, etc. They are also important for halophytes, glycophytes, blue-green algae cultures and herbage plants.

Salt index

Salt index (SI) is the percentage ratio of the increment in the osmotic pressure produced by a fertilizer, to that produced by the same weight of sodium nitrate ($NaNO_3$). The salt index of a fertilizer is determined by placing the material in the soil and measuring the osmotic pressure of the soil solution. The salt index of potassium sulphate is 46.1 and that of potassium chloride is 116.3, compared to 100 of sodium nitrate.

Fertilizer salts differ greatly in their effect on the concentration of the soil solution. Mixed fertilizers of the same grade may vary widely in the salt index, depending on the carriers from which they are formulated. A higher analysis fertilizer has a lower salt index per unit of the plant nutrient than a lower analysis fertilizer. Increasing the row width increases the quantity of fertilizer applied in a row. Nitrogen and potassium salts have much higher salt indices and thus, are much more detrimental to germination than phosphate salts placed close to (or in contact with) the seed. While considering fertilizer placement at planting, salt effects need to be carefully considered as, for instance, high rates of high-analysis fertilizers, when placed near the seed, can cause salt damage. The salt index is also used to determine the suitability of irrigation waters containing salts in excess of 600 ppm, assuming that plants can tolerate a maximum of 1170 ppm of sodium chloride. All salt concentrations are expressed in ppm.

$$\text{SI} = (\text{Total Na-}24.5) - [\text{Total Ca–Ca in } CaCO_3,\ Ca(HCO_3)_2] \times 4.85$$

The salt index is negative for good quality waters and positive for waters unsuitable for irrigation. But several objections exist for using the salt index to judge the quality of irrigation water.

Salting out

Salting out refers to selection of minor quantity of seeds or other material from a large bulk with the purpose of evaluating the lot. It is also a process in which the water-solubility of an organic solid or liquid is reduced by adding a salt (usually sodium chloride) to an aqueous solution of the substance, for precipitating out the substance. Ions of the dissolved salt attract and hold water molecules, thus making them less free to react with the solute. The result of this is to decrease the solubility of the solute molecules, with consequent separation or precipitation. Colloidal suspensions of proteins, soaps and similar substances are precipitated in this way.

Salting-out temperature of solution fertilizer

The salting-out saturation temperature of a solution fertilizer is that temperature below which dissolved constituents begin to crystallize (e.g., ammonium nitrate/urea/water) and above which the final crystals dissolve in the solution. This temperature determines the extent to which the fertilizer may be stored outside during winter days. The temperature also determines the time of the year at which these solutions may be applied in the field. This is one of the main properties indicated in the specifications of nitrogen-fertilizer solutions.

The salting-out temperature varies with the plant nutrient concentration. It is minus 18°, minus 10° and plus 2°C for 28, 30 and 32%, respectively, for aqueous solutions of ammonium nitrate and urea. Ammonium polyphosphate has a salting-out temperature of 0°C. Salting-out temperatures of various fertilizer solution mixtures, containing urea-ammonium nitrate, ammonium polyphosphate, potassium chloride and water, can be predicted from the solubility curves.

Salt injury

When an excess concentration of soluble salts comes in contact with plant roots or germinating seeds, it causes injury through plasmolysis, moisture scarcity or actual toxicity. This injury to the plant roots or seeds is known as salt injury or **fertilizer burn**. Here, the plant dries up and exhibits symptoms similar to those found in drought conditions.

A nitrogen fertilizer contributes to germination delay and seedling damage more than to osmotic effects. Free ammonia is toxic, whereas ammonium ion (NH_4^+) is not. Urea, diammonium phosphate (DAP), ammonium carbonate [$(NH_4)_2CO_3$] and ammonium hydroxide (NH_4OH) cause more damage than monoammonium phosphate (MAP), ammonium sulphate [$(NH_4)_2SO_4$] and ammonium nitrate (NH_4NO_3). To avoid salt injury, the fertilizer is appropriately broadcast or placed to the side and below the seed.

Saltpeter

Saltpeter is another name for potassium nitrate, a white crystalline salty substance used in preserving meat and as a constituent of gun powder. It provides both potassium and nitrogen and is used as a fertilizer. (See also Nitre; Potassium nitrate.)

Salt process of sodium nitrate production: See Sodium nitrate production processes

Salt tolerance

The extent to which a plant can tolerate salt concentration without adversely affecting the yield is its salt tolerance. Though toxicity is due primarily to a high concentration of sodium chloride, other ions may also affect plant growth because of the osmotic effect.

Salts usually damage young plants. High salt concentrations increase seed germination time by several days or completely inhibit germination. Salts move with water; evaporation moves them to the surface where they accumulate. Plant species, as also different parts of the same plant, have varying tolerance levels to soil salt. The plant tolerance improves as the plant matures. The salt tolerance of plants varies among the species and also depends heavily on the conditions under which a crop is grown. There are many factors influencing the salt tolerance in the plant, the most important being the plant species, temperature, salt composition, stage of plant growth, salinity level, environmental variables, soil fertility and cultivars.

Plant tolerance to salinity is usually appraised in one of the following ways: (a) the ability of the plant to survive in saline soils, (b) the absolute plant growth or yield, and (c) the growth or yield in saline soil compared with that in non-saline soils. Of the above, the relative yield criterion is the best, because it permits a useful expression for plant tolerance.

Plant tolerance mechanisms for salinity adaptation are classified into those that allow the growing cells of the plant to avoid a high ion concentration and those that permit the cells to cope with the high ion concentration. Salt avoidance mechanisms involve exclusion at the root, absorption by xylem parenchyma cells, xylem-phloem exchange systems, distribution of ion gradients between growing and non-growing portions of the plant, and for **halophytes**, sequestration of the ions into salt glands or trichomes. In general, exclusion mechanisms are effective at a low to moderate salinity, whereas halophytes use ion accumulation as the primary mechanism at high salt levels, presumably in conjunction with the capacity to compartmentalize ions in the vacuole.

Both barley and cotton have considerable salt tolerance, but high concentrations of salts cause more vegetative growth (stems and leaves) than seed heads. The rice grain yield is reduced before vegetative growth is affected.

Tomato, which is tolerant to salinity suffers reduction in yield by 10% for every 0.15 S/m increase in conductivity beyond the saturation extract at EC >0.2 S/m or above, up to which point no reduction in yield is witnessed. Many sensitive fruits, (such as citrus, stone fruits and black berries) are injured by as little as 5% exchangeable sodium. Grapes are tolerant to sodium. As the absorption of sodium and/or chloride in leaves causes leaf damage, salty water should not be used in sprinkler irrigation (especially for stone fruit and citrus trees) though it may be used in surface irrigation. In salty soils, calcium precipitates as insoluble carbonate or sulphate causing calcium-deficiencies, such as **blossom end rot of tomatoes** and **internal browning of lettuce**.

Sample

A sample is a small representative portion taken from a large quantity of material like water, soil, etc., such that the qualitative and quantitative chemical analysis of the sample can be taken as that of the original material. It is used to obtain information on physical and chemical composition of different materials like fertilizers, soils, water or plants. For this, a proper sampling procedure has to be followed. Sampling methods fall under three main categories: (a) in which all the material is examined, (b) in which casual sampling is done on ad hoc basis, and (c) in which portions of the material are selected after considering statistical probabilities.

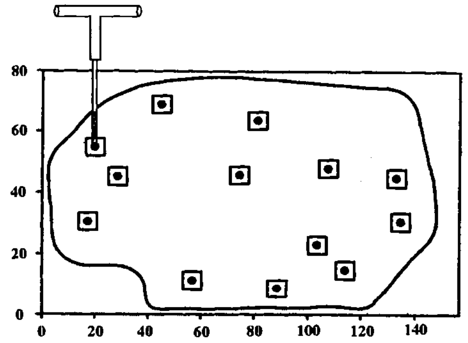
Selecting a small group of entities to represent a large number is known as a **statistical sample**. In **random sampling**, each individual of the population has an equal chance of being a part of the sample.

In **stratified random sampling**, the population is divided into strata, each of which is randomly sampled, with the samples from different strata being pooled.

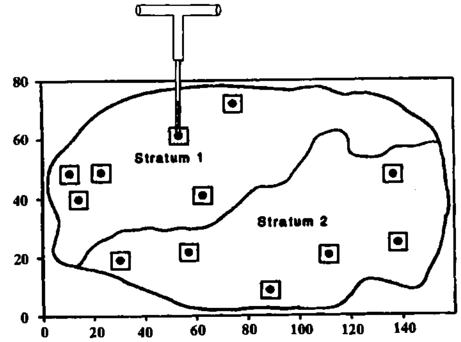
In **systematic sampling**, individual samples are chosen at fixed intervals of the relevant parameter (Fig.S.1); for example, picking up every tenth animal in a population.

In **replacement sampling**, each individual sample chosen is replaced, before the next selection is made.

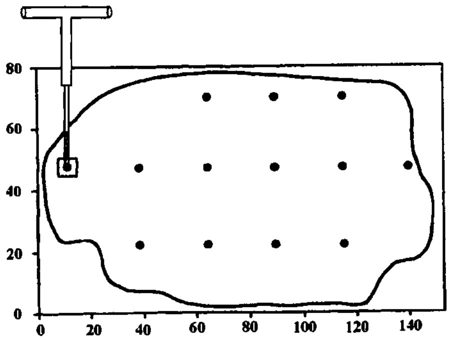
Soils, fertilizers, plants, sediments, etc., are bulk and non-homogeneous materials that contain particles of varied composition, which are unevenly distributed within the material. In this case, a number of increments are taken randomly from points in the bulk material so that each component has an equal chance of being selected. The combination of these increments forms the **gross sample** or **composite sample**, which is generally



Random sampling



Stratified random sampling



Systematic sampling

Fig.S.1: Different methods of soil sampling.

large for direct analysis and hence divided further to get a sub-sample. If for example soil is to be analysed, 20 to 25 field locations are taken to get a good representative composite sample. The process of particle size reduction is carried out on the sample before taking it for analysis. Usually, 0.5 kg of the soil is taken from a field (representing 10 million kg or 4 hectares of land). The sampling area varies from 2 to 8 hectares, and more for a layer field. Areas varying in appearance, slope, drainage, soil types or past treatment are sampled separately to minimize the influence of any local non-uniformity in the soil.

Samples are taken from the depth of tillage which varies from 15 to 30 cm for cultivated crops. With no-till or minimum till, samples are taken from a depth of up to 5 cm and another lot from 5 to 20 cm. In low rainfall areas, 20 to 60 cm deep soil samples are taken to measure the nitrate (NO_3^-) and the moisture.

Regardless of sampling problems associated with soil variability, the quantity of nutrients extracted by the soil test should be close, if not equal, to that absorbed by the crop. For example, phosphorus extracted by **Bray-1 test** in a 2.4 ha field may vary from 20 to 80 ppm which could be close to the amount absorbed by a crop in that area.

The **sampling error**, particularly in the case of heterogeneous materials like soils, fertilizers, etc., is the most important source of uncertainty in the analysis. If we represent the sampling error as S_S and analytical error as S_A, the **total error** S_T is given by

$$S_T = S_S^2 + S_A^2$$

Or

$$S_T = V_S + V_A$$

where V_S is the sampling variance and V_A is the analytical variance.

Sampling error: See Sample

Sampling unit

A defined quantity of material, which may be representative of the sample, and which has a boundary (physical, imaginary or hypothetical) is a sampling unit. For example, a container or a particular time interval to sample the flow of material is a sampling unit. A 'lot' is any known material, for example, fertilizer or soil, to be sampled officially.

Sand

A tiny, granular, loose mineral substance, such as the one found on beaches or dunes and resulting from the erosion of quartz or siliceous rocks is called sand. Sand can be white to pale yellow to brown in color and is one of the fillers used in fertilizer mixtures. Sand grains are mostly siliceous, sometimes calcareous, gypseous or of volcanic origin, formed after disintegrating from crystalline rocks by weathering or erosion, giving fragments of sizes in the range 50 μm to 2 mm (Fig.S.2). After the disintegration of rocks, the resulting sands are displaced by water, glaciers or wind. The mineral composition of sands and grain size varies.

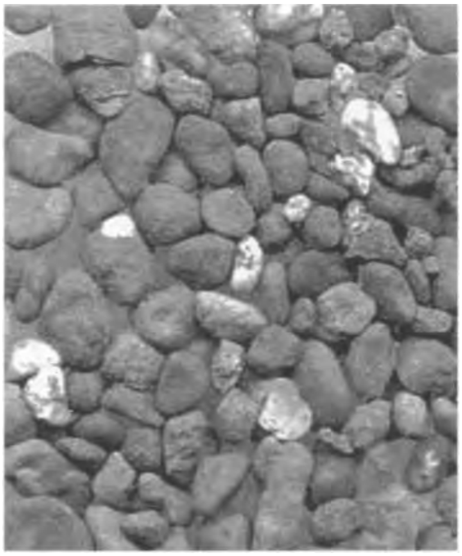


Fig.S.2: Sand particles.

From a particle size distribution of 0.01 to 2 mm diameter, the material is subdivided into (a) fine sand, 0.01 to 0.05 mm, (b) moderately fine sand, 0.05 to 0.2 mm, (c) moderately coarse sand, 0.2 to 0.5 mm, (d) coarse sand, 0.5 to 1 mm, and (e) very coarse sand, 1.0 to 2.0 mm.

For commercial use, sand is produced by crushing large material like sandstone or slag into limestone sand and slag sand, respectively. Various granular materials containing sand-like particles, which may not be of inorganic composition, may also be called sand.

S and A method for available nitrogen

S and A method is short for **Subbiah and Asija method** which is useful for estimating available nitrogen in the soil. It estimates the amount of available nitrogen that can be oxidized in an alkaline medium.

Sand down

The magnesium deficiency in tobacco is known as sand down and is seen as the loss of green color at the tips of the lower leaves. As the deficiency worsens, the upper leaves become bleached and white in color.

Sandy classes

A sandy class describes a soil textural class containing sand, silt and clay in different proportions. Based on the differing proportions, there may be classes like **sandy clay**, sandy clay loam, and **sandy loam** which are generally represented by the USDA soil textural triangle.

For example, if the sand content in a sandy soil is more than 55%, it is called sandy loam, and if the sand content is more than 45% it is called sandy clay. When the sand content in soil exceeds (a) 20% but is much less than 70%, the soil is **silt loam**, and (b) 70% and clay is less than 15% (most often between 6 and 10% clay), it is **sandy soil**. It has a critical bulk density of 1.60 to 1.85 g/cm^3. Sandy soils are predominantly found in savannah regions. Sandy soils are accounted for by the widespread occurrence of sedimentary and granitic parent material and erosion of cultivated soils whereby most of the silt and clay are removed.

The presence of fine sands is useful for soil compaction, soil capping and crust formation, thereby increasing the surface run-off, erosion and water permeability. This reduces the emergence of seedlings.

Sandy clay: See Sandy classes

Sandy loam: See Sandy classes

Sandy soil: See Sandy classes

Saponification

Saponification refers to the reaction of esters with alkali to give alcohols and salts of carboxylic acids. The process is usually carried out on glyceryl esters of fatty acids, forming a sodium salt which is called soap.

$$\mathrm{RCOOR'+NaOH \longrightarrow RCOONa + R'OH}$$

The saponification number is the number of milligrams of potassium hydroxide required to hydrolyze one gram sample of an ester. (See also Hydrolysis.)

Saponite

Saponite is an example of smectite, a 2:1 clay mineral. This 2:1 layer has aluminum octahedral sheets sandwiched between two silicon tetrahedral sheets to make a unit cell. In saponite, all the octahedral holes are filled with magnesium ions and 15 to 20% of the tetrahedral holes are filled with aluminum ions. The rest of the holes are filled with silicon. (See also Smectite.)

Saprist

Saprist, which is a sub-order of **histosols**, is a kind of black soil with highly decomposed organic material and very little brittle plant fibers. Saprist soil changes its color on drying and gives out a turbid liquid when pressed. Its bulk density is 0.2 g/cm^3 or more. The black soil is saturated with water many times in a year and cannot be used for most crops, unless artificially drained. It occurs in areas where the ground-water level fluctuates within the soil and is subject to aerobic decomposition. When fibrists and hemists are drained, either artificially or naturally, they will normally continue to decompose and convert to saprists.

Saprobe: See Saprophyte

Sapropelic coal: See Coal

Saprophage

Saprophage is an organism that feeds on non-living organic matter.

Saprophyte

Saprophyte, also called **saprobe** or **saprotroph**, is an organism which obtains its food only from dead or decaying tissues of plants or animals. Through their action, they produce certain important compounds through which living beings receive carbon, nitrogen and other elements vital to life. Saprobe generally refers to such organisms of lower plants like fungi, protozoa, etc., while saprotroph refers to higher plants.

Saprophytes do not carry out photosynthesis. Most fungi and bacteria are saprophytes. They creep over the food, secreting digestive juices and absorbing the resulting solution. Digestion is extra cellular and the products are assimilated and absorbed within the body of the organism. They play an important role in recycling nutrients, decomposing organic matter and releasing nutrients for plant growth (and are thus called **decomposers**). Some flowering plants, such as the pine sap, are saprophytes.

If the dead material being fed on by a saprophyte is part of a living host, the term perthophyte is applicable, as in the case of organisms which kill some host tissues and obtain nutrition.

Saprotroph: See Saprophyte

SAR

SAR is short for **sodium adsorption ratio**, a ratio of sodium ions to other cations, mainly calcium and magnesium ions.

Sarcodina

Sarcodina is a colony of **protozoa** which are usually unicellular and microscopic organisms of the phylum or subkingdom protozoa.

Saturated extract

A saturated solution of soil paste extracted with water is called a saturated extract. A soil extract is used for analysis. During a chemical analysis of the soil sample, the total quantity of salts extracted by dilution or saturation with water (soil:water ratio, 1:10 or 1:5, or the liquid limit) is used for laboratory experiments. The determination of such saturated extracts gives the total soluble salts present in the soil.

Saturated flow

Saturated flow occurs when soil pores are full of water. Saturation of soil is said to have occurred when even the largest soil pores are filled with water. Such soil is also described as being waterlogged. This happens during rainstorm or irrigation or when there is little or no air in the pores.

Saturation flow is the movement of water into the soil by rain or by irrigation, due to gravity pull. It starts with water infiltration. When the soil profile is wetted, more water moves through the wetted soil and this is termed **percolation**. The percolating water moving through the soil carries nutrients and other salts. This water infiltration is rapid when there are large and continuous pores in the soil. The rate of water movement into the soil is controlled by (a) the percentage of sand, silt and clay, (b) soil structure and its organic matter, (c) soil depth up to hardpan, bedrock or other impervious layers, (d) amount of soil water, (e) soil temperature, and (f) soil compaction.

The vertical flow of water through the soil is given by **Darcy's law** which states that the volume of water passing through a soil area is directly proportional to the area which receives the water and the water pressure, and inversely proportional to the thickness of the soil traversed by the water. In both saturated and unsaturated flows, water flows under hydraulic gradient. In the saturated flow, the hydraulic head is most important, whereas in the unsaturated flow, it is the matric potential (or head) which is most significant.

Saturated solution: See Solution

Saturation index

Saturation index (**SI**) is an index used for the purpose of predicting carbonate deposition in boilers from irrigation water as a function of the degree of calcium carbonate saturation. It is defined as:

$$SI = 8.4 - pHc$$
$$PHc = \{pK_2 - pK_{sp}\} + pCa^{2+} + p_{alk}$$

where pK_2 and pK_{sp} are the negative logarithms of the dissociation constant of bicarbonate (HCO_3^-) and the solubility product of calcium carbonate, pCa^{2+} is the negative logarithm of divalent calcium (Ca^{2+}) concentration and p_{alk} is the negative logarithm of alkalinity concentration, both carbonate and bicarbonate ($HCO_3^- + CO_3^{2-}$). Values of pHc below 8.4 indicate the tendency to precipitate lime from applied water. An improvement in the calculation of sodium adsorption ratio has been made by introducing the SI index in the derivation of SAR. (See also Water quality.)

Saturation percentage

Saturation percentage is the amount of water a soil holds when all the pores are filled with water. It is expressed on dry-weight basis.

Savannah

A savannah is a vegetative or ecological zone, found in tropical and sub-tropical regions lying between equatorial forests and dry deserts.

The savannah has poor drainage and widely scattered trees in the midst of dense grasses. It gets seasonal rainfall and is an intermediate stage between a true grassland and forest vegetation. The trees are usually 6 to 12 m high, strongly rooted, and characterized by flattened crowns. They exhibit drought-resistant features, including partial or total seasonal loss of leaves (deciduous), water storage modifications and reduced leaves which are fire resistant (**pyrophytic plants** with thick barks and thick bud scales).

Commonly found trees in a savannah include isoberlinia, baobab, eucalyptus and pine; the grasses are often tall, reaching up to 3.5 m in height, and providing fuel for dry season fires. Typical grasses are elephant grass, *Panicum* spp., *Pennisetum* spp., *Andropogon* spp. and *Imperata cylindrica*.

A modern definition of savannah includes a variety of physiognomically or environmentally similar vegetation types in tropical and extra tropical regions. Examples of such savannah are forest tundra, forest steppe and everglades.

Owing to intense human activity on the forest-savannah boundary, savannah vegetation has been rapidly encroaching upon tropical rain forests, creating an ecological zone of transition, commonly known in West Africa as **derived savannah**.

Scabrous leaf

The leaf surface provides many characteristics for identification. When the surface of a leaf is rough or harsh to touch, the leaf is known as a scabrous leaf. (See also Leaf.)

Scalar

Quantities that do not have a direction but have only magnitude are called scalar quantities. Mass, work, power, etc., are examples of scalar quantities. Quantities such as velocity and acceleration, that have not only magnitude but also direction are known as **vector** quantities. (See also Power.)

Scale leaves

Scale leaves are leaves which lack chlorophyll. They develop on rhizomes and protect the inner leaves of a bud. (See also Leaf.)

Schoenite

Schoenite is the name for a naturally-occurring potassium sulphate, from which it can be separated by fractional crystallization.

Schomaker-Mclean-Pratt buffer

The lime requirement of a soil is measured by reacting the soil extract with calcium carbonate or calcium hydroxide. However, this method for determining soil acidity is time-consuming.

The Schomaker-Mclean-Pratt (**SMP**) buffer, consisting of p-nitrophenol-triethanolamine-potassium chromate-calcium acetate and calcium chloride buffer (adjusted to pH 7.5 using sodium hydroxide) is found to be the most preferred buffer among soil scientists. Analysis of lime requirement using SMP buffer is a method especially suited for soils having properties like lime requirement >4 meq/100 g, pH <5.8, organic matter <10%, and containing soluble aluminum. (See also Lime requirement.)

Schorlite

Tourmaline, which is a borosilicate, has a variant containing iron, and is called schorlite. Schorlite can be used as a boron nutrient, and its insoluble nature makes it a slow-release fertilizer.

Schwanniomyces occidentalis

Schwanniomyces occidentalis is a fungus that has the ability to convert insoluble phosphates (in the soil) into soluble phosphates by secreting organic acids such as formic, acetic, propionic and succinic acids. In the reduced pH conditions, the phosphates dissolve, while the hydroxyl acids produce complexes with iron, calcium, aluminum and magnesium. (See also Phosphate-solubilizing micro-organisms.)

Science Ventures Inc.-developed flash sulphur cycle process: See Sulphuric acid production processes

Scion : See Root stock

Sclerenchyma

Sclerenchyma is a strengthening tissue composed of cells with thick and heavily lignified cell walls.

Scorching

Scorching is the act of burning the surface due to exposure to heat. Nutrient deficiency, excessive use of fertilizers and close proximity of fertilizers to seeds or seedlings cause scorching of plant tissues. Scorching leads to discoloring and injuring plants, in turn hindering their growth. Foliar sprays are also sometimes known to cause leaf-burns.

Scottish Agricultural Industries process for non-granular monoammonium phosphate

The Scottish Agricultural Industries (**SAI**) process for non-granular monoammonium phosphate involves the neutralization of phosphoric acid (containing 50% phosphorus pentoxide) with ammonia to a mole ratio of 1.35. The resulting hot slurry is mixed with more phosphoric acid in a specially designed mixer. The product, sold under the trade name **PhoSAI**, contains around 6% moisture, 11% nitrogen and 50% water-soluble phosphorus (P_2O_5). The SAI process can also be modified to produce non-regular diammonium phosphate, called **Di-PhoSAI**, or ammonium phosphate-sulphate. The process of making non-granular monoammonium phosphate (PhoSAI) gives the product an advantage in that, the impurities precipitate into a gelatinous form that coat the phosphate. (See also Ammonium phosphate.)

Scrap mica: See Flake mica

Screen analysis

The particle size distribution of dried soil and fertilizers is carried out by screen analysis or **sieve analysis** which is concerned with the determination of the quantity of material which passes through, or held on a set of screens of varying mesh sizes. The portion of the sample that does not pass through a sieve of specified aperture is called an oversized sample. Different standard sieves like ASTM (American), DIN (French), BIS (India), etc. are used in the sieve analysis.

Screen type method for determination of abrasion resistance

The screen type method is a method for determination of abrasion resistance of granules. It is essential to evaluate the capacity of granules to withstand fracturing as a result of granule-to-granule contact and the granule-to-equipment contact during handling. (See also Granular strength.)

Scrubbing

Scrubbing removes one or more components from a mixture of gases and vapors by passing the mixture upward, with the counter current of a descending liquid. The latter is so chosen as to dissolve only the desired component. The gas or vapor may be broken into fine bubbles upon entering a tower filled with liquid. More frequently, the tower is filled with coke, broken stone or other packing material, over which the liquid flows over a relatively large surface. In the manufacture of ammonium chloride fertilizer, for instance, excess hydrochloric acid gas is scrubbed to prevent the pollution of the environment.

Scrubbing of coke-oven gas in the production of ammonium sulphate: See Ammonium sulphate production processes

SCU

SCU is short for **sulphur-coated urea**. Granular or prilled urea may be coated with sulphur and a sealant wax. Molten sulphur is sprayed on heated urea (at around 70°C) in a tumbler, followed by a spray of molten wax-coaltar mixture. The material is cooled and coated with clay. The final product contains about 76% urea, 19% sulphur, 3% wax, 0.5% coaltar and 1.5% clay. It is used as a slow-release fertilizer.

SD

SD is short for **standard deviation**.

Seasons

Seasons are divisions of the year, characterized by cyclical changes in a predominant weather pattern. In the temperate zones, there are four seasons: spring, summer, autumn (fall) and winter. These result from the constant inclination of the earth's polar axis ($66\frac{1}{2}^{0}$ from the ecliptic) as the earth orbits the sun. During summer in the northern hemisphere, the North Pole is tilted toward the sun, and in winter, when the solar radiation strikes the hemisphere more obliquely , the North Pole is away from the sun. The summer and winter solstices (about June 21 and December 22), popularly known as mid-summer and mid-winter, strictly speaking mark the beginning of summer and winter respectively. Thus, spring begins on the vernal equinox (about March 21) and autumn at autumnal equinox (about September 23).

The Indian subcontinent and south-east Asia experience a fifth season known as monsoon. Monsoon winds blow in this region and cause rains. There is a south-west monsoon and a north-east monsoon. The farmers in the region depend on the monsoon for their agriculture.

Secondary host

An organism (and intermediate or alternate organism) in which a parasite spends its life after it has attained sexual maturity in the first host, is known as secondary host.

Secondary implements

Tillage operations following primary tillage are intended to create better soil conditions before planting the seed. The implements used in this process are known as secondary implements, and their operations consume less power per unit area compared to conventional tillage operations. The implements used are harrows, cultivators, clod crushers, etc. Not much soil conversion and shifting occur in this process.

Secondary minerals

Secondary minerals result from the decomposition of a primary mineral or from the re-precipitation of the products of decomposition of a primary mineral. A secondary mineral is a mineral formed later than the rock enclosing it, usually at the expense of an earlier formed primary mineral.

Secondary nutrients

Secondary nutrients, namely, calcium, magnesium and sulphur, are essential for plants. Secondary nutrients are required by plants in moderate to large quantities. They are called secondary because they are not applied directly (like macro fertilizers), but along with NPK fertilizers. (See also Plant nutrients.)

Secondary phloem

Phloem is the tissue conducting material in plants - from the site of production to regions where it is needed (such as growing points). In young plants and newly formed tissues of mature plants, the phloem is formed by the apical meristem. In most plants, secondary phloem is differentiated from the vascular cambium which replaces the earlier older one. (See also Phloem.)

Secondary raw material fertilizers

In Germany, organic fertilizers are designated as secondary raw material fertilizers. **Organic fertilizers** are products made from the wastes of animal husbandry (stable manure or slurry manure), plant decomposition products (**compost** or **peat**), or waste treatment plants (composted garbage or **sewage sludge**). They are costlier than inorganic materials, when considered on the basis of gain per unit of nitrogen and phosphorus or potassium and sulphur.

Secondary standard solution

Standard solutions used in volumetric analysis are of two types, primary and secondary. The secondary solution is made from substances that are not available in 100% pure form, and hence, need to be standardized with a primary standard compound. Sodium carbonate is the secondary standard for acid-base titrations, and hence, need a primary standard like potassium hydrogen phthalate. (See also Standard solution.)

Secondary symptom

A symptom following the primary symptom in a disease is called a secondary symptom.

Secondary tillage: See Tillage

Sedimentary rocks

Sedimentary rocks are a group of rocks formed as a result of the accumulation and consolidation of sediments. They are one of the three major rock groups that form the earth's crust. Most sedimentary rocks are formed from pre-existing rocks that have been broken down through mechanical processes into small pieces. These have since been transported, pressed and consolidated. Sedimentary rocks vary in hardness (depending on pressure) and in composition (depending on the composition of the original deposit). Sandstone (Fig.S.3) originates mostly from sand-sized sediments; shale originates mostly from clay-sized sediments. **Limestone** is rich in carbonates from the shells found in lakes or from ocean organisms. Most sedimentary rocks are softer and more porous than igneous rocks. Clastic rocks and chemical rocks are the two types of sedimentary rocks known.

Fig.S.3: Picture of sedimentary rocks formed by water pressure.

Sedimentation

Soil particles, sand, minerals or organic solid material washed from the land into aquatic systems as a result of natural and human activities are called sediments. Sediments get transported from the site of origin through the medium of water, wind, ice or gravity.

Sedimentation is a process by which solid particles (sediments) settle through a column of liquid. The driving force for the process is the difference in the density of the solid and the liquid. The greater the particle size or greater the difference in the densities of the liquid and the solid, the faster is the sedimentation.

Ordinarily, sedimentation is accomplished by the force of gravity. If the particle size is very small, or if the difference in density is very less, a centrifugal force may be applied. In the simplest case, **Stokes' law** determines the rate of sedimentation, but the predicted rate is rarely reached in practice. The colloidal particles are separated from the solvent by centrifugation.

The rate of sedimentation in an ultracentrifuge can be measured, thereby allowing an estimation of the size of macro-molecules to be made. Particles too small to settle at a practicable rate are often amenable to flocculation by agents such as alum, lime, alumina and sodium silicate.

The sedimentation method is used in several industrial processes, for example, to obtain concentrated slurry from a dilute suspension of a solid in a liquid (called **thickening**) or to remove solid particles so as to obtain a clear supernatant liquid. This is called **clarification**.

Sediments result from both physical and chemical depositions. The first kind relates to clastic or detrital sediments deposited by mechanical action. Clastics or detrital sediments range from large agglomerates like pebbles, cobbles and boulders to small ones like shale, sandstone, silts, mud and sand. These are deposited by high velocity, high-density currents of streams and rivers, as well as near-shore littoral ocean currents. Such coarse materials are transported by rivers during floods, landslides and mudflows. Sands accumulate as river bars, dunes, alluvial fans, beach deposits, barrier islands and offshore marine bars, and are a major component of deltas. In the second kind of sediments by chemical deposition, chemical sediments are formed by the reaction between the dissolved components in water and the environment, to form precipitates. The precipitation may be inorganic or it may take place by the action of organisms, such as molluscs that secrete a calcium carbonate shell.

By far the most important chemical sediments are predominantly of calcium carbonates. Other chemical sediments are siliceous sediments, phosphatic sediments, ferruginous sediments (iron-rich), manganese sediments, etc. A group of rocks formed by the accumulation and consolidation of sediments is known as **sedimentary rocks**.

Seed

A seed, also referred to as **grain** or kernel, is a planting material, produced by means of sexual propagation. It contains the essence of the next generation and completes the life cycle of a flowering plant. Following fertilization, the whole flower begins to change from within. Sepals, petals and stamens often drop off as the ovary expands greatly to become a fruit. Within the ovary, each fertilized ovule gets converted into a seed, while the integuments of the ovule develop into an outer coating of the seed. In short, seeds develop from the fertilized ovule, have an embryonic plant with some form of nutritive tissues within the seed coat.

The food storage tissue is called the endosperm. Starch is an important food reserve in the endosperm, as in cereals and legumes. The other examples are sugar in sweet corn, protein in soybean and wheat, and fat in coconut, cacao, castor bean and most palms. Growth promoting substances, like gibberellin, also occur in seeds. The seeds or bulbs of some plants are highly toxic, as in case of hyacinth, larkspur, castorbean, cashew nut shells, etc.

Seeds are an important source of vegetable oil. They are differentiated as dicots (a seed having two seed leaves or **cotyledons**; for example, lima bean) and **monocots** (a seed having one cotyledon; for example, corn kernel) as shown in Fig.S.4. Cotyledons absorb nutrients from the endosperm, thus often becoming large and fleshy. Monocots have a single small cotyledon which transfers food from the endosperm to the embryo. Several monocot families have large amount of endosperms.

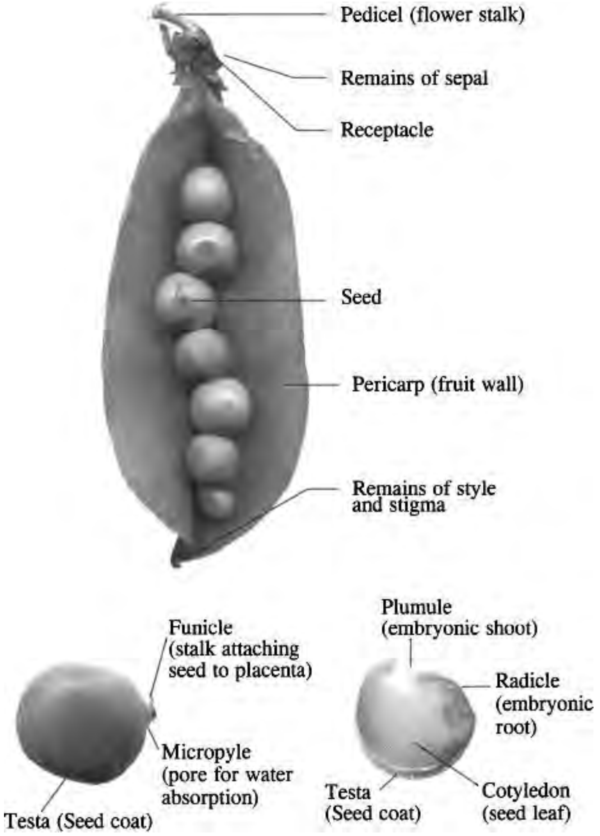


Fig.S.4: Dicot seeds in a pod (top) and structure of a seed (Pea seed).

Many seeds become valuable food material for humans and animals because of the stored nutrient reserves in cotyledons or endosperm.

Appropriate environmental conditions, such as adequate moisture, oxygen and temperature, lead to seed germination. All these conditions notwithstanding though, some seeds do not germinate and are called dormant seeds. They undergo certain internal changes which do not allow germination.

The seed during germination gives rise to its first structure called **radicle**. The radicle develops to produce the primary root. In the case of monocots, the radicle first breaks through the coleorhiza. This early formation of the root system enables the developing seed to absorb water for its growth. The plumule then emerges and gives rise to the shoot (Fig.S.5). The cotyledons are carried above the ground with the expanding hypocotyl in most dicots, whereas in other cases, the cotyledons remain below the ground. As soon as the tissues of the seedling emerge from underground and are exposed to sunlight, they develop chlorophyll and begin to photosynthesize.

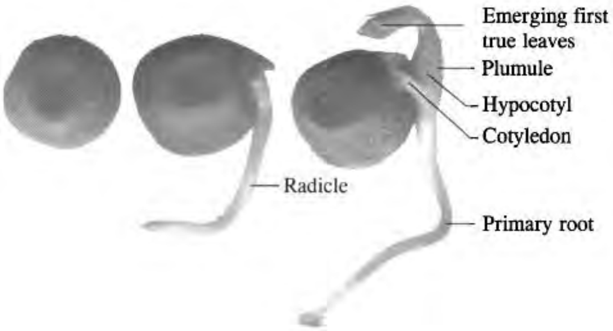


Fig.S.5: Stages of germination in a dicot seed.

In the life of a plant, seedling formation is the most critical stage. Seedlings are vulnerable to attack by pathogens and predators, and to environmental stress. A full grown plant remains relatively unaffected by environmental stress.

Seed bank

Seed bank, also known as **gene bank**, is a repository of plant seed varieties, stored and preserved in a highly controlled environment. Seed banks aim to preserve native or wild seed varieties as well as modern varieties of each plant species, such that genetic diversity may be preserved and a sound base be created for further research. (See also Germplasm.)

Seedbed

The seedbed is the soil prepared for sowing seeds (Fig.S.6). Soil serves as the root zone for plants and provides a site for storage, anchorage and exchange of mineral nutrients. It is also a medium through which water and air can move. Tillage practices modify these properties. The sowing depth and the seedbed quality influence germination and emergence of the crop. The operations involved in seedbed preparation are: harrowing, levelling, soil compaction, and preparing ridges, furrows, basins, raised beds, etc.

A seedbed is a 5 cm wide strip prepared such that fine and firm soil can receive the seeds of row crops. Seedbeds may be placed a meter apart. The seedbed for broadcast or narrow-row cereals, which may comprise the entire surface to be seeded, facilitates quick germination and provides a good medium for the growth of plant roots.

The seedbed should be firm underneath, with a loose friable soil structure on the surface. A fine firm seedbed ensures good contact between the seed and the soil, promotes capillary moisture movement from below and reduces the risk of soil crusting. The depth of cultivation of a seedbed is about 5 cm.

Different crops require different kinds of seedbeds. For example, a wheat seedbed should have fine tilth in the upper few centimeters of the soil, whereas sorghum needs a firm and compact seedbed for proper root development. Pearl millet and tobacco need seedbeds with fine tilth, while groundnut requires a loose soil subsurface for proper development of pods.

The root bed is not a clearly defined zone, as roots may penetrate well below the cultivated zone. For crops like paddy, tobacco and many vegetable crops, the seeds

Fig.S.6: Seedbed preparation before sowing.

are first sown in small and well-prepared nursery beds. In India, *kharif* season nurseries usually have raised beds about 15 to 25 cm high, while the winter and summer season nurseries rest in flat beds. The nursery soils should be friable and fertile to promote growth.

The size of the nursery beds may vary according to convenience. For example, paddy nurseries may be about 120 cm wide, 6 to 10 cm high and 10 to 12 m long. The raised nursery beds for vegetables may be about 100 cm wide, 20 to 25 cm high and about 1 to 2 m long. Flat beds of 1.5 to 2.5 m^2 size (depending on the slope of the land) may also be used to raise seedlings. The seeds are either broadcast or sown quite thick in closely arranged rows. When the seedlings are a few weeks old, they are transplanted in the field.

Seed inoculation

Dressing the seeds of leguminous plants with a culture of nitrogen fixing bacteria is known as seed inoculation. This procedure is used when the soil is deficient in the nitrogen-fixing bacterial strain, appropriate to that legume. In the absence of seed inoculation, root nodule formation is restricted. Symbiotic heterotrophic bacteria, specific to a given crop, are frequently added or inoculated as dry powder at the rate of 25 g inoculum/ kg of seed. An alternate technique to encourage nodulation is to resort to heavier applications of inoculums, mixed into peat granules added to the soil, as the seed is planted. Seed inoculation is commonly carried out by preparing a slurry of biofertilizer by mixing about 250 g of biofertilizer in half a liter of water, and evenly spreading it on 10 to 15 kg of seed by hand. These coated seeds are briefly dried in shade and immediately sowed thereafter.

The formation of a coherent ball of one or more inoculated seeds by mixing them with materials like fertilizer, clay, pesticide or insecticide is known as **seed pellet**. Seed pellets are useful in maintaining the inoculum's activity during adverse soil conditions. An application of chemicals to seeds, instead of to the *soil*, reduces the cost as well as the time for correcting the soil.

A cheap and efficient adhesive is necessary to make pelleting agents stick to the seed. For this, gum acacia is used as a 45% aqueous solution prepared by slight heating. The slurry of the adhesive and inoculants is mixed with seeds which then get coated uniformly with neutralizing agents like calcium carbonate, ground rock phosphate, bentonite clay, milk powder, humates and gypsum - also known as **pelletants**. The latter create a neutral zone around the seed by their buffering action and establish a congenial root environment for the successful activity of inoculated micro-organisms.

It has to be noted that bacterial species inducing the nodule formation are generally specific to a particular legume. For example, species specific to lupines will not induce nodulation in trifolii. In contrast, some bacterial species can interact symbiotically with several similar legumes.

Seedling inoculation

The application of a biofertilizer inoculum directly to the roots of a sapling is called seedling inoculation. Since the inoculant is a culture of nitrogen-fixing bacteria, and other friendly micro-organisms, the growth of the plant is immediately encouraged. In addition, sapling inoculation may provide useful nutrients that are deficient in the soil.

The steps involved in the process of applying an inoculant to the roots are: (a) mixing around 2 kg of the inoculant in 15 liters of water, (b) soaking the plant roots with the solution for half an hour, and (c) transplanting the plant to the field immediately.

Seedling roots

Seedling roots, **primary roots** or **seminal roots**, which are produced from the seed at germination, are one of the two sets of roots that support the growth of plants. The other type of roots are called adventitious roots. (See also Root.)

Seed pellet: See Seed inoculation

Seed rate

The quantity of seed used for sowing a unit area is known as the seed rate. For example, if 100 kg of wheat seeds are required for sowing an area of one hectare, 100 kg/ha is the seed rate for wheat. The seed rate depends on the quality and purity of the seed and its germinability for one hectare. A seed pedigree assures that the established standards are met. The seed grading, according to the germination process, is based on minimum percent germination and the same holds for all pedigreed classes at 85% and 75%, for grades 1 and 2, respectively. In practice, the actual germination values may be much higher.

An optimum seed rate of any crop is one that will raise an optimum population of plants in a unit area to give maximum yield. Since the space required by each plant varies, even among the varieties of the same species, the seed rates differ widely.

Crops that branch or have a good tillering habit require more space per plant; hence, fewer plants are possible per unit area. For example, the distance between two plants is 1.5 × 2 m for castor and 30 × 15 cm for groundnut. Different varieties of the same crop may require different spacing; for example, in cotton, the AK-235 variety is planted with a spacing of 45 × 22.5 cm, whereas the HY-4 variety is sown with a spacing of 1.5×2 m.

The actual seed quantity of any crop required to be sown is more than the theoretical value based on the seed rate because the latter does not consider the risks involved such as causalities due to defects in the seed, seedbed, germination, damage due to insects, intercultural operations, etc. Optimum seed rates for different crops have been fixed. For instance, a higher seed rate is recommended for Mexican wheat, sorghum hybrids and IR-8, a medium-duration variety of rice.

The spacing and the seed rate can differ according to the purpose intended for growing a particular crop. For example, the seed rate of sorghum grain may be 7.5 to 10 kg/ha, but for fodder it may be 65 kg/ha. Similarly, sun hemp grown for fiber is sown very thick to discourage branching and to develop a good quality fiber, whereas sun hemp grown for green manuring is allowed to tiller.

Segregation in plants

Segregation occurs because the progeny may have contrasting genetic features from those of the parents. The homologous allelic pairs separate during meiosis in developing reproductive cells which then contain one allele from each pair.

The progeny tends to resemble its parent in all fundamental characteristics, except possibly in some minor respects. While being part of the same species, the organism grows in its own way to be unique. This variation within plants and animals is due to environmental conditions, such as those relating to moisture, temperature, nutrition, as also hybridization. The latter refers to breeding of similar organisms which differ from each other in more than one feature. Mutation can also cause variations.

Gregor Mendel, in his **law of segregation**, proposed that when gametes are formed, the gene pairs which are hereditary factors separate in such a way that each sex cell (egg or sperm) only receives one of each kind of factor or gene. This concept is known as the **principle of segregation**.

Segregation tendency in fertilizers

In segregation, components separate from the mixture because of differences in sizes, density or weight. Fertilizer blends tend to segregate because of differences in the particle size and the shape of blend components. This makes the composition heterogeneous. Similarly, segregation also occurs due to excessive vibration or poor handling during fertilizer blending. This can be avoided by using blended ingredients of similar sized particles.

Selective herbicides

Herbicides that selectively reach and disrupt vital functions of a targeted plant are called selective herbicides. Pesticide selectivity is not always unique. With herbicides, the difference between a target species and a desirable one is quite limited.

Selectivity is often achieved mechanically by using directed sprays or shields which are restricted to the weeds while protecting the crops. It is also achieved by involving a differential rooting depth between the weeds and the crops. Another way to ensure selectivity is by timing the spray application. Crops with waxy leaves and an upright growth can be treated with herbicides. Biochemical selectivity is a common mechanism used to control weeds. (See also Weedicides.)

Selective phytotoxic adjuvant

Selective phytotoxic is one of the three oil adjuvants used in herbicide sprays for many years to improve their foliar penetration. (See also Phytotoxic selective adjuvants.)

Selenite

Selenite, which is a salt of selenic acid (H_2SeO_3), and very similar to sulphite, is made by the oxidation of selenium by nitric acid. The low solubility of iron-selenite complexes is responsible for the non-toxic level of selenium in plants growing on acid soils having a very high total selenium content. Plants absorb selenite, but generally to a lesser extent, than selenate, which is another form of selenium.

Selenium

Selenium (Se) is a metalloid element belonging to Group 16 (formerly VIB) of the Periodic Table (Fig.S.7). It is an essential ingredient in the forage for animals to prevent muscular dystrophy or **white muscle disease** which weakens the heart of cattle and sheep.

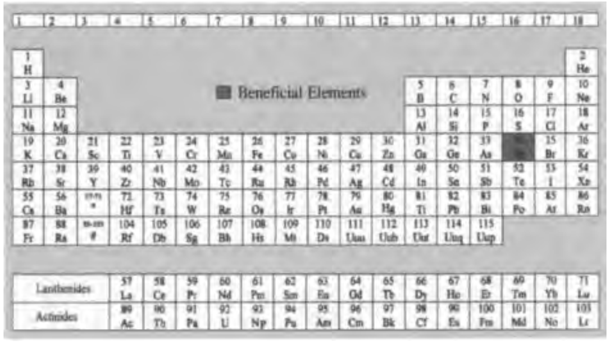


Fig.S.7: Position of selenium in the Periodic Table.

However, selenium is not essential for plants, and its uptake by plants varies. Certain species of *Astragals* absorb more selenium than others because of a special amino acid in them. Plants like mustard, cabbage and onions absorb moderate amounts of selenium. This absorbed selenium accumulates in the tissues of these plants, and no treatment can remove it. The excess soil selenium content can be corrected by the addition of barium chloride or calcium sulphate, which may form insoluble selenate.

Chemically, selenium resembles sulphur. Its total concentration in most soils is between 0.1 and 0.3 ppm as selenides, elemental selenium, selenites, selenates and organic selenium compounds. The selenium uptake is the highest in basic soil and the lowest in neutral soil.

There has been some concern about the increased **selenium deficiencies** in cattle due to a negative effect of sulphate on the selenate ion uptake by crops. Such livestock disorders are severe after a wet summer. This is due to a lowered soil redox potential, converting selinium into forms unavailable for plant uptake. This is also pronounced in soils with increased nitrate deposition which converts the selenate and selenite into elemental selenium or its gaseous form. On the other hand, winter forage is seen to contain higher amounts of selenium.

Phosphate rocks and superphosphates containing 20 ppm or more of selenium may be sufficient for plants to protect the livestock from being deficient in selenium.

Fertilization programs to produce selenium-adequate forage, specifically suited to grazing animals, are a subject of continuing interest. Fertilization with selenites is preferred to other easily available selenates in view of the former's slow-acting nature. Fertilization with selenites is preferred also because they produce a lesser level of selenium in plants than selenates do. Selenium of roughly 75 g/ha for forages and 15 g/ha for foliar application is satisfactory.

The regions around San Jonquin Valley and Salton Sea in California are prone to selenium hazards. Studies to reduce soluble selenium in high-selenium soils are in progress. Plants like milkvetch, mustard, woody asters, and prince's plume can accumulate very high (1000 to 10,000 mg/ha) selenium and lower its content in the soil.

However, pasture plants containing high concentrations of selenium harm feeding animals and cause blind stagger, alkali disease or even death. A high selenium concentration in the soil gives rise to '**selenium poisoning**'. A certain group of plants, called **selenium extractors**, have an extraordinary ability to absorb or extract selenium from the soil. Selenium extractors are primarily shrubs or weeds native to semi-arid and desert rangelands.

Selenium is also used in xerography, decolorization of glasses, and as a pigment in plastics, paints, enamels, glass, ceramics and inks. (See also Hyperaccumulator plants.)

Selenium deficiency: See Selenium

Selenium extractors: See Selenium

Selenium poisoning: See Selenium

Self-fertilization

In self-fertilization, the male and female gametes are derived from the same individual. Among plants, self-fertilization (also called **autogamy**) is common in many cultivated species like in wheat and oats. However, self-fertilization is a form of in-breeding and does not allow mixing of the genetic material. If it occurs for a long time (over generations) it may result in the offspring being less vigorous and less productive, than those occurring from cross-fertilization.

Self-mixing soils: See Self-mulching soil

Self-mulching black clays

Self-mulching black clays is another name for black soils in Australia. Self-mulching clayey soils are those that have a surface layer that is either loose and coarse or so well-aggregated that it does not crust or seal under the impact of rain, and instead serves as granular mulch upon drying. This may include soils that crack into a granular mulch due to high shrink-swell potentials.

Self-mulching soil

Mulch is a mixture of wet straw, leaves, etc., spread over the ground around a plant to insulate or enrich the soil. A self-mulching soil has a loose or well-aggregated surface which does not crust or seal under the impact of rains, but instead forms a granular mulch when dry. This is caused alternately by severe desiccation and re-moistening or by freezing and thawing in the upper soil layer. Vertisols, with their property of high swelling and contracting, are **self-mixing soils** (or self-mulching soils). When dry and cracked, the loosened soil material on the surface falls into the cracks. When wet, the same soil material is pushed up and about. Over decades, these soils develop a wavy surface. The effect of this is pronounced in some clay soils wherein an aerated crumby horizon is formed at the surface and rains do not form an impermeable crust over the surface. Self-mulching facilitates agricultural operations, and in the dry season, provides protection against evaporation.

Semi-anthracite coal

Semi-anthracite coal is a rank of coal. It has a fixed carbon content of 86 to 92%. (See also Coal.)

Semi-arid climate

Semi-arid climate is one where the moisture content is generally more than that found in arid conditions, but which still limits the growth of most crops. The mean annual temperature is higher than 18°C and the rainfall exceeds the potential evapotranspiration for 2 to 7 months.

In semi-arid climate, dry land farming methods of irrigation are required for crop production, especially when the average yearly rainfall is as low as 38 cm. Regions that experience semi-arid climate are semi-arid regions. In **cool semi-arid regions**, the annual precipitation can be as low as 38 cm; in **tropical semi-arid regions** it can reach as high as 114 to 127 cm.

Principal vegetation in semi-arid regions is drought-resistant grass, with a short plant life.

Semi-bituminous coal

Semi-bituminous coal is a class of coal classified according to the carbon content, and is mainly used in power generation. (See also Coal.)

Semi-digger

Semi-digger is one type of modern plow.

Semi-direct method for recovery of ammonia or ammonium sulphate: See Ammonium sulphate recovery by the semi-direct method

Semi-fibrous peat (lenist)

Semi-fibrous peat is essentially a partially decomposed plant material. According to the degree of decomposition and transformation of the plant debris, the following three types of peat are distinguished: (i) Fibrous peat (**fibrist**). (ii) **Altered peat** (**saprist**). (iii) Semi-fibrous peat (lenist). (See also Peat.)

Seminal roots

Seedling roots are also called seminal roots or **primary roots**. (See also Root.)

Semiochemicals

Semiochemicals are those chemicals that elicit a sexual response or attract insects. They deliver a message to the members of the same group or different species of animals or plants.

Semiochemicals are produced within the body but are emitted externally to elicit a response. There are three groups of chemical messengers: allomones, **kairomones** and pheromones. Allomones are chemicals that give adaptive advantage to the producer. For example, leaves of black walnut tree contain a herbicide, juglone, that appears after the leaves fall to the ground. Antibiotics are also a kind of allomones.

The semiochemical, namely, kairomones is given off by one species that induces a greater behavioral response in another species than in the species exuding the compound. Floral scents are kairomones to the honeybee. The third semiochemical, namely, pheromones, affects the receptors of the same species. In other words, they are specific within the species. Social insects such as bees, ants, wasps and termites use these substances. Since pheromones are less volatile compounds, the indicators persist for some time.

Semiochemicals are isolated and synthesized for various uses like controlling insect pests and weeds and protecting plants or forest timber. (See also Hormone; Sex pheromones.)

Senescence

Senescence refers to changes occurring in an organism (or in a part thereof) between maturity and death. Characteristically, there is deterioration of the function as the cells become less efficient in maintaining and replacing the vital components.

Senescence leads to a decline in the physical ability of animals, and also leads to a reduced mental ability in human beings. Not all parts of the body necessarily become senescent at the same rate or time or age; for example, deciduous trees shed only senescent leaves in autumn.

Septa: See Mycelium

Septage

The anaerobic residues from septic tanks is referred to as septage. The primary constituents of septage are human and industrial waste.

Septum

Septum is singular of **septa**.

Sequestering agents: See Sequestration

Sequestration

Sequestration is a process of forming coordination complexes of ions in a solution so that the usual precipitation reactions of metal ions are prevented. The complexing of metallic ions (which are plant nutrients) with organic compounds in solution helps plants to absorb nutrients easily; for example, **polyphosphates** sequester impurities like iron in phosphoric acid in the wet-process. They also sequester micronutrients. Calcium soap precipitates are not produced from hard water treated with certain polyphosphates and metaphosphates.

Sequestration prevents the chemical effect of the ion without removing it from the solution, by forming coordination complexes; for example, sequestration of calcium ions (Ca^{2+}) in water softening. It is also a way of supplying ions in a protected form. The sequestrated ions may be used directly in soil or water spray solutions.

Two groups of organic **sequestering agents** of economic importance are amino polycarboxylic acids (such as ethylenediaminetetraacetic acid) or hydroxyl carboxylic acids (such as gluconic acid, citric acid and tartaric acid). In food industry, sequestering agents help to stabilize the color, flavor and texture of the product.

Sequestrone

Sequestrone, also called sodium-ferric salt of ethylenediaminetetraacetic acid (**EDTA**), is a major **chelating agent** used for foliar sprays in controlling chlorosis.

Serpentine

Serpentine is a mineral consisting of magnesium silicate. With a green and white color and a mottled appearance, this mineral looks like a snake's skin.

Serpentine has a general composition of $Mg_3Si_2O_5(OH)_4$.

Serpentine schemes for irrigation

Serpentine schemes for irrigation, also known as **dead-end serpentine scheme** or **block serpentine scheme** and **meander furrows scheme**, are made by cutting passageways across the furrow direction to connect several channels so that water flows back and forth like a snake's trail.

Serpentine superphosphate

Serpentine superphosphate is a special grade of **single superphosphate** obtained by mixing 20% **serpentine** with 80% single superphosphate.

Serpentine superphosphate improves physical properties of single superphosphates by reaction with free acid, and also supplies magnesium to crops.

Sesbania: See Organic rice farming

Sesquioxide clays: See Sesquioxides

Sesquioxides

Sesquioxides refer to a group of oxides and hydroxides of iron and aluminum with 1.5 atoms of oxygen per atom of the respective metal. The general formula is R_2O_3. Manganese oxides and titanium oxides are also often included in this group.

Sesquioxides also refer to a group of clays containing oxides of iron and aluminum, which are normally found in wet, hot and excessively weathered old soils of the tropics. These are called **sesquioxide clays**. Small amounts of these clays exist in even such soils that are exposed to relatively less weathering. Iron oxides color the soil in shades of red and yellow.

Sesquioxides may be crystalline or amorphous. They do not swell when wet and exhibit low fertility owing to their low exchange capacity. These clays are not sticky, do not behave like silicate clays and are toxic because of the presence of aluminum. They aggregate to form large stable particles.

Sesquioxides increase the bonding of the accompanying mineral particles, and have the greatest influence on their structural characteristics (by increasing the strength of the failure zones). The extent of cementation can be modified by pH, since sequioxides have a pH-dependent solubility.

A sesquioxide mixture with kaolinite exhibits low stickiness. The presence of a large percentage of oxides of aluminum and iron helps adsorption of phosphorus and the formation of insoluble phosphates, and results in a lesser availability of phosphorus to the plant.

Settled density

Settled density is another name for **loose pour bulk density**.

Sewage

Sewage is watery material from chemical plants, municipal waste and septic systems. Safe disposal of large quantities of sewage and septage poses an economic problem.

The end products of all sewage treatment processes are **sewage sludge** and **effluents**. Both components of sewage are used to increase crop production. Sewage sludge is the solid portion produced during sewage treatment. Sewage effluent is essentially clear liquid, containing low concentrations of plant nutrients and traces of organic matter, which after chlorinating can be used for irrigation purposes. Common methods for disposal of sewage include its burning, burial and composting.

On average, sewage contains 22 ppm, 5 ppm and 15 ppm of NPK, respectively. In addition, it contains micronutrients like Zn, Cu, Fe and undesirable materials like heavy metals (Ni, Cd, Pb). All sewage and septage sludges generated annually would replace only about 1%, 4% and 0.5% N, P, K fertilizers, respectively. Sewage is allowed to stand in a settling tank or a septic tank to let the heavier portion to settle, and for organic matter to undergo preliminary fermentation and oxidation. This oxidized sludge is called **activated sludge** which is odorless. It contains 3 to 6% N, 2% P and 1% K on dry weight basis.

Raw sewage should not be used directly for growing vegetables as it may contain toxic elements and bacteria which are dangerous to health. Treated sewage wastewater can be used on fields and thus plowed back into the soil. Field crops grown with sewage irrigation include: (a) fodder crops like oats, sorghum, maize, (b) sugar cane, and (c) vegetable crops like cabbage, cauliflower, potato, lady's finger, brinjal and leafy vegetables.

Waste material, usually liquid, originating from households (kitchen, bath and washings), but not including urine or feces, is referred to as **sullage**.

Sewage effluent: See Sewage

Sewage farm

A sewage farm is one that uses sludge from sewage treatment tanks as a fertilizer and the effluent as irrigation water.

For a piece of land to be suitable to be a sewage farm depends on its capacity in terms of (a) infiltration, (b) permeability, (c) cation / anion exchange, (d) phosphorus adsorption, and (e) holding water. Apart from these, the soil texture, soil structure and the type of clay also determine the suitability of the soil for waste water disposal. Therefore, a sandy soil is preferred for sewage disposal as it is porous enough to act as a filter. A forest is considered an ideal ecosystem to discharge sewage effluent.

Sewage sludge

Sewage sludge is partially dried residue of sewage treatment works and is sometimes used as a fertilizer. It is poor in potash and less beneficial to soil texture than farmyard manure, and must be treated to ward off any diseases or health hazard. Its burial, incineration and drying (for use as a fertilizer) are among the methods for its final disposal. The law prohibits dumping of sewage into the ocean.

There are two types of sewage sludge : (a) **Imhoff sludge** - a low grade sludge containing 2 to 3% ammonia and about 1% phosphoric acid, (b) **Activated sludge** - a high grade sludge containing 5 to 7.5% ammonia and 2.5 to 4% phosphoric acid.

Sewage sludge contains toxic heavy metals such as B, Cd, Cu, Hg, Ni, Pb, Se and Zn, and other substances toxic to plants and animals. Sewage contains pinworms and tapeworms, and organisms causing cholera, diarrhoea, hepatitis, poliomyelitis, etc. Safe disposal of large quantities of **septage**, sewage and effluent waste waters pose one of the most formidable problems to modern society. The problem has both technical and economic dimensions, especially since the 1981 legal ban on the old practice of cities near the coasts dumping human and other solid wastes into the ocean. The disposal of sludge in soil has to avoid surface water and underground water pollution.

Four techniques commonly used in sludge treatment, to reduce the hazard of soil pathogens to near zero are: (a) composting outside for at least 21 days, (b) storing the sludge as a semi-liquid, anaerobic digestion of the sludge for at least 60 days at 20°C or 120 days at 4°C or some other appropriate combination, (c) treating the sludge, when moist, with lime for at least 3 hours, and (d) pasteurizing it for 30 minutes at 70°C.

Running sewage through settling tanks without access to air is one way of handling sewage sludge. Sludge or solid matter is decomposed by anaerobic bacteria. Lagooning can also be used effectively following an activated sludge treatment. It is possible to run sewage through settling tanks and pump air or oxygen through porous plates at the bottom of the tanks. The waste acts as a nutrient for aerobic bacteria which consume the polluting organic matter. The resulting solids are filtered and dried and used as fertilizers.

Considering that (a) fuel costs can be prohibitive (sewage and septage contains a large quantity of water), (b) sewage burning, polluting, and (c) transporting sewage sludge, cost ineffective – management of sewage sludge is a challenge, if not properly planned.

Sludge utilization has more potential in forests than in agronomic crops. Some potential uses of sludge are in mine spoil reclamation, for turf grass on golf courses and cemeteries, around commercial nurseries, on construction sites, and in forests and rangelands. Sludge disposal in soil is a must; however, retention of nitrogen in the soil must be ensured.

Although variable in chemical composition, sludge contains 4% N, 2% P and 0.4% K on dry weight basis. Depending on whether the sludge is subjected to mechanical purification, biological purification or chemical purification, the nutrient contents vary. Some treatments (like treating with lime) reduce the pH levels and help reduce uptake of heavy metals.

Sex pheromone

Sex pheromone is a chemical substance produced exogenously by an organism to influence the behavior or physiology of other members of the same species. Pheromones are made of complex volatile compounds like nitrogen heterocycles, esters, alkanes, etc. It is concerned with direct facilitation of mating. Sex pheromones are generated in some species by males, and in some others, by females.

Sex pheromones can be synthesized to control insects. If an area is sprayed with synthetic female sex attractant molecules, the males of that species become so confused that mating does not occur. (See also Attractants.)

SGN

SGN is short for **size guide number**.

Sheep manure

Sheep manure has the shape of small pellets. It is considered to be the most effective of the non-poultry manures. It promotes quick growth of crops and can be dried, bagged and sold.

Sheep manure contains 1% N, 0.75% P and 0.40% K. Ideally, 60 kg of this manure is required to be spread over a 93 sq. meter of land. Generally, wet feces from young animals like calves are mixed with sheep manure, before applying.

Sheet erosion

Uniform erosion or removal of the surface soil, in thin layers, under the influence of the surface run-off water or wind is called sheet erosion or **laminar erosion** or **sheet washings**.

Sheet erosion is clearly visible on denuded, sloping or recently tilled soil, as light colored sheets of soil. The dark-colored organic matter is carried away, leaving behind light-colored soils, leading in turn to reduced productivity.

Sheet erosion usually does not take place on its own. Sheet erosion and **rill erosion** work hand in hand.

Sheet erosion consists of two essential processes. In the first phase, soil particles are detached from the soil mass by the impact of raindrops. In the second phase, water, (from heavy rainfall), flows over the sloping surface and carries the detached particles with it. The transportation of soil particles is maximal when the thickness of the sheet of water is nearly equal to the particle diameter.

Sheet erosion is mainly responsible for shaping of pediments or erosion fans.

Sheet muscovite

Sheet muscovite is a type of commercial **mica** used as a dielectric material in capacitors and vacuum tubes.

Sheet washings

Sheet erosion is also called sheet washings.

Shifting cultivation

Shifting cultivation is a kind of subsistence farming. It involves clearing of a certain patch of land, say a forest, burning felled material and raising a crop by dribbling seed with hand tools. After the chosen soil loses its fertility, another portion of the forest is chosen up for clearing, burning, etc., and the process is repeated.

Ashes and decomposing organic matter provide nutrients to crops grown this way. Such soils lose their productivity after about 5 years.

With the increasing population pressure on natural resources, migrants, who are ignorant of the local agricultural practices, have taken to shifting cultivation. Therefore, the rate of forest clearance has increased, the bush-fallow period has shortened and the total stock of nutrients in the ecosystem has declined.

Shifting cultivation is an inefficient method, resorted to by migrants or nomads. An alternative to it is the minimum tillage system practiced in combination with surface organic mulch, lime and fertilizers. Another farming system is called bush-fallow, in which bushes and trees are cleared from virgin land, then the land is allowed to lie fallow for a while before cultivation.

Shifting cultivation, also called **slash and burn agriculture**, is widespread in the tropics. It is practiced on some 500 million hectares of rain forest and open forest land, which constitutes about a quarter of the potential arable land of these regions. The cycle begins with the clearing and burning of natural vegetation which, in rain forests, releases a great store of available nutrients for the growth of crops such as maize, cowpeas, cassava and groundnuts. However, the nutrient loss from ash, erosion and leaching can be high, and the encroachment of weeds which compete with crops for nutrients, is rapid. Shifting cultivation is a dominant cropping practice on oxisols.

Traditionally, very little chemical fertilizer is used in shifting cultivation. Re-growth of native forest vegetation is vital to the stability of such agricultural systems. During the re-growth period, deep rooting trees or perennial grasses restore the soil fertility. They draw nutrients from the subsoil and the weathering parent material, and return large quantities of litter (up to 10 tons carbon/ha/year) to the soil surface.

Experience in the savannah shows that a cycle of 2 to 4 years of cropping and 6 to 12 years of fallow can maintain fertility in the long term, but 1 to 2 years of cropping and 10 to 20 years of fallow period are preferred in the wet forest zones. With reduced land availability, shifting cultivation is often replaced by sedentary occupation and reduced fallow period. When the land is cropped continuously, its fertility can be maintained only through manuring.

The following are the reasons for adopting shifting cultivation: (i) Oxisols and ultisols are acidic, with a low nutrient content. Ashes from the burned vegetation act as lime and fertilizer. (ii) A desirable soil structure in the tropics deteriorates rapidly under tillage. (iii) Weeds increase in numbers each year on the cultivated land. (iv) Damage-causing insects and crop diseases increase in frequency and severity each year when crops occupy the same field. (v) Burning of natural vegetation reduces the number of hiding and breeding places for mosquitoes, pests, etc. (vi) Forest burning encourages the growth of grasses, thereby providing more grazing areas for domestic animals.

Shoddy

Shoddy refers to a waste product of the wool or fiber industry. It consists of discarded shreds and fragments of material used as a fertilizer by horticulturists.

Shoddy contains 3 to 12% nitrogen, depending on the amount of pure wool (which is a protein) or other wastes, like cotton.

Short dung

Farmyard manure stored in heaps is called short dung. The material is degraded into simpler liquids, and ammonia is released by bacterial activity.

Short grain rice

Rice is classified on the basis of the size of the grain. Short grain rice is one of the classes, the others being **long grain rice** and **medium grain rice**. Short grain rice is rounded. It mostly contains starch, because of the very high content of amylopectin. This rice, on cooking, becomes sticky.

SI

SI is an abbreviation of **saturation index**.

SI is also an abbreviation for international system of units, now in use in most countries. SI is a modification of the system known as MKSA units (Giorgi system) adopted by the 11th General Conference of Weights and Measures.

Side dressing

The process of applying a liquid or solid fertilizer to the side of a row crop during its growth period is called side dressing. The fertilizer is placed generally 15 cm away from the stalk, vine or trunk of the growing plant, by a hopper or dispenser.

Nitrogen is side-dressed to corn when it is about 50 cm tall. Nitrogen fertilizers are spread between the rows or around the plants of sugar cane, tobacco, cotton, cauliflower, brinjal and tomato.

Side dressing allows greater flexibility to the farmer since it can be done at any time without damaging the crop. Side dressing, is performed around the base of the fruit trees once, twice or thrice a year to supply additional doses of nitrogen.

Sierra process for production of polymer-encapsulated fertilizers

A range of fertilizers, which are polymer-coated, and of the controlled-release kind, is available for use in high-value crops to meet the plant requirement of precise nutrient-release control. Three manufacturing processes namely, the Sierra process, the **Chisso-Asahi process** and the **Pursel Technologies reactive layers coating process**, are used for producing these fertilizers. In the Sierra process, a co-polymer of dicyclopentadiene (with drying or semi-drying oils in an organic solvent) is used as coating material. The fertilizer granules are coated with two layers in a coating drum operating at 65 to 70°C. The addition of maleic acid improves the drying time of the oil. (See also Polymer-encapsulated controlled-release fertilizers.)

Sieve analysis

Sieve analysis is another term for **screen analysis**.

Sieve diameter: See Sieving

Sieving

In the analysis of solid powders like soil or fertilizer, different sizes of solids (like pebbles, gravels and sands) of up to 50 μm, mixed in the powder are separated from the soil by passing it through a series of sieves with different sizes of openings.

Sieves are made of straight, parallel and equidistant wires at right angles to each other. The openings are square, whereas a normal strainer has circular openings. The length of the side of the smallest square opening, through which the sample passes, is known as the **sieve diameter**.

The number of meshes per inch specifies the sieve size openings, without reference to their actual size. The opening in the CGS system can be approximated on the assumption that it is 0.63 of the mesh interval and given by:

$$\text{mm per opening} = \frac{16}{\text{Meshes per inch}}$$

A 100-mesh screen sieve has an opening of 0.16 mm.

Popularly known sieves are **AFNOR** (France), **ASTM** (USA), **Tyler** (USA), **BSA** (UK), **DIN** (Germany) and **BIS** (India). In AFNOR, the length of the sides is stepped in geometrical progression with a common ratio of 1.259.

The percent distribution of particle sizes is determined by passing a measured sample of the soil or sediment through standard sieves. This is known as **sieve analysis** (or **screen analysis**).

Significant difference in analysis

The significant difference in analysis is a **measure of reliability** of deviation of the observed value from the expected value. This is dependent on the precision with which the experiment is conducted.

There are two methods for comparing the results. (a) The **Students' t-test**, and (b) the **variance ratio test (F-test)**. These methods require the knowledge of the degrees of freedom which in statistical terms is the number of independent values necessary to determine statistical quantity. Thus, a sample of n values has n degrees of freedom, whereas the $\Sigma(x)^2$ has n–1 degrees of freedom because for any defined value of S, only (n–1) values can be freely assigned, the nth value being automatically defined from the other values.

The Students' t-test is used for small samples to compare the mean from a sample with some standard value and to express some level of confidence in the significance of the comparison. It is also used to test the difference between the means of two sets of data, X_1 and X_2, using the equation

$$t = \frac{(\bar{X} - \mu)\sqrt{n}}{S}$$

where μ is the true value, S is the standard deviation, $\bar{X}$ is the mean value and n is the number of determinants. The **t-table** speaks of the probability of difference between the experimental results and the true value.

The **F-test** is used to compare the precision of two sets of data. For example, to validate the results of two different analytical methods, or that of two different laboratories, the F test is useful and is derived from the equation

$$F = \frac{S_A^2}{S_B^2}$$

where S_A and S_B are the standard deviations observed in two different laboratories. The larger value is always used in the numerator so that the F value is greater than unity. The value of F thus obtained is checked for its significance by comparing it with the values in the F-table calculated from the F-distribution corresponding to the number of degrees of freedom for the two sets of data. The differences are considered significant, if the calculated F value is less than that from the F-table corresponding to 10%, 5% or 1% significance indicating a probability of not less than 90, 95 or 99%, respectively.

The F test has wider applications than the 't' test as it provides an overall test for several differences, whereas the latter deals with a single difference.

Silica

Silica is silicon dioxide, one of the most abundant materials on the earth's crust. Quartz is an example of silica. It is used as a filler in fertilizers, and also, in the manufacture of glass, ceramics, abrasives, rubber and cosmetics.

Silica fertilizers

Fertilizers containing silicon as the main ingredient are called silica fertilizers. Some plant species, such as flooded rice and grasses grown under upland conditions, absorb a large amount of silicon which accumulates in leaves and stems, and increases the stalk strength. Silicon is essential for rice and is present upto 20% in the plant parts.

Sugar cane is reported to have a high silicon requirement. Soil amendment with silica fertilizers at the rate of 5 to 30 t/ha has shown a significant increase in sugar cane production.

Silicate fertilizers are commonly recommended for basal application, but top dressing at panicle initiation is also common. Top dressing is difficult but it controls the release of nitrogen to rice at critical times. It increases the soil pH, release of ammonia and mineralization of organic matter.

Silica gel

A hard granular hygroscopic form of hydrated **silica** is called silica gel. It is made by heating a coagulated sol of sodium silicate. It is used as a **catalyst** and a **desiccant**.

Silica soil

Silica soil is a fluid suspension of colloidal silica in water. It binds soil particles with organic and inorganic complexing agents to form water-stable crumbs. It also leads to better pore distribution which is required for optimal and stable plant growth.

Silicate

Any of the widely occurring compounds containing silicon, oxygen and one or more metals with or without hydrogen is called silicate. The silicon and oxygen may combine with organic groups to form similar esters. Most rocks and many minerals, except limestone and dolomite, are silicates. Typical natural silicates are gemstones, except for diamond. Portland cement, because it is manufactured from chalk and clay, contains a high percentage of calcium silicates.

Sodium silicate is the best known of the synthetic silicates.

Silicate clays

Silicate clays are a group of clay minerals, made up essentially of hydrous aluminum silicates. According to the classification of clay minerals, silicate clays are grouped on the basis of the number of sheets of silicon and aluminum atoms in their unit layers. Broadly, there are two major kinds, namely, minerals having one layer each of Si-tetrahedra and Al-octahedra (1:1 layer silicates) and those having one layer of Al-octahedra and 2 layers of Si-tetrahedra (2:1 layer silicates). The distinct groups are: (a) kandites (which have one silicon sheet and one aluminum sheet), (b) **smectites** (which have two silicon sheets for every aluminum sheet), (c) **vermiculite** (which is also a 2:1 silicon to aluminum structure but which has properties different from those of smectites), and (d) **chlorite** (which has two silicon and one aluminum sheet plus a sheet of magnesium atoms between adjacent silicon sheets). Montmorillonite, humus, mica (illite), vermiculite, chlorite and kaolinite belong to the class of silicate clays.

Kandites are distinguished from other clay minerals by three properties. First, they are 1:1 layer minerals. Second, there is little substitution of aluminum for silicon in the tetrahedral sheet or other cations for aluminum in the octahedral sheet. Third, the interlayer between the two sheets is closed so that little water and few cations can enter between the sheets.

The large charge and the available interlayer surface make smectites one of the most reactive parts of the mineral fraction. Smectites, because of their enormous expanding nature, have a very large internal surface area (550 to 650 m^2/g) and CEC (80 to 120 cmol/kg). They are major clay minerals in vertisols.

Vermiculite is a 2:1 layer expanding silicate mineral and has a net negative charge of 0.7. This charge attracts and holds cations like Ca^{2+}, Mg^{2+} in the interlayer. It has a high CEC (100 to 180 cmol/kg). Chlorite is a 2:1:1 layer silicate and has low CEC value (15 to 40 cmol/kg). (See also Clay minerals.)

Siliceous plants: See Timber and range site indices

Silicon

Some plants need silicon (Si) in addition to micro and macro nutrients. It is one of the most abundant elements absorbed by plants. Silicon belongs to Group 14 (formerly IVB) of the Periodic Table (Fig.S.8). It is an essential trace element for the normal growth of higher animals, as it is involved in the formation of bones and cartilages. Crops grown in the absence of soluble silica are more prone to mildews than those provided with soluble silica. Rice, cucumber, gherkin and barley require silicon. Silicon improves the growth of sugar cane. Silicon corrects soil toxicities arising from the presence of excessive quantities of Mn, Fe and active Al. The oxidizing power of rice roots and their tolerance to the high level of iron and manganese are attributed to silicon nutrition.

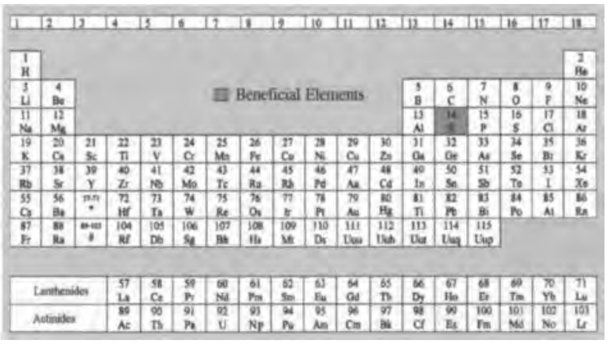


Fig.S.8: Position of silicon in the Periodic Table.

In a field trial, when parts of a rice crop had a silica to nitrogen ratio of 11:2, 10 tons/ha of extra rice was produced. Silicon helps to (a) maintain the erectness of rice leaves, (b) increase resistance to insect pests, (c) improve photosynthesis, (d) increase the number of stems, and (e) improve the fresh as well as dry weights of rice plants. If silica is withheld during the reproductive period, the number of spikelets per panicle and the ripened grain percentage decreases.

Silicon contributes to the structure of cell wall, thus (a) making the cell wall more immune to diseases, (b) improving the stalk strength, and (c) increasing the resistance to lodging. Rice and sugar cane respond favorably to silicon fertilizers. Enzyme-silicon complexes formed in sugar cane act as protectors or regulators of photosynthesis and enzyme activity. By suppressing the invertase activity in sugar cane, silicon increases sugar production.

Silicon and oxygen occupy 75% of the earth's crust, of which silicon alone is 27.7%. Silica, which occurs to the extent of 60 to 80% as insoluble quartz silica, is in the form of mono-silicic acid [$Si(OH)_4$], the availability of which increases with increasing soil pH and temperature. Roughly, 130 ppm silicon (SiO_2) is the critical limit of the available silicon in air-dry soil for maximizing wetland rice yield; the critical limit is raised by adding silicon (as SiO_2).

Silicon uptake by plants differ with plant species. Gramineae contains 10 to 20 times more silicon than that normally found in legumes and dicotyledons. Paddy contains 4.6 to 7.0% of silicon in the straw. Oxides of iron and aluminum, liming, flooding and nutrient supply influence silicon-uptake; high soil-water content increases the uptake in rice, barley, oats, sorghum and sugar cane.

The quantity of silica fertilizer to be added to the soil is guided by the ratio of the available silica to organic matter, which if less than 100, warrants the use of fertilizer; if the ratio is more than 100, it calls for the addition of organic matter; if less than 50, it indicates that the soil is suffering from silicon shortage. For a silicon-deficient area, the addition of 2 ton/ha of silica fertilizer is recommended. **Freckling**, which is a necrotic leaf spot condition, is a symptom of low levels of silicon in a sugar cane plant that receives direct sunlight, the ultraviolet (UV) radiation in sunlight being the causative agent. Sufficient quantities of silicon in a sugar cane plant filters out harmful UV radiation.

Major silica fertilizers include calcium silicate slag, calcium silicate and sodium meta-silicate. 1.5 to 2.0 tons of silicate slag per hectare usually provides sufficient silicon for rice crops produced in low-silicon soils. Silicate fertilizers serve as a source of silicon and a liming material in acid soils. Slags from the steel industry, ground basic-slag (containing varying quantities of Al, Ca, Fe, Mn, Mg and Si), and wollastonite (Ca-Mg silicate) are all silicate fertilizers.

Sodium silicate increases the crop yield in phosphate-deficient soils, possibly because silicates help increase the assimilation of phosphoric acid by the plant and not the soil. However, according to some, silicate increases the amount of available soil phosphate. Heavy applications of nitrogen make the rice plant more susceptible to fungal attack because of the decreased silicon concentration in the straw.

The favorable effects of silicon on plant growth have also been attributed to potassium.

Silt

Soil is made of particles of various sizes. Silt, a constituent of soil, comprises particles of sizes between those of clay and sand. According to the international particle-size system, a silt particle size is about 2 to 50 μm in diameter. It is further divided into **fine silt** (2 to 20 μm) and **coarse silt** (20 to 50 μm). The percentage of silt particles in a particular soil is taken into consideration while defining soil texture.

Silt is often carried as suspended particles in running water and deposited on riverbeds, riverbanks or in lakes as alluvial sediments.

A soil that contains 40% or more of clay and 40% or more of silt is called **silt clay**. A soil with 27 to 40% clay and less than 20% sand is known as **silt-clay loam. Silt loam** has 30% or more silt and 12 to 27% clay. Similarly, silt loam soil consists of 50 to 80% silt, less than 12% clay and the rest sand.

Silt-clay loam

Silt-clay loam is a soil textural class containing a relatively large amount of silt, a lesser quantity of clay and a still smaller quantity of sand. A soil with 27 to 40% clay and less than 20% sand is known as silt-clay loam. In the **feel method for determination of soil texture**, silt-clay loam gives a very smooth feel and forms a moderately hard ball when dry. It sticks to the fingers and shows some flaking on the ribbon surface similar to silt loam. (See also Silt.)

Silt loam

Silt loam is a soil textural class containing large amount of silt and small quantities of clay and sand. It has either 30% or more of silt and 12 to 27% of clay or 50 to 80% of silt, less than 12% of clay and the rest sand.

Silt loam gives a smooth, slick, buttery feel, on touch. It forms a firm ball and stains the finger. It has a slight tendency to ribbon with a flat surface.

The determination of the soil texture is possible by the **international pipette method**. It is based on the rate of fall of solid particles in a liquid medium as per Stokes' law. Assuming the average particle sizes of sand, silt and clay as 50, 5 and 2 μm respectively, the quantities of particles are calculated and the textural class determined. A rough but quick method like the **feel method for determination of soil texture** is useful for *in-situ* determination of soil texture.

Silty clays

Silty clays are a soil textural class that contains a relatively large amount of silt and clay and a small amount of sand (80 to 60% clay and silt and less than 20% sand).

Silvics: See Silviculture

Silviculture

Silviculture is the science of growing and tending forest trees. The study of the life history and general characteristics of forest trees and crops is called **silvics**. The practice of cultivating forage crops in association with forest crops on the same land and at the same time is called **silvipasture**. The intervening spaces between rows of trees are utilized for growing nutritious grasses to prevent the growth of weeds in that place.

Silvipasture: See Silviculture

Simazines

Simazines are synthetic compounds obtained from **triazines**, used as herbicides to kill broad-leaved weeds and grasses before they germinate.

Simple decomposition

Simple decomposition is the breaking down of a material into two or more simpler compounds. For example, water decomposes to form oxygen and hydrogen. Calcium carbonate decomposes into calcium oxide and carbon dioxide on heating.

Simple lipids

Simple lipids are a class of lipids lacking fatty acids in its structure. They are triglycerides or fats, steroids and terpenes. (See also Steroids.)

Simple sugars: See Sugar

Single fertilizer

In Thailand, single fertilizer is the term used for **straight fertilizer**, such as ammonium nitrate, potassium chloride, etc.

Single superphosphate

Single superphosphate (SSP), also referred to as **ordinary** or **common superphosphate** $Ca(H_2PO_4)_2$, is the first chemically manufactured commercial fertilizer. John B Lawes of England coined the term superphosphate.

Single superphosphate is produced as a combination of rock phosphate and concentrated sulphuric acid. Approximately equal amounts of the two ingredients are thoroughly mixed, dried and cured.

Chemically, SSP contains monocalcium phosphate and calcium sulphate. The hardened mass is either ground or granulated (Fig.S.9). The final product is grey, brown or white in color and contains 16% water-soluble P_2O_5 (7% P), 12% S, 21% Ca and about 4% phosphoric acid by weight. The elemental analysis indicates that the fertilizer has more sulphur than phosphorus. Its granular variety has a bulk density of 0.961 g/cm^3, angle of repose 26° and a critical humidity of 93.7% at 30°C.

Fig.S.9: Granular single superphosphate fertilizer.

The monocalcium phosphate of single superphosphate dissolves in the soil moisture and the roots absorb phosphoric acid in that form. The rest of the solution of monocalcium phosphate precipitates in the soil pores and forms different phosphate compounds which are water-insoluble and do not leach out. A compound like dicalcium phosphate dissolves in carbonic acid in water and becomes available to plants, but the insoluble tri-calcium phosphate remains fixed in the soil. Where soil is markedly acidic (ie., rich in active iron and aluminum) monocalcium phosphate gets converted into insoluble phosphate compounds, as shown below:

$$2Ca(H_2PO_4)_2 + Fe_2O_3 \longrightarrow 2FePO_4 + 2CaHPO_4 + 3H_2O$$

Iron and aluminum phosphates are so insoluble that phosphorus is unavailable to the plant. This is why single superphosphate does not perform well in acidic soils unless it is limed.

If single superphosphate is applied just before sowing, plants get enough supply of phosphorus at their critical growing stages. Single superphosphate is not suitable for top dressing because of its slow movement. Sometimes, single superphosphate is mixed with lime or dolomite in order to increase its effectiveness. The production of single superphosphate is on the rise in tropical countries, like India.

Single superphosphate (SSP), compared to various sulphur-containing fertilizers like DAP and TSP, significantly increases the grain yield of many agronomically important crops like wheat, chickpea and groundnut. Its compatible nature leads to its wide use in the preparation of fertilizer mixtures. It can be freely mixed with ammonium phosphate, ammonium sulphate, ammonium chloride, muriate of potash and sulphate of potash. Mixtures of SSP with materials containing free lime or calcium ammonium nitrate or urea should not be stored for long as they cause reversion of water-soluble phosphate.

In order to get the maximum benefits, single superphosphate should be applied to soils deficient in phosphorus as well as sulphur. The time, place and the quantity of application are critical. (See also Single superphosphate production processes.)

Single superphosphate production, batch process: See Single superphosphate production processes

Single superphosphate production, continuous process: See Single superphosphate production processes

Single superphosphate production processes

Single superphosphate (SSP), also known as **normal** or **ordinary superphosphate**, has been a major phosphate fertilizer for a long time. Single superphosphate is the principal phosphate fertilizer because of the following reasons: (i) The production process is simple, requires little skill and small investment. (ii) It sets a standard of comparison for other phosphate fertilizers. (iii) It supplies two secondary nutrient elements, namely, sulphur and calcium. Despite these advantages, single superphosphate has a low phosphorus content (16 to 22% P_2O_5), and a 6 to 10% moisture content. These properties sometimes make SSP production uneconomical.

The grade of phosphate rock determines the quality of the product. Low reactivity of the rock calls for its fine grinding. It is difficult to make SSP from igneous apatites. Up to a point, the presence of aluminum and iron compounds can be tolerated, though they reduce the solubility of phosphorus in water. The increase in the ratio of CaO: P_2O_5 raises the consumption of sulphuric acid per unit of P_2O_5 and decreases the grade. Silica has no adverse effect and a higher chloride content in the phosphate rock is acceptable.

The main overall reaction in the manufacture of single superphosphate is:

$$Ca_3(PO_4)_2 + 2H_2SO_4 + H_2O \longrightarrow Ca(H_2PO_4)_2 \cdot H_2O + 2CaSO_4 + 108.44\ \text{kcal}$$

The reaction takes place in two stages. In the first stage, sulphuric acid reacts with the phosphate rock, forming phosphoric acid and calcium sulphate. In the second step, phosphoric acid reacts with more phosphate rock, forming monocalcium phosphate. The first step occurs readily, while the second stage takes several days. Since most phosphate rock is fluorapatite, fluorides react with sulphuric acid to give hydrogen fluoride, which reacts with silica to form silicon tetra fluoride as well as fluorosilicates.

A technical variation among single superphosphates is the **Kotka superphosphate**, a mixture of superphosphate and phosphate rock. It is so named because it was originally made in Kotka, Finland. It needs little curing and the free acid content is low. Its effectiveness is equal to that of equivalent amounts of fully **acidulated superphosphate** and raw phosphate rock applied separately.

Another special grade single superphosphate is **serpentine superphosphate**, a product obtained by mixing 20% **serpentine** (a mineral consisting of magnesium silicate) with 80% single superphosphate. Serpentine supplies magnesium to crops and improves the physical properties of single superphosphate by reaction with free acid. For serpentine superphosphate to be effective, SSP must contain at least 16% phosphorus (as P_2O_5) soluble in neutral ammonium citrate, of which at least 93% is water-soluble.

'**Enriched superphosphate**' is essentially a mixture of single superphosphate and triple superphosphate made by acidulation of phosphate rock with a mixture of sulphuric and phosphoric acids. The grade contains 25 to 35% phosphorus (as P_2O_5) and is useful for application in sulphur deficient areas.

A few operations are involved in the manufacture of single superphosphate. These include the following: (i) A finely ground (less than 100 meshes) phosphate rock is mixed with sulphuric acid in a cone mixer. The commercial concentrated sulphuric acid (77 to 98%) is diluted to around 68 to 75% before reacting with the rock. (ii) The fluid material from the cone mixer goes to a den where it solidifies owing to a continued reaction and crystallization of monocalcium phosphate. The superphosphate is removed from the den after 0.5 to 4 hours. It is still at a temperature of about 100°C and plastic in nature. (iii) The product from the den is sent to storage piles for final curing of 2 to 6 weeks. During curing, the free acid, moisture and the unreacted rock content decreases, whereas the available water-soluble phosphorus content increases. As the reaction approaches completion during curing, the material hardens and cools. The cured product is crushed in a hammer mill or cage mill to a size of about 6-mesh. (iv) When granular superphosphate is required, the product is granulated before or after curing. Granulation before curing is advantageous as it requires less steam or water. After granulation, the product is dried in a direct contact drier and screened.

Initially, SSP was produced by the batch mixing process. Now, there is a wide variety of both batch and continuous mixers and dens. These are described below: In one typical **batch process**, rock phosphate and sulphuric acid in correct quantities are added to a pan mixer of 1 to 2 tons capacity. After mixing for 2 minutes, the fluid slurry is discharged into a box den which has a 10 to 40 ton capacity. When the den is filled completely (1 hour), it is moved slowly to a mechanical cutter which removes thin slices of the product to a conveyor. Some plants have two dens, which are used alternatively. This set up gives a production rate of 40 tons per hour.

Batch mixing is competitive for the following cases: (i) When only igneous rock is available, batch mixing and associated denning are preferred since precise control of mixing conditions is possible. Also, the den can be made tight enough to contain the very fluid slurry. (ii) For a small phosphate source in a remote place, batch process can be built.

In a typical **continuous process**, the den is a broad field den. The mixer may be a cone mixer, paddle mixer or a cone mixer with a mixing impeller. The retention time of the dens can be varied by changing the speed of the conveyor, but usually ranges from 30 minutes to 1 hour. The production of 1 ton SSP having 20% available phosphorus as P_2O_5 requires 625 kg of ground rock phosphate, 320 kg of sulphuric acid and 90 kg of water. The reaction generates considerable heat.

A 20-ton per hour of non-granular superphosphate would need 60 kW electrical load. The capital cost of SSP production varies widely depending on the battery limits adopted. SSP plants often use sulphuric acid that is a byproduct. Phosphate rocks are ground at the site of mining.

The costs of bagging, transportation and storage of SSP are high, because the mass of SSP required is more than twice that for TSP. Hence small plants of SSP are economically better suited to serve small local markets.

Sink

The term sink has many connotations. In physics, a sink refers to a body or process used to absorb or dissipate heat. Soil acts as a reservoir for carbon monoxide. The depression in the land surface where water collects is also called a sink. Water flows downward under the force of gravity. It must be disposed of into a sink where its presence is desirable. If the sink exists downhill, the cost and effort of pumping can be minimized or avoided. In the context of agriculture, the term sink designates the plant parts (like fruits, grains and tubers) that store photosynthates.

Even under favorable conditions of light, water, nutrients, temperature and freedom from pests and diseases, grain yield is likely to be limited either by the capacity for photosynthesis (source) or by the storage of photosynthates (the sink). This aspect is still a matter of speculation. In barley, neither the source nor the sink appears to limit the grain yield; the feedback interactions suggest that the photosynthetic rate may adjust to the requirements of the grain.

The sink size in most cereals is dependent on the number of heads per unit area, spikelets per head, grains per spikelet, grain volume and grain weight. A study of wheat and rice suggest that the storage capacity may be a major limitation to the grain yield. Split fertilizer applications provide a greater opportunity for a sink-source balance to exist. A single nitrogen application at the planting time or seedling stage may limit either the sink or the source at a subsequent critical period of the yield.

SIR

SIR is short for **Storie index rating of fertility**.

Six course rotation

An agricultural system in which six crops are rotated is called a six course rotation or East Lothian rotation.

Size guide number

Agrochemicals, fertilizers or their mixtures that neither interact nor exhibit their individual characteristics when mixed, are said to be compatible with one another. This compatibility can be chemical or physical. The knowledge of compatibility is essential for preparing fertilizer blends from individual salts.

There are two techniques based on the particle size analysis to determine the physical compatibility, [namely, the **cumulative particle size** distribution and size guide number (SGN)]. The SGN technique entails median particle size determination of each blended ingredient by locating the 50% cumulative retained point from the size distribution curve. The particle size at 50% of the cumulative retained point is multiplied by 100 and rounded off to the nearest five. This number is referred to as the SGN of that blend ingredient. The SGN of each bulk blend ingredient is compared and its compatibility evaluated. If the difference in cumulative particle size distribution between the ingredients is more than 20%, the ingredients are incompatible and if it ranges from 0 to 10%, they are compatible.

Slag

Slag is a fused agglomerate, usually of silicates, which separates during metal smelting and floats on the surface of the molten metal. It is formed by the combination of flux with gangue of ore, ash of fuel and perhaps furnace lining.

Slag is often used as the medium to separate impurities from metal.

Slag also means the residue or ash from coal gasification processes. It may run as high as 40% depending on the rank of coal used.

Slaked lime

Slaked lime is another name for calcium hydroxide or hydrated lime. It contains 50% calcium and is a standard liming material. Slaked lime is prepared by hydrating calcium oxide and has a **calcium carbonate equivalent** of 136.

Slaking

The process of manufacturing calcium hydroxide is called slaking.

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

Slash and burn agriculture: See Shifting cultivation

Sleet: See Precipitation

SLESA

SLESA is short for **soil loss estimator for southern Africa**. (See Erosion prediction.)

Slide method for quantification of root colonization

Slide method for quantification of root colonization is a microscopic technique used for the estimation of **VAM** fungi in fragments of colonized roots. The method includes staining of root fragments with acid fuchsin and trypan blue. As there are no morphological symptoms due to infection of VAM (except with certain plants), slide method is the most common method used to detect VAM root colonization. The slide method estimates the length of the colonized roots.

Slow-growing *Rhizobium* bacteria

Slow-growing *Rhizobium* bacteria are those with a slow growth pattern. Most of the slow-growing *Rhizobium* bacteria utilize the Enter-Douderoff pathway. These strains can utilize most sugars except a few like sucrose and trehalose. They also consume pentose and produce alkali on the medium in which they grow. The genes for nitrogen fixation are in their chromosomes. Their uptake of glutamic acid and ketoglutaric acid is very rapid. Examples of such strains are *Bradyrhizobium japonicum* and *Rhizobium lupini*. *Bradyrhizobium japonicum* grows on nodulating soybean, *Lotus*, *Vigna* and *Cicer* types of legumes.

Slow release fertilizers: See Coated fertilizers

Sludge

Sludge is a semi-liquid mass removed from the liquid flow of **sewage**. Domestic sewage containing more than 20% solid is also called sludge. The solids may contain nutrient and toxic elements, depending on the source of the sludge and its treatment.

Sludge is disposed of by burning and burying it, or by adding it to water or soil. The preferred choice is to incorporate sludge into the soil, since this method does not pollute water. Disposal is more common than sludge utilization because of the potential health hazards, high transporting cost and low fertilizer value. Heavy metal contaminants are also a matter of concern.

A potential use of sludge is in mine spoil reclamation. The sludge disposal can be done in soils having clay and organic content. (See Activated sludge.)

Sludge disposal in the dihydrate process of phosphoric acid production: See Phosphoric acid production processes

Slurry

Slurry is a paste consisting of a suspension of finely divided solids in a liquid. Slurrying technique is used in the manufacture of phosphoric acid by wet process. For example, a slurry prepared out of microbial cultures (like *Rhizobium, Azotobacter, Azospirillum* cultures, etc.) in water is applied to seeds before sowing so as to facilitate the root-nodule production for nitrogen-fixation, especially in legumes.

Slurry fertilizers are fluid mixtures containing dissolved and undissolved plant nutrients which are used because of their low cost, availability of higher grades, capacity for mixing easily with sparingly soluble micronutrients, herbicides and insecticides. To ensure homogeneity, these materials are continuously agitated mechanically.

Slurry fertilizers have grades like 7-14-21, 3-10-30, and 4-12-24. Secondary nutrients and micronutrients from relatively cheap sources, herbicides and pesticides can be blended satisfactorily. Also as there is no problem of salting-out, high analysis grades can be formulated easily. The most popular phosphate material used in slurry fertilizer is ammonium polyphosphate.

The major disadvantages of slurry fertilizers are their higher viscosity and settling characteristics. Hence, they are not easy to handle and store. All nutrients are not immediately available to crops through slurry fertigation. The slurries transmit diseases that can be controlled, if slurries are used only on arable land. The harmful organisms die if slurries are stored for at least 60 days.

Slurry-based nitrophosphate-type process

The slurry-based nitrophosphate-type process is one of the processes for the manufacture of NPK granular fertilizers. (See also Particle size distribution of fertilizers.)

Slurry fertilizers: See Slurry

Slurry granulation

Slurry granulation is a process in which slurry is utilized in the form of granules which spread evenly on the soil surface, avoiding segregation. In Europe, slurry granulation is widely practiced for the production of N, NP and NPK fertilizers. Granulation is made in fluid-bed spray granulators or by spray drying and spherodisers. Slurry granulation, which is affected by various impurities, is controlled in the liquid phase. Usually, a thin film of slurry having the required fertilizer composition is sprayed onto small solid particles. The granules are built up in layers. The process is mainly controlled through recycling and by the slurry water content (the recycling ratio being 5:1 or more).

Slurry manure

Slurry manure is a mixture of all the components of manure - excreta, urine, wasted fodder, spilled water, etc. The inputs may be collected in a tank. If a proper system is inbuilt to channelize all the inputs so that they may be collected, the combined benefits can have a high nutrient value. Urine, for instance, if effectively collected, contains two-thirds of manure nitrogen. It is also a very effective means of quick plant nutrition. Loss of ammonia, which occurs in this open system, may be prevented by covering the mix with straw.

Small bag storage test

Small bag storage test is for evaluation of the caking tendency of a fertilizer. In order to facilitate storage conditions, 1800 cm^3 of the material is sealed in a moisture-resistant bag and stored under a predetermined pressure for a specified period of time (from 1 to 12 months). By measuring the hardness and percentage of lumps formed during storage, the caking tendency can be estimated. However, the small-bag storage test takes a long time to complete and is not always reliable.

Small soil families: See Soil family

Smectites

Smectite is a 2:1 clay mineral which undergoes reversible expansion on absorbing water. This 2:1 layer aluminosilicate has aluminum octahedral sheets sandwiched between two silicon tetrahedral sheets to make a unit cell. Some examples of smectite are **montmorillonite**, **beidellite**, **nontronite** and **saponite**.

Each member of the smectite family has a slightly different chemistry depending on the kind, amount and location of isomorphous substitution.

Pyrophyllite without interlayer water or any substitution has a spacing of 0.96 nm. Montmorillonite often has some aluminum substituting for silicon and some iron and magnesium substituting for aluminum, and is hydrated with a range of spacing up to 1.8 nm. Nontronite has no aluminum in the octahedral sheet but has iron instead. Saponite has all the magnesium ions and aluminum ions in the octahedral sheet. Hectorite has some lithium in the octahedral sheet. The large charge and the available interlayer surface make smectites one of the most reactive parts of the mineral fraction.

Smectite has an octahedral sheet that shares oxygen ions between two tetrahedral sheets. A cation substitution occurs in both octahedral and tetrahedral sheets. The di-octahedral (containing aluminum) smectite, montmorillonite, is the most common member in soils. Because of its enormous expanding nature, smectite has a very large internal surface area (550 to 650 m^2/g or more) and cation exchange capacity (CEC) of 80 to 120 moles/kg. These are the major clay minerals in vertisols, such as the black cotton soils of India and the backlands of Texas. The interlayer expansion of smectites is related to the type of interlayer ions. In some cases individual layers completely separate, producing extremely small-sized particles. The shrink-swell potential is one of the most important engineering properties of the soils.

Smectites are widely used as binding agents for moulding sands in metallurgical castings, drilling fluids, lubricants and waterproofing agents. They are also used to retard the movement of water and chemicals used in inks, cosmetics and polish. Smectites have variable proportions of Na, Al, Fe and Mg and have good absorptive and swelling properties and high cation-exchange capacities. Smectites have high specific surface areas and these undergo major changes on hydration and desiccation in the interlayer spacing.

Smoothing drainage system

Smoothing is a surface drainage system, in which a uniform slope of the land is maintained by removing minor ridges and depressions without changing the topography of the land. This allows the flow of surface water toward the ditches. Land needs to be smoothened, approximately once in two years, and repairs have to be done annually.

SMP buffer

SMP buffer is short for **Schomaker-Mclean-Pratt buffer**.

SNI

SNI is short for **soil nutrient index**.

Soaking test

Soaking test is a type of **puddle test of soil** for evaluating the suitability of a particular clay. The clay is moulded into a ball of 50 mm diameter and kept in a 600 ml beaker, immersed in water. The sample is observed at regular intervals of a few hours each for up to 4 days. If no disintegration of the ball is observed, then the clay is considered suitable for use.

Soap clay

Bentonite is also called soap clay.

Social forestry

Social forestry is a program of forestry development and conservation under various soil and agro-climatic conditions. It is done through planting trees on wastelands or community lands, and reforestation of degraded forests. This is different from **agroforestry**, which is meant for farm holdings.

Societe Industrielle d'Acide Phosphorique et d'Engrais (SIAPE) process: See Phosphoric acid production processes

Soda fulvic acid

Soda fulvic acid is a type of fulvic acid soluble in alkali. It is abundant in young humus and organic matter-enriched soils. (See also Fulvic acid.)

Sodicity

Sodicity is a term used for soil or water with excess sodium. High sodicity is a state of **sodium hazard** and is unfavorable to plant growth.

Sodic water is similar to **saline water** and is characterized by a high **exchangeable sodium percentage (ESP)** or **sodium adsorption ratio (SAR)**.

Sodic soils are characterized by a large proportion of sodium in the total exchangeable cations. In addition, for SAR >13 (or ESP >15%), sodic soils have electrical conductivity (EC) less than 4 dS/m. Some define sodic soils as a non-saline soil with an ESP of >15% and EC <4 dS/m.

Sodic soils are usually alkaline, with a pH value of upto 10 pH. They tend to be sodic, because of the abundance of sodium salts in sodic soils, but not necessarily saline.

Sodic soils are characterized by their impermeability which is caused by the sodium ions dispersing the clay and humus into individual hydrated particles. This happens because sodic soils are low in other soluble salts, or may even be non-saline. However, in the presence of other salts like those of Ca, Mg, etc. in significant quantities, flocculation can occur among colloidal particles. A low concentration of calcium makes the soil or water even more toxic to certain plants.

Sodic soils are sometimes called **black alkali**, because of the color of humus particles that disperse and move with water.

Unless corrected, sodic soil is not suitable for vegetation or agriculture. It is costly and difficult to reclaim such soils as it needs large amounts of amendments to control the sodium accumulation. The soil, which may be low in oxygen, not only becomes impermeable, but also difficult to till and drain. This is especially true when the salinity and the sodium adsorption ratio are high in the irrigation water used for leaching.

The exchangeable Ca, Mg and Al ions stick close to the colloid surfaces of the leached soils, even at low salinity levels. However, sodium is loosely held and ready to hydrate, which makes sodic colloids disperse.

The problem of sodium is most severe with montmorillonitic soils and the least with slightly swollen kaolinitic soils and sesquioxide clays.

Every year, enormous amounts of salts are added to the soil, by way of irrigation water. A proper understanding of the quality of this water is thus necessary for effective planning of crops.

The quality of irrigation water is determined on the basis of the (a) total salinity, (b) sodicity, (c) anion composition, and (d) concentration of toxic elements. The impact of irrigation water quality on agriculture is studied in terms of salinity hazard, sodicity hazard and toxicity hazard. Fig.S.10 and Table-S.2 give the irrigation water quality criteria of the U.S. Department of Agriculture (USDA).

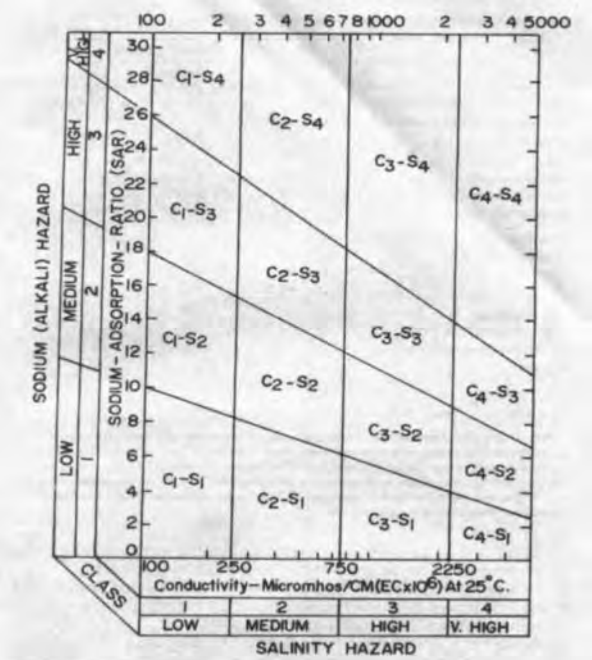


Fig.S.10: U.S. Salinity staff diagram of USDA for clarifying irrigation water. (Source: Richards, 1954. Reproduced from "Soil Salinity and Water Quality", 1996, by R. Chhabra. Oxford & IBH Publishing Co. Pvt. Ltd., India. With permission.)

Crops to be grown in alkaline soils have to be carefully chosen to obtain acceptable yields. Sodicity tolerance ratings for different crops are fixed on the basis of crop hazard as manifested by a 50% reduction in relative yields. A correlation exists between the exchangeable sodium percentage (ESP) range and the crop tolerance. Table-S.3. shows the range of ESP that crops can tolerate.

Table-S.2: Salinity and sodicity of water and their use in irrigation.

Salinity/ sodicity class	Description and use
C1	Low salinity water which can be used for irrigation with most crops on most soils.
C2	Medium salinity water which can be used for plants with moderate salt tolerance.
C3	High salinity water which cannot be used on the soil with restricted drainage.
C4	Very high salinity water which is unsuitable for irrigation, except where the soils are highly permeable and high salt-tolerant crops are to be grown.
S1	Low sodium water can be used for irrigation of most soils. Sodium-sensitive crops may still accumulate injurious levels of sodium.
S2	Medium sodium water, presents hazard for fine-textured soils; may be used on coarse-textured or organic soils with good permeability.
S3	High sodium water unsuitable, except in the case of gypsiferous soils.
S4	Very high sodium water generally unsatisfactory, except where gypsum amendment is made.

Source: USDA Handbook, 60. As adapted by U. Aswathanarayan's "Soil Resources and the Environment", 1999. Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, India. With permission.

Table-S.3: Crops and their tolerance to exchangeable sodium percentage (ESP).

ESP range	Crops
10–15	Safflower, mash, peas, lentil, pigeon-pea, urd bean
16–20	Bengal gram, soybean
20–25	Peanut, cowpea, onion, pearl millet
25–30	Linseed, garlic, guar
30–50	Raya, sunflower, wheat
50–60	Barley, sesbania
60–70	Rice

Source: Gupta and Abrol, 1990. As adapted by U. Aswathanarayan's "Soil Resources and the Environment", 1999. Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, India. With permission.

Some crops exhibit sodium toxicity even at relatively low ESP levels (2-10). However, most field crops are moderately tolerant to sodicity (See Table-S.4).

Alkaline soils or sodic soils are reclaimed by the process of amendment which involves removing part or whole of the exchangeable sodium by calcium ions in the root zone, using gypsum, sulphur, etc. (See also Salt affected soils.)

Sodicity hazards: See Water quality

Sodicity tolerance

Sodic soils have a high sodium content (ESP > 15%) and a high pH (8.5 to 10). With such a high proportion of exchangeable sodium ions, soils become impervious to water, difficult to till, hard to drain, low in oxygen and restrictive to root growth. All these factors may interfere with the water absorption and nutrient uptake because of the existence of an osmotic pressure in the soil solution, but not in the root cells.

The **sodium adsorption ratio (SAR)** is used to estimate the ratio of the sodium content to the magnesium (plus calcium) content in water. Good quality irrigation water may contain salt concentration of up to 1000 ppm. Irrigation water with a 1000 to 3000 ppm salt concentration is considered marginally useful for irrigation. The Food and Agriculture Organization (FAO) has issued guidelines for water quality usable for irrigation. An exchangeable sodium concentration of above 15% (SAR = 13) exert the greatest adverse effect on plant growth, because it disperses soil.

Plant species have variable tolerances to the sodicity of soil. Glycophytes are highly sensitive to salt, whereas halophytes (like dwarf glasswort) can tolerate a higher salt concentration. Specific effects on different parts of the plant vary. Plant tolerances usually improve with plant maturity. Both barley and cotton have considerable salt tolerance, but a high salt concentration affects its vegetative growth more than the seed heads. A high salt concentration reduces rice yield and affects vegetative growth. Saline soils reduce the yield of tomatoes by 10% for each 0.15 S/m of conductivity. Oranges are salt-sensitive and show a yield reduction even at conductivities of 0.25 S/m. Many fruits, including citrus fruits, stone fruits and blackberries are injured by as little as 5% of exchangeable sodium, while grapes are quite sodium-tolerant.

On the basis of extensive studies, the relative sodicity tolerances of crops have been correlated to percent exchangeable sodium. Table-S.4 summarizes the relative tolerance of various crops to exchangeable sodium.

Table-S.4: Relative tolerance of some crops to exchangeable Sodium.

Crop reaction to exchangeable sodium	Crops
Sensitive	Gram, chickpea, soybean, groundnut, sesamum, pea, maize, cotton, cowpea, lentil.
Moderately tolerant	Wheat, barley, oats, lucern, turnip, sunflower, safflower, linseed, berseem, onion, garlic, pearl millet.
Tolerant	Paragram, bermuda grass, rice, Rhodes grass, sesbania, sugar beet.

Source: Adapted with permission from "Soil Salinity and Water Quality", 1996, by Ranbir Chhabra. Oxford and IBH Publishing Co. Pvt.Ltd. With permission.

Salt tolerance of crops is judged using two criteria: (a) threshold soil salinity (Ct) which leads to a reduction in yields and is expressed in terms of electrical conductivity (EC) in dS/meter, and (b) slope (S) which corresponds to a decrease in the percent yield per unit of salinity increasing beyond the threshold. The slope (S) is given by:

$$S = \frac{50}{(EC_{50\%\ \text{yield}} - EC_{\text{threshold}})}$$

The decrease in relative yield (YR) of crops due to an increase in salinity is given as:

$$YR = 100 - S(C - C_t)$$

where C is the salinity of the soil saturation extract (dS/m), C_t is the salinity threshold value (C for 100% yield) and S is the yield loss per unit increase in salinity.

Sodic soil: See Sodicity

Sodic water: See Sodicity

Sodium

Sodium (Na) is a silvery reactive element belonging to Group 1 (formerly IA) of the Periodic Table (Fig.S.11). It is not an essential element for any crop (including salt marsh plants), but it is useful in certain biological processes. Some crops grow better with sodium which is absorbed as an ion.

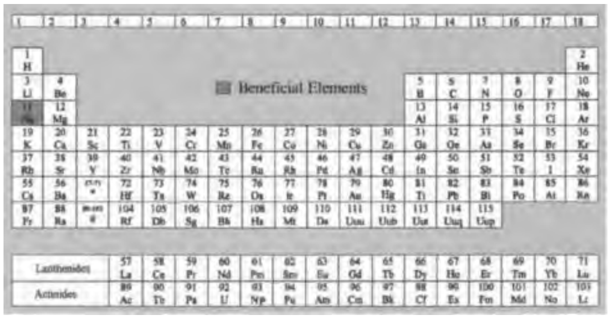


Fig.S.11: Position of sodium in the Periodic Table.

Sodium influences water retention in sugar beet and increases drought resistance. The supportive role of sodium is not clear in some plants; however, in crops like celery, marigold, sugar beet, turnip, etc., it increases the amount of water held by a unit dry weight of the leaf tissue and increases the succulence of the plant (which is why these plants have a greater drought resistance and increased leaf area.) Sugar beet and marigold in western Europe, for instance, need a good supply of sodium for satisfactory yields. In potassium deficient soils, sodium helps the growth of crops like barley and prevents the accumulation of other toxic cations, because deficiency of one cation leads to accumulation of the other.

Sodium concentration varies widely from 0.01 to 10% in leaves. Sugar beet petioles frequently contain the upper end of the range. In low-sodium soils, beet leaves are dark green, thin and dull in hue and exhibit interveinal necrosis similar to that resulting from potassium deficiency.

Sodium is essential for halophytic plants. Plants that possess the C_4 dicarboxylic acid photosynthetic pathway, require sodium as an essential nutrient. Sodium has a role in inducing crassulacean acid metabolism that is responsible for water stress. The lack of sodium causes certain plant species to shift their carbon dioxide fixation pathway from C_4 to C_3. Water economy in plants seems to be related to the C_4 dicarboxylic photosynthetic pathway of plants in fine textured soils. The benefits of sodium are high when potassium is deficient.

The sodium demand of the crops is independent of, and perhaps greater than, their potassium demand. The important sodium-containing fertilizers are potassium fertilizers with a wide ranging content of sodium chloride, sodium nitrate, rhenania phosphate and multiple nutrient fertilizers with sodium salts.

Sodium nitrate is available as a natural product, **Chile saltpeter**, which contains trace amounts of micronutrients, like boron. Synthetically, it is made from nitric acid and sodium hydroxide.

The presence of sodium in soils is restricted to arid and semi-arid regions. It is one of the most loosely held metallic ions and is readily lost in leaching water. In fine textured soils, sodium accumulation inhibits plant growth.

A high concentration of sodium is undesirable in water as sodium is adsorbed on cation exchange sites, causing soil aggregates to break down, sealing the soil pores, and making it impermeable to water flow. **Sodium adsorption ratio** (**SAR**) is used to estimate the exchangeable percent sodium of soil; a low value indicates low sodium content.

In sodic soils, exchangeable sodium is above 15% and its adsorption rate (SAR) is 13. The permeability is the limiting factor in the reclamation of sodic soil. A high salt content in water keeps sodic soils flocculated (joining of colloidal particles to form clusters) and the floccules are highly porous and allow penetration of the leaching waters. Thus, the first water used for leaching may be moderately salty. Sodic soil with low salt concentrations readily loses its structure because it allows soil colloids (clay and humus) to disperse into individual hydrated particles.

Some of the effects ascribed to sodium may also be due to the chloride ion in sodium chloride. In addition to toxicity due to high concentrations of sodium and chloride, sodium chloride affects plant growth because of the osmotic effect which increases the potential forces that hold water in the soil and makes it difficult for the plant roots to extract moisture.

Fine textured clayey soils with low exchangeable sodium (10%) and sandier soils with 20% exchangeable sodium experience dispersion damage. Colloid dispersal makes the soil impermeable to water and affects plant growth. The impermeability to water causes soils to form hard surface crusts when dry. Uncorrected sodicity makes most soils inhospitable to vegetation and agriculture.

Even if water could move downward freely in dispersed sodic soils, it alone cannot leach out the excess exchangeable sodium, which must be replaced by another cation and then leached downward and out of the root zone. Calcium is used for replacing sodium in such soils. Gypsum is the most convenient and the cheapest of all the calcium compounds for this purpose. Calcium solubilized from gypsum replaces sodium, leaving sodium sulphate in water, which is then leached out. In India, calcareous saline-sodic soil leaching with good low-salt irrigation water was found effective in removing the exchangeable sodium without the addition of gypsum. Several materials are used for the reclamation of sodic soils. Compared to gypsum efficiency of 1 as the base, the efficiency is 0.57 for sulphuric acid, 0.18 for sulphur, 0.75 for lime sulphur and 1.62 for iron sulphide.

Sodium adsorption ratio

Sodium adsorption ratio is the same as **exchangeable sodium percentage** (**ESP**) and is the ratio of the concentration of sodium to the square root of half of calcium and magnesium concentrations. All the concentrations are expressed in molarities and measured in the saturation extract.

Sodium borate

Sodium borate is a salt of boric acid and sodium hydroxide or carbonate. One such compound is **borax**, a micronutrient source, which is used to overcome boron deficiency.

Sodium calcium phosphate

Calcining of phosphate rock, sodium carbonate and silica in a rotary kiln at 1250°C gives '**Rhenania**', that is calcium sodium phosphate, $CaNa(PO_4)$. (See also Calcium sodium phosphate.)

Sodium hazard of water

The chemical properties of water determine its suitability for irrigation. One of the properties is the concentration of sodium to other cations. The sodium hazard or the proportion of sodium to other cations in water is given by the **sodium adsorption ratio** (**SAR**), given as:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{(\text{Ca}^{2+}+\text{Mg}^{2+})/2}}$$

where Na^+, $Ca^{2+}+Mg^{2+}$ are the concentrations in milli equivalent per liter of the respective ions. A high concentration of bicarbonate ions may result in the precipitation of calcium and magnesium bicarbonates from the soil solution, leading to an increase in the relative proportions of sodium and thus, the sodium hazard. Many plants are sensitive to chloride concentrations and to high sodium levels in their leaves. Salts and other solutes lower the osmotic component of the water potential. Water enters plants only if the water potential is lower inside the roots than in the soil.

Sodium metaphosphate

Sodium metaphosphate is the salt of metaphosphoric acid having a molecular formula $(NaPO_3)_n$, where n ranges from 3 to 10 (for cyclic molecules) or may be much larger (for polymers).

Cyclic molecules have alternate phosphorus and oxygen atoms in the rings and start with trimetaphosphate $(NaPO_3)_3$ to at least decametaphosphate. Sodium hexametaphosphate may be a polymer where n is between 10 and 20.

Vitreous sodium phosphates have a $Na_2O:P_2O_5$ ratio near unity and are called **Graham's salts**. The average number of phosphorus atoms in these vitreous glasses ranges from 25 to infinity.

Sodium molybdate

Sodium molybdate $(Na_2MoO_4{\cdot}2H_2O)$, which is an important molybdenum source, is applied along with other fertilizers or as a foliar spray (with 39% molybdenum). Sodium molybdate is the sodium salt of molybdic acid. Fusing molybdenum oxide with sodium carbonate or hydroxide makes sodium molybdate.

$$Na_2CO_3 + MoO_3 \longrightarrow Na_2MoO_4 + CO_2$$

Molybdenum is an essential component of the enzyme nitrate reductase which catalyzes the conversion of nitrate (NO_3^-) to nitrite (NO_2^-). It is also a component of the nitrogenase enzyme involved in nitrogen fixation by root nodule bacteria of leguminous crops. Soaking seeds in sodium molybdate solution (made with slurry or dust) before sowing is an effective seed treatment. Sodium molybdate, the most commonly used fertilizer supplying molybdenum, is used as foliar spray, or in mixed fertilizers. It is also used in seed treatment.

Sodium nitrate

Sodium nitrate is the oldest known nitrogenous fertilizer. It is a white, shiny crystal available in nature as **Chilean saltpeter** or **Chilean nitrate**.

Sodium nitrate is manufactured by two methods. In the first, known as the **Guggenheim method**, the fertilizer is extracted from a mined product, called **caliche**, mined mostly in Chile; hence the name (Chilean saltpeter or Chilean nitrate). The caliche is dissolved in warm water and then cooled to 0°C to produce sodium nitrate crystals, which are circulated through heat exchangers. The circulation keeps the crystals suspended, to finally form pellets. Caliche mined in Chile, contains sodium nitrate (8 to 20%), potassium and magnesium nitrates and salts like borates, sulphates and chlorides. Approximately, one ton of sodium nitrate of 99% purity is obtained from 10 tons of caliche. Sodium nitrate is shipped in airtight containers. The pellets are also coated to impart free-flowing characteristics.

Sodium nitrate is also manufactured from nitric acid and soda ash, using salt and oyster shells. Nitric acid is reacted with soda ash forming sodium nitrate solution. Most water is removed by evaporation and the rest is heated to a high temperature and sprayed through nozzles. Sodium nitrate solidifies as pellets while coming through the nozzles.

Sodium nitrate fertilizer is water-soluble. It contains 16% nitrogen and about 26% sodium. Plants absorb most of the nitrogen in a nitrate form and sodium nitrate is a commonly preferred fertilizer, although the nitrogen content of sodium nitrate is lesser than that in many other inorganic nitrogen fertilizers. Sodium nitrate has a neutralizing effect on soil acidity because of its inherent basic residual effect. Its neutralizing value is 0.82 kg of calcium carbonate equivalent to 0.45 kg of sodium nitrate.

The field crops which benefit most from sodium nitrate application are sugar beet and cotton. If applied excessively, sodium nitrate can damage the soil structure by reducing the flocculation. But normal applications of 100 to 200 kg of fertilizer/hectare/year do not affect the soil structure.

Sodium nitrate manufacture by Guggenheim method: See Guggenheim method for sodium nitrate

Sodium nitrate production processes

Sodium nitrate is a white crystalline substance with about 16% of nitrogen content. It is available as a crystalline, prilled or ground material.

Before the availability of synthetic ammonia and its derivatives, sodium nitrate was the source of chemical nitrogen fertilizer. Sodium nitrate is found mainly on the Chilean coastal range. It is applied as a surface dressing for cotton, tobacco and some vegetable crops. But its use as a nitrogen fertilizer has declined. Sodium nitrate is prone to leaching in soil, like other nitrates. However, because of the metallic cations, it does not promote soil acidity.

Sodium nitrate is produced by **Guggenheim method** from sodium nitrate ore (**Caliche**). This crystalline product of about 48 mesh size contains 3.5% moisture.

Sodium nitrate can be stored and shipped in bulk under low humidity conditions and packed in moisture resistant bags for use in tropical climates or humid conditions. It is a toxic product and a potential fire hazard. The prilled sodium nitrate of 10 to 20 mesh size is about 98% pure and contains 0.2% to 0.3% free moisture.

Guggenheim method of sodium nitrate manufacture permits ore (caliche) containing under 10% nitrate. Caliche, mined by open-pit operations, is crushed to a 1.0 to 2.0 cm size product and leached with water at 40°C in a series of vats. After extraction and washing, the residue is transported to a waste dump. The filtrates are combined with liquor from leach tanks and are chilled in shell-and-tube units to precipitate crystalline sodium nitrate. The sodium nitrate slurry is dewatered and washed in batch centrifuges to yield a crystalline product. When a grained or pill-type product is required, the centrifuged salt is melted at about 325°C in a reverberator furnace, sprayed in large towers, cooled and screened to yield pellets of 10 to 20 mesh size.

Several chemical methods for the manufacture of sodium nitrate have been developed. All these methods produce sodium nitrate solution that is concentrated, crystallized and centrifuged. One of the methods involve the production of **sodium nitrate by the salt process developed by Allied Chemical Corporation**. Appreciable quantities of sodium nitrate are made by this method. In this process, nitric acid and sodium chloride are reacted to get sodium nitrate, chlorine, nitrosyl chloride and water.

$$4HNO_3 + 3NaCl \longrightarrow 3NaNO_3 + Cl_2 + 2H_2O + NOCl$$

Nitrosyl chloride can be reacted with sodium carbonate to get additional sodium nitrate, sodium chloride, nitric oxide and carbon dioxide.

$$3NOCl+2Na_2CO_3 \longrightarrow NaNO_3+3NaCl+2NO+2CO_2$$

The U.S. method for the manufacture of sodium nitrate and sodium nitrite from ammonia and sodium carbonate, as developed by GIAP, is based on the oxidation of ammonia in the presence of a platinum catalyst at atmospheric pressure. The oxides of nitrogen, thus produced, are cooled and absorbed in an aqueous solution of sodium carbonate. The two reactions taking place are:

$$Na_2CO_3 + NO + NO_2 \longrightarrow 2NaNO_2 + CO_2$$
$$Na_2CO_3 + 2NO_2 \longrightarrow NaNO_3 + NaNO_2 + CO_2$$

The solution from the first absorber is filtered and evaporated. Crystalline sodium nitrite is separated from the solution in the primary centrifuge, dried in a rotary drum and sent to storage. The mother liquor from the primary centrifuge is further evaporated and centrifuged. The mother liquor from the secondary centrifuge is fed to a column reactor where the liquor is treated with nitric acid to convert sodium nitrite ($NaNO_2$) to sodium nitrate ($NaNO_3$).

$$3NaNO_2 + 2HNO_3 \longrightarrow 3NaNO_3 + 2NO + H_2O$$

Sodium nitrite has a large application in the production of dyes and building materials, food industry, iodine industry, the machine building industry and many others. Such a wide application of nitrite and nitrates justifies this production method.

Sodium nitrate, salt process by Allied Chemical Corporation: See Sodium nitrate production processes

Sodium potassium nitrate

Sodium potassium nitrate is refined from Chilean caliche. It is a mixture of sodium and potassium nitrates which is difficult to get in a granular form.

Sodium potassium nitrate is manufactured and marketed mostly as white pellets which contain 15% nitrogen and 14% potassium (as K_2O). It is a good source of potassium and nitrogen for cotton and tobacco.

Sodium tetraborate

Borate is a salt of boric acid (H_3BO_3). Sodium tetraborate, also called borax, sodium borate, sodium pyroborate and sodium tetraborate decahydrate ($Na_2B_4O_7{\cdot}10H_2O$) is a type of borate, and is used as a fertilizer to reduce boron deficiency. It is a white salt, finely ground for fertilizer application. Two commercial products contain borax with varying degrees of hydration. Borax is also used for making boron frits.

Soft rock phosphate

Soft rock phosphate is one of the four kinds of phosphate rock, the others being, **hard rock phosphate**, **land pebble phosphate** and **river pebble phosphate**. These have varying amounts of phosphorus (2 to 21%).

Soft rock phosphate is also called colloidal phosphate or Lonfosco. It contains around 20% of phosphorus and about 15% of calcium. Soft rock phosphate also contains carbonate and clay, and hence is less pure. It has a BPL (bone phosphate of lime) value of 40 to 60.

The phosphorus in soft rock phosphate is released at a medium rate of 2% per season and does not leach away. It can balance acidic soil. It is safe for orchards, pastures and vegetable beds since it does not burn plant roots.

Soft wheat

Soft wheat is the kind of wheat that is produced in areas with enough rain. Soft wheat has lesser protein content than hard wheat.

Soil

Soil is a creation of nature and consists mostly of minerals (45%) and very little organic matter (about 5%). It provides a habitat to man and animals, and supports plant life.

Soil is the unconsolidated mineral material on the immediate surface of the earth that serves as a medium for plant growth.

The factors controlling the rate of soil formation and the final product are (a) parent material, (b) climate, (c) biota, (d) topography, and (e) time. These five factors interact to produce all varieties of natural soils. Soil differs from the material from which it is formed in many physical, chemical, biological and morphological properties and characteristics.

Mankind has indirectly or directly created soils. When natural soils are not suitable, people extensively modify soils to suit their needs.

Soil usually has two or more horizontal layers, which can be seen from the **soil profile** in a vertical cross-section. The horizontal layers of the soil, with their own texture and color, are called **soil horizons**. The thickness and composition of horizons distinguish one soil from another; each horizon has a distinct identity. There are three almost distinct horizons namely, the plow **layer**, the **leached layer** and the **accumulation layer**.

Mature soil may be described in terms of the following four soil horizons: (i) **A horizon** is the uppermost layer, containing organic matter, though most soluble chemicals have been leached from it. (ii) **B horizon** is strongly leached with little or no organic matter. A and B together are often called the topsoil. (iii) **C horizon** is the subsoil, a layer of the weathered and shattered rock. (iv) **D horizon** is the bedrock. The main types of soil are pedalfers, pedocals and laterites or latosols.

Soils may also be classified in terms of texture. Loams, with roughly equal proportions of sand, silt and clay, together with humus, are among the richest agricultural soils. Wearing away of the soil is a primary cause of concern in agriculture.

Soil accretion

Generally, **accretion** means the addition of external matter to something, and the growth it causes. A gradual addition of external material to a soil, like alluvia, on the banks of a river, thereby increasing the land area little by little due to deposits caused by floods, is called soil accretion. These deposits are often observed after intense rains or storms. The formation of a delta at the river mouth is an example of soil accretion.

Soil acidity

Chemically, soil can be acidic, alkaline or neutral. It is (a) acidic when pH is below 7, (b) alkaline, when pH is above 7, and (c) neutral, when the pH is equal to 7. Most soils exhibit a pH between 4 and 8.5. Soil pH is measured in soil-water mixtures in the ratio 1:1 or 2:1.

The two causes of soil acidity are hydrogen ions (H^+) and aluminum ions (Al^{3+}). The following are some of the sources producing soil acidity: (i) Root respiration and the decomposing organic matter generate carbon dioxide which, after dissolution in water, forms carbonic acid. This acidic water percolates through the soil and makes the soil acidic. (ii) Ammonium nitrate, ammonium phosphate, ammonium sulphate, urea and other ammonium-containing fertilizers are oxidized by bacteria, which in turn produce nitrate and ammonium ions. These are considered to be acid-forming agents. (iii) Fertilizers and fungicides containing sulphur get oxidized to acidic oxides. (iv) Leaching of Ca^{++}, Mg^{++}, K^+ and other basic elements out of the soil increases the acidity. (v) In industrial areas, sulphur and nitrogen oxides in the atmosphere are converted into sulphuric and nitric acids respectively, which dissolve in raindrops and descend as acid rain. **Acid rain** percolates through the soil and makes the soil acidic.

Aluminum ions create acidity as they react with water and form hydrogen ions:

$$Al^{3+} + 3H_2O \longrightarrow Al(OH)_3 + 3H^+$$

Soluble aluminum is one of the most damaging elements to roots as it restricts the growth and development of root apex cells at pH below 5.5.

Finely ground limestone is used to reduce soil acidity and increase soil alkalinity. Plants require soils of different pH for their growth (Fig.S.12). Highly acidic soils are not favorable for most plants. Some plants do well in high pH conditions while others do well at much lower pH values. Alfalfa has one of the highest pH requirements while potato has among the lowest.

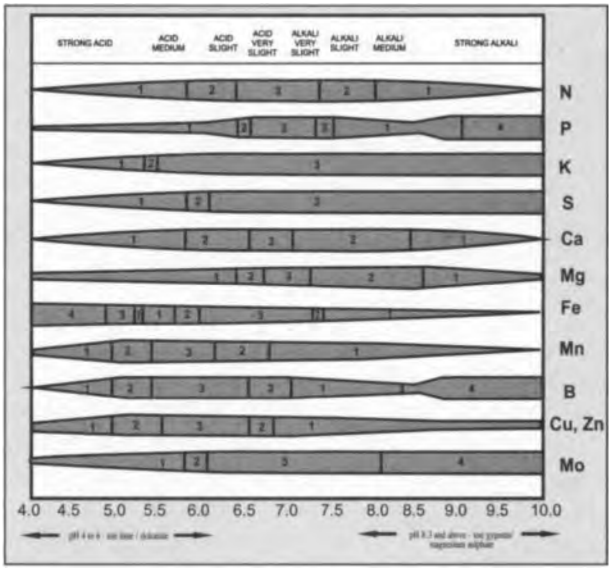


Fig.S.12: A bar diagram showing the effect of soil pH on the availability of plant nutrient elements. Nutrient availability increases or decreases as per the thickness of the bar. The thicker the bar, the more the availability, and vice versa. Similarly, the number code - 1 indicates very little availability, 2, marginal availability, and 3, sufficient availability. Even though the bar is thick, the number code 4 signifies very little availability because of the absence of complimentary elements and soil interactions. (Courtesy: Institute of Micronutrient Technology, Pune, India).

One way to correct soil acidity is to flood the soil to raise the soil pH to 7, but this method is appropriate only for crops like rice, taro, etc. which tolerate waterlogging. The other method is the microbial process which also raises soil pH to 7. However, the most important and practical solution is liming – applying finely ground limestone or calcium carbonate to the affected soil.

Soil acidity, correcting of: See Soil acidity

Soil additive

Generally, an **additive** is a substance added to another material to improve the properties of the latter. Additives are added in small amounts to prevent corrosion, to stabilize a polymer, etc. A small quantity of kaolin or talc added to ammonium nitrate granules or prills makes the prills free flowing; similarly, 0.3 to 0.4% formaldehyde added to urea makes urea abrasion-resistant.

There are three types of soil additives: (i) Some additive materials add to the permanency of the soil aggregate formation and can thereby improve the soil structure by increasing both the infiltration and the percolation rates. (ii) There are wetting agents, which do not change the soil but change the angle of contact of soil water with the soil surface, and thus enhance the rate of water flow through the soil. Such soil additives affect water movement at deeper levels and need periodic replacement as the wetting agents generally leach out with a continued flow of water. (iii) Some materials decrease the infiltration capacity by causing soil particles to swell and become hydrophilic. For instance, fine clays can be added to soil to make it swell and reduce the pores in between the particles and, in turn, reduce the infiltration rate. Sealants, such as petroleum or plastic films, are applied to soil surfaces to decrease or prevent infiltration. A decreased infiltration is necessary to decrease the water loss from reservoirs or irrigation canals or to increase the run-off to surface water supplies for direct use or for ground water recharge. (See also Soil conditioners.)

Soil air

Soil air is the gaseous phase of soil, meaning, that volume of soil not being occupied by liquid or solid. The composition of soil air is similar to, but not identical with, the air we breathe. It is similar because some soil pores are open to the atmosphere. It is different because soil movement is slow and soil organisms (and root exudates) affect the composition of the soil atmosphere since they take oxygen from the soil air and release carbon dioxide into it. Soil air is also almost saturated with water vapor. The relative humidity is always between 99 and 100%. (See also Aeration soil.)

Soil alkalinity

Plants do best when the pH is right. The degree of acidity or alkalinity of a soil is an important chemical property expressed in terms of pH units ranging from 0 to 14. A pH of 7 is neutral, below 7 is acidic and above 7 is alkaline. Most soils have a pH between 4 and 8.5.

Alkalinity could be due to the residual fertilizer effect, as in the case of calcium nitrate or sodium nitrate. Most black cotton soils are alkaline.

Micronutrients are not available to plants in an alkaline environment as they get precipitated as hydroxides or oxides. A finely-ground limestone is a commonly used soil amendment to reduce soil acidity. (See also Lime requirement.)

Soil ameliorants

Soil ameliorants are substances which are added to a soil to improve its physical and chemical properties, thereby increasing the productivity. The addition of lime to acid soils and of gypsum to saline soils are the common examples of ameliorants. In fact, a fertilizer too, in a way, is a soil ameliorant. These substances are also commonly referred to as **soil amendments**. (See also Plant nutrients; Amelioration.)

Soil amendment

Substances other than fertilizers and manures, incorporated in a soil to improve its physical, chemical, or biological properties, are known as soil amendments. For example, sand added to a very clayey soil amends the clayey soil. Lime, gypsum, sawdust or synthetic conditioners added to the soil to make it more productive, are amendments.

Organic amendments, such as crop residues, animal manures, wood manufacturing residues, industrial organic waste, or fiber-harvesting wastes are used as additives to improve the physical conditions of the soil, increase its water-holding capacity or improve the absorption of plant nutrients.

Sodic soils, which suffer from problems of low water permeability, waterlogging, run-off, erosion, slow internal drainage, inadequate aeration, trafficability and compaction due to their poor physical and chemical properties, are improved by applying soil amendments, such as calcium as CaO, $CaCO_3$, $CaSO_4$ (gypsum) or sugar-mill press mud. These rectify the deleterious effects of acidity on plant growth and simultaneously improve the soil structure, because the calcium (Ca^{2+}) ions tend to flocculate.

Organic polymers, especially polysaccharides and polyacrylamides, have been studied extensively as soil amendments for improving aggregate stability, for maintaining a high infiltration rate and reducing seal formation. A small amount of polymer (10 to 20 kg/ha) sprayed directly onto the soil surface or added to the applied water stabilizes and cements the aggregates to the soil surface and maintains a high infiltration rate in the soil with exchangeable sodium percentage less than 5.

Soil analysis: See Laboratory analysis of soil; Diagnostic techniques

Soil analysis methods with fertilizers

Soil analysis is a rapid chemical method to assess the soil fertility status. It provides information on fertilizer requirement. The method also enables the user to develop profitable fertilizer recommendations in field experiments on all appropriate soils and under different cultural practices. These experiments, need to be repeated for several years to find the effect of weather changes. Changes in cultivars, nutrient loss processes and newly adapted cultural practices will naturally call for repetition of the exercise from time to time. The knowledge of soil-plant relations is essential to have a meaningful interpretation of the results. (See also Diagnostic techniques.)

Soil associations

Soil associations are areas of soil units that contain two or more kinds of soils generally associated in a regularly repeating pattern and individually large and distinct enough to be separated on the soil survey maps. But since there is a degree of uniformity in pattern and extent of the dominant soils, soil associations are considered as one soil unit, thus saving the surveyor time and money in delineating each soil separately.

Soil auger

The soil auger is a tool with a pointed tip used for collecting soil samples for analysis (Fig.S.13). **Augers**

Fig.S.13: Soil auger, a tool used in soil sampling.

are of two types: a **worm-type** and a **hollow cylinder type**, with a cutting edge or a screw at one end.

An **auger-type spreader**, with a mechanical transverse distribution arrangement is preferred for applying powder fertilizers. Fertilizers flowing from the hopper are conveyed to the auger, driven by various means and are then transported to the spreader tubes with adjustable discharge spouts.

Soil buffering capacity

Soil buffer capacity is the ability of ions associated with the solid phase of soil to buffer changes in ion concentration in the solution phase. In acid soils, buffering refers to the ability of the absorbed aluminum, protons and hydroxyl-aluminum to maintain a certain concentration of H^+ in solution.

The potassium buffer capacity is the ability of the solid phase of the soil to buffer the changes in the K^+ concentration of the soil solution. Soils with high potassium buffer capacity tend to be fine-textured. They contain a large amount of fixed potassium or interlayer potassium (as abundant mica and vermiculite are present) that can be released. In these soils the solution potassium is quickly replenished when removed by the roots. (See also Buffering capacity.)

Soil classification

There are infinite varieties of soil. Moreover, the soil-forming factors can combine in infinite ways. Also, soil formation never stops, though the addition of soils is a slow process. More than 15,000 kinds of individual soils exist, for instance, in the United States, and many more the world over. It is next to impossible to recall the names of all these soils and their properties. For this reason, soil information is organized by several classification systems in use in different countries. One of the most widely used is by the United States Department of Agriculture (USDA).

There are natural and technical classification systems. The natural systems classify what is seen, and the technical systems classify what is inferred about the uses and interpretation of soils.

In soil taxonomy, as in plant taxonomy, there are many levels of generalization for classification. The twelve **soil orders** of soil taxonomy are designed to contain all the soils of the world. Each order is a broad grouping of similar soils separated by particular morphological characteristics. Within these broad groups are more specific smaller groups - **soil suborders**, **soil great groups**, subgroups, families and series.

Countries such as Canada, and international organizations such as FAO of the United Nations, have also developed soil classification systems. The USDA land capability classification is an interpretative or technical classification. Soils are grouped based on their specific uses. Other examples of similar classifications are **Storie index**, the timber site index and ratings of non-agricultural uses of soils. (See also Soil taxonomy.)

Soil colloids: See Colloid

Soil color

Soil color is an important diagnostic tool, widely used to describe and classify soil types. Organic matter (humus) makes the soil grey, dark grey, black or dark brown. The mineral elements give a range of colors to the soil. For example, oxides of manganese (III) and iron (III) add red, brown, reddish brown, brownish yellow or yellow colors; iron (II) oxide adds a greenish or bluish tinge.

The aeration and weathering status of the environment also influence the colors of soil minerals. Poor drainage or chemically reducing conditions make some minerals dull grey, but in a well-drained soil they become bright yellow or brown, especially if they are oxidized. Many tropical soils are red because of the presence of iron (III) oxide. Highly hydrated iron oxides are yellow but with decreased hydration, the yellow changes to red.

Soil color indicates many soil features. A difference in soil color from adjacent soils indicates a difference in the mineral origin of the soil or in the soil development. White color is common when salts or carbonate (lime) deposits are present in the soil. Spots of different colors (mottles), usually rust color, indicate that the soil has had long periods of inadequate aeration. Bluish, greyish and greenish subsoils (gleying), with or without mottles, are indicative of longer periods of waterlogged conditions and of inadequate aeration.

Soil colors alone should not be used to identify soil minerals because too many variables influence the soil color. For instance, many black soils in the tropics are low in organic matter. Iron and manganese may be indicated as red, brown, yellow, blue or green in different areas. As the soil color differs with the moisture status, most color examinations are carried out on moist samples to provide some basis of uniformity. Soil colors are very easily and accurately determined by comparing them with the **American Munsell color charts** scheme.

Generally, dark brown to black color denotes a high content of humus and a good soil structure. Red or brown color of the laterites indicates ferric compounds of iron. The accumulation of alkali makes the soil white or black depending on the nature of the salts.

The Munsell scheme expresses color by combining three variables: (a) hue or dominant spectral color relating to the dominant wavelength of light, (b) value or relative brightness with reference to the total quantity of light received, and (c) chroma or relative purity of the color corresponding to the intensity of the spectral color. The **Munsell code** consists of a certain number of sheets, each one of which represents a hue. Each hue consists of small, colored rectangles, the value being given on the Y axis, and the chroma on the X axis. If the soil has a uniform color, the designation of the color does not pose any problem. However, if there is any mottling, it is necessary to designate the color of the matrix first and then that of the spots. It is proper to specify whether the color is in the dry or moist state and, if possible, to state the color in both the conditions. The color is noted for each horizon, which in some cases is of the fundamental importance at certain levels in the classification.

Soil complex

A soil complex is a map unit consisting of two or more kinds of soils that are well mixed and limited in very small areas. But, since the pattern is so intricate, the two components cannot be separated at the selected map scale. The major soils of the area provide the name for the unit. A-B complex, 5 to 15% slope, or Opequon-Hagerstown complex, steep are examples.

Soil conditioners

Soil conditioners are chemicals added to maintain the physical condition or to improve the structure of the soil (Fig.S.14). They exert biotic, chemical or physical influences on soils in order to improve the soil structure and water regime. The cohesion of micro-aggregates to form macro-aggregates (>250 μm) is enhanced by microbial polysaccharides and polyuronide gums, which act like glue, whereas fungal hyphae and fine plant rootlets enmesh the aggregates. A good structure for crop growth depends on the existence of water-stable aggregates of around 10 mm diameter. Synthetic macromolecules, called soil conditioners, have been used for the same purpose.

The main soil conditioner types are (a) soluble polymers (hydrophilic) like polyvinyl alcohol (PVA), polyacrylamide (PAM) and polyethylene glycol (PEG), and (b) mollifiable polymers (hydrophobic) like bitumen, polyvinyl acetate and polyurethane. Their application is at the rate of 0.2 g (soluble polymer) or 10 g (emulsifiable polymer) per kg of soil. Soluble polymers require moist conditions to diffuse into larger pores (>30 μm diameter) where they are most effective. With bitumen emulsions, the soil should be allowed to dry to achieve maximum aggregate stability.

Fig.S.14: Organic soil conditioner.

Only a shallow depth of the soil can be easily treated with soil conditioners. For this as well as for reasons of high costs, soil conditioners are used in special situations like the need to (a) stabilize sand dunes against wind erosion, (b) stabilize bare surfaces of rehabilitated mine spoil and road cuttings, (c) protect the surface of land fills from erosion until vegetation is established, and (d) protect the fine surface tilth of seedbeds, especially that of high value vegetable crops and sugar beet.

Different types of synthetic soil conditioners are listed below:

(i) Foams: Foamed polystyrene and foamed urea-formaldehyde resins are used as **foamed soil conditioners**. Foamed phenolic and polyurethane resins are used as florists' mounting media or plant growth media.

Closed-cell expandable polystyrene foams are used as soil conditioners in the form of flakes, beads or raspings. These foams do not absorb water. The permeability to water between expandable polystyrene flakes is (a) without compression, roughly the same as that of fine gravel, (b) under 25% compression, that of coarse sand, and (c) at 75% compression, that of fine sand.

Polystyrene foams are odorless, chemically neutral and friendly to plants. They resist attack by acids and alkalis, and are resistant to degradation by soil bacteria. Physical degradation occurs under the action of UV radiation and biodegradation is caused by soil fungi. As the process of degradation is slow, foams remain effective as soil conditioners for a long time.

The uses of foam range from its incorporation into soils and garden substrates, to its application as a conditioner of a weak-structured peat. Foams, when incorporated in a soil, help in loosening, aerating and draining the soil. Foams are used in crop farming and landscaping, and have proved useful as drainage aids in slit drainage and as filter material for covering drain pipes. Expandable foams of 1 to 2 mm diameter are recommended for soil aeration and structural stabilization around the tree roots.

Urea-formaldehyde foams are condensates of urea with formaldehyde, with densities in the range 2 to 50 kg/m^3, and are used as soil conditioners. For example, foams with a density of 22 kg/m^3 are used for mixing with soils and substrates. Such foams absorb up to 90% water by volume. At atmospheric pressure, after the initial slow uptake, the rewetting is very fast and water release is uniform, going to completion.

Foams are biodegradable, but also expensive, thus restricting their application to garden crops, pot and container plants, cut flowers, flower bulbs, fruits, vegetables, in landscaping and golf courses.

(ii) **Colloidal silicates**: Colloidal silicates as soil conditioners include compounds of polysilicic acid, synthetically produced and stabilized by a high content of soluble silicic acid along with flocculating electrolytes. **Agrosil colloidal silicate** consists of (a) partly dehydrated sodium silicate, (b) electrolytes (phosphate and sulphate), and (c) an organic additive to retard ageing. Colloidal silicates are solid, fine-grained and easily dispersible with water. Moreover, they are porous, and when incorporated in soil, they fill the voids between the soil particles, and form water-stable crumbs. In soil, colloidal silicates help to hold phosphate in solution or aid its activation by desorption. The quantities used are 7 to 20 kg/100 m^2. In gardening and landscaping, the life of colloidal silicates is 3 to 5 years.

Direct effects of colloidal silicates include improving water and sorption characteristics, soil structure and fixing heavy metals. Indirect effects include the improvement of soil life, release of excess water and enhanced phosphate mobility.

(iii) **Polymer dispersions and emulsions**: Polymer dispersions and emulsions as soil conditioners include polyvinyl acetate, polyvinyl propionate, butadiene-styrene copolymer, cis-butadiene and various acrylic polymers in aqueous solutions. These are applied to soils to cross-link particles of the uppermost soil layer to form a closed film or coating which is permeable to precipitation and which diminishes into evaporation. They promote crumbs.

Polymer dispersions are degraded by UV radiation and hence have a limited life. Their stability depends on ambient conditions. They are used for protecting seeds during landscaping as well as for growing vegetables and flower-bulbs growing. They are applied at planting time by spraying along with fertilizers, and can also be sprayed after planting. The quantities of polymer dispersions used vary between 10 and 50 g/m^2. Their dilution with water, which varies between 1:1 and 1:60, depends on the purpose of use.

(iv) **Tensides**: Tensides (as soil conditioners) include ammonium lauryl sulphate, ethoxylated alkylphenol, polyoxy-ethylene esters of alkylated phenols, polyoxyethylene, alkylpolyglycosides, sulphosuccinates and polypropylene oxides. Water-repellent organic matter absorbs on the hydrophobic ends of the molecules of these so-called wetting agents, and the hydrophilic ends link the soil particles with water. Spraying of wetting agents on to the affected areas at the rate of 10 to 20 l/ha increases the water absorption and overall efficiency.

Soil conservation

Soil conservation means the protection, improvement and use of soil in a way that ensures better returns. It is a combination of all management and land use methods that safeguard the soil against depletion or deterioration by natural or human induced factors. For soil conservation, a number of techniques are employed to protect the soil against erosion or physical and chemical degradation. The degree of protection depends on the slope, fertility, morphological and chemical properties of the soil and climatic conditions.

Soil erosion alters inherent soil properties. It removes essential plant nutrients from the top soil layers, reduces water-holding capacity of soil, and depletes organic matter – all of which lead to a decrease in the yield. Soil erosion can be reduced by keeping the soil covered with vegetation during periods of heavy rainfall and winds. Some of the other important conservation practices are: (a) mulch farming, (b) planting cover crops, (c) no-tillage farming, (d) appropriate crop rotation, (e) contour farming, (f) construction of terraces and diversion bases on sloping lands, and (g) keeping the land under pastures.

Soil consistence

Soil consistence means its resistance to deform. It also means the degree of cohesion of the soil mass. The attributes of soil material are expressed in terms of its degree of cohesion and adhesion or its resistance to rupture or deform.

The consistency of soil varies with its water content and degree of cementation. The variation of soil consistency at various moisture levels is described as loose, friable, firm, hard, brittle, plastic, sticky and soft. (See also Consistence of soil.)

Soil control section

Soil taxonomy defines three special zones or layers for the purpose of classification. They are **epipedons**, **diagnostic horizons** and the control section. Soil control section is of a defined thickness. It is not a generic soil horizon which exists within the pedon, but is used for defining the soil moisture regime, particle size classes, and mineralogy classes for differentiating the series. The location of the control section depends on its intended use and the presence or absence of the diagnostic sub-surface horizons. If there are no sub-surface diagnostic horizons, the control section starts at 25 cm below the surface and extends to 100 cm. If there is a diagnostic sub-surface horizon, such as an argillic horizon, the control section starts at the top of the diagnostic horizon and extends to a defined depth. (See also Soil moisture regime.)

Soil creep

Mass wasting involves the movement of large masses of soil. It can be instantaneous (as in a landslide) or slow and persistent (stretching over many years). The latter process is known as soil creep. This slow flow of the material in the form of mud over the frozen subsoil, particularly in high mountains and cold climates (as in Greenland), is an instance of soil creep.

Soil creep is also known as **solifluction**. The speed of the flow is 5 to 50 cm/year. Alternate thawing and freezing of snow in rock crevices breaks the rocks, leading to soil movement. (See also Nivation.)

Soil degradation

Soils are neither permanent nor indestructible. They can be altered or even destroyed by a variety of causes, including mismanagement.

When soil becomes less productive for human use, it is considered degraded. Soil degradation is caused by (a) erosion which removes fertile surface soil, translocates it and often deposits poor soil material on top of good soil, (b) clogging of the surface pores, resulting in the slowing down of water penetration, (c) compaction of soil, which is also a kind of degradation making root extension difficult, (d) the concentration of soluble salts which hinders plant growth, (e) the loss of humus which slowly degrades the soil, (f) addition of harmful substances such as waste oils, gasoline, herbicides, etc., and (g) sewage sludge, and ore-smelting wastes which leave behind heavy metals and radioactive elements in the soil, thus degrading it.

Soil degradation can either be natural or be brought about by intensive cultivation or unsuitable techniques. It is often accompanied by a change in the morphology of the profile (such as the appearance of an **E horizon**). It leads to the loss of the physico-chemical properties of the soil, such as its structure, water retention capacity and porosity.

Soil erosion by water, wind and gravity occurs continuously. Fortunately, the soil formation rate normally exceeds or equals the natural degradation rate. Soil crusting and **soil creep** are caused by gravity, and assisted by water. Soil crusting and sealing of the surface (for a few millimeters) reduce the rate of water penetration into soil. Soil compaction also reduces water penetration.

The events leading up to soil degradation occur without human interference, but human activity enhances the degradation rate. At present, soil degradation affects 15% of the global land area. All regions of the world are affected but hillsides and dryland regions are the most vulnerable. The main human activities causing soil degradation are: (a) deforestation, (b) agricultural mismanagement, (c) industrial pollution, and (d) wars.

Agricultural mismanagement can induce and accelerate soil degradation by (a) inappropriate cropping patterns on easily degradable land without resorting to preventive measures, (b) tilling or leaving the land fallow at wrong times, (c) irrigation without proper drainage, resulting in salt accumulation or waterlogging, (d) overgrazing leading to reduced water holding capacity of soil, (e) failing to replace nutrients removed with harvested crops, and (f) soil compaction brought on by heavy machines or grazing animals.

Denitrification is a worldwide problem which reduces soil productivity. In order to use organic soils (histosols) for agriculture, they must be drained; but when drained they decompose rapidly.

The causes of soil degradation and erosion can be controlled in many cases; for example, ripping the soil or deep plowing can reduce compaction; soluble salts can be washed out to reclaim soils. However, soils contaminated by heavy metals can almost never be reclaimed totally.

One empirical equation to assess soil degradation is

$$D = f(C,S,T,V,L,M)$$

where D is the soil degradation, C is the climatic factor, S is the soil factor, T is the topography factor, V is the natural vegetation factor, L is the land use factor and M is the management factor.

Soil drainage class

Soil drainage class is a kind of non-agricultural soil classification. The climate, the position of the pedon in the landscape and the properties that influence the water flow through the pedon determine the soil drainage class. Such soils have slow internal drainage because of the clay texture or dense impermeable horizons, and have red and yellow mottles in the wet zone. Mottles are described by their abundance, size and contrast.

USDA recognizes seven soil drainage classes which are (a) excessively drained (dry soil), (b) well-drained (no-gleyed spots), (c) moderately well-drained (slight gleying), (d) well-drained, (e) imperfectly drained (considerable gleying), (f) very poorly drained (very considerable gleying), and (g) undrained.

The drainage class of soils depends upon factors like the level of water table and its fluctuations, the permeability of the soil and the topographic conditions. It is the interaction of these characteristics that determines the drainage class, which can be evaluated by the extent of gleying or the amount of reduction.

Soil erodibility index

The soil erosion rate on agricultural land is affected by rainfall characteristics, soil erodibility, slope characteristics, vegetative cover and/or management practices. Soil loss is predicted based on the **universal soil loss equation (USLE)** and is given by

$$A = RKLSCP$$

where A is the computed soil loss per unit area (as tons per acre), R is the rainfall factor, K is the soil-erodibility factor, L is the slope-length factor, S is the slope-gradient factor, C is the cropping management factor and P is the erosion-control practice factor.

The soil erodibility factor is a single number that combines many soil properties which influence the soil's reaction to rainfall and run-off. It is a function of silt, very fine sand, organic matter content, soil structure and the soil permeability of the least permeable horizon. Silt and very fine sand are the most easily moved particles. Increasing the organic matter in soil reduces erodibility because it helps to strengthen soil aggregation. Soil structure and permeability relate to the rapidity of ponding and run-off initiation. Soils with a strong structure do not detach easily and are, therefore, less erodible than soils with weak or no structures.

The soil factors influencing the erodibility by water are the ones that (a) affect the infiltration rate, permeability and total retention capacity, and (b) allow soil to resist dispersion, splashing, abrasion and the transporting forces of rainfall and run-off. The erodibility factor has been experimentally determined for major soils. The soil loss from a plot of 25 m length with a 9% slope, maintained in fallow and with all tillage up and down the slope is determined, and divided by the storm producing rainfall factor, giving the erodibility index. (See also Erosion prediction; Erosion control.)

Soil erosion

The process of removal and thinning of the soil layer due to climatic and physical processes (wind, rainfall, deforestation, etc) is called soil erosion. Ice, wind and run-off water transport soil from one place to another. This is a natural process that occurs without human intervention and can lead to a loss of agricultural land and, if unchecked, to desertification (Fig.S.15).

Many years ago, eroded soils from hills, hillocks, etc. led to the formation of very productive river delta and valley bottom soils. Today, the world over, erosion is probably the most serious threat to agricultural sustainability, affecting about 900 million hectares of land, water erosion alone accounting for about 75% of the total soil loss.

Moving water takes away soil from one place and deposits it at some other place, damaging both places in the following ways: (a) removal of the most productive soil parts, that is, clays and organic matter, along with their nutrients, (b) reduction of the top soil layer, restricting rooting depth, (c) clogging of irrigation systems, waterways and reservoirs by eroded materials, (d) silt deposition, lowering the capacity of reservoirs, (e) possible damage to aquatic systems by silt deposits covering up fish breeding areas, (f) eutrophication caused by water bodies, getting enriched by phosphorus and nitrogen, (g) reduced water infiltration, and (h) reduction of pedon thickness and water storage capacity of soil.

Silt deposits improve the productivity of receiving areas – both the land and estuary – but at the cost of the eroded region. Prevention of soil erosion is a key issue in the sustainability of agriculture and fertilizers. This can be achieved by (a) increasing crop growth so as to quickly cover the soil to reduce the action of rain drops, (b) retaining crop roots (that bind the soil particles) and residues to cover the soil after harvest, thus retaining organic matter, and (c) re-establishing plant cover where erosion has removed the top soil and the nutrients along with it.

The following measures reduce soil loss: (a) making soil banks, growing strips of grass or forests to intercept water and growing hedges for protection against wind, (b) growing cover crops and having intercropping systems, (c) practising conservation tillages, (d) having

Fig.S.15: Water erosion carries away the fertile layer of soil.

systems dealing with drainage, mulching and contour plowing, and (e) terracing (forming horizontal patches of land on steep hills).

Specialized arable cropping is generally more vulnerable to erosion than mixed farming. There are two basic types of erosion - geological and accelerated. **Geological erosion** takes place under natural conditions - when the land surface and native vegetation have not been interfered with by human activity. Geological erosion is a slow process in which the removal of surface soil may be effectively matched by soil formation. Geological erosion accompanied by human activity causes **accelerated erosion**, which leads to the rapid removal of topsoil. Accelerated erosion is rapid, often destructive and caused principally by wind and water.

Erosion by water is mainly due to (a) raindrops which splash the flowing mud, and detach the silts or fine sands, (clay or clay loams resist such detachment), and (b) runoff water which creeps off the soil particles of wet, supersaturated downhill soil by rolling or dragging, or by surface flow or sheets. Some of the soil particles enter low places and form deep depressions or channels. The water flowing in the channels takes away a large amount of mud, and deposits it downstream.

Dry, loosely aggregated, bare soils are removed by strong winds. This phenomenon is called **wind erosion** by which dry humus, clay, silt, sands, etc. are carried away - the lightest being moved the farthest. Soils covered by grasses or forests, or well-aggregated soils, erode less compared to steep and poorly-covered soils. Pulverized silts and very fine sands erode easily.

Erosion is a two-way problem: a loss of fertility and soil depth in the eroding place, and the addition of unwanted sediment in the receiving place. A universal soil loss equation is used to estimate soil loss by erosion on agricultural land. The cost of soil erosion includes reduced soil productivity and a higher cost of crop production. Offsite costs are due to silting of watercourses and reservoirs, and reduced water quality.

Soil, exchange capacity of: See Clay

Soil exsiccation

Several factors cause the reduction of soil moisture. When the absence of rains causes dryness in a soil, it is called desiccation. But when factors other than no-rain situation cause the soil dryness, it is referred to as soil exsiccation.

Plant roots taking up water from soil and leaving it dry, earthworms using up moisture and reducing it from that soil, or subsurface drainage drying up marsh areas are some examples of soil exsiccation.

Soil family

Soil family represents the soil group intermediate to the soil series and the great soil group. Within the same subgroup, all soils developed from the same petrological material constitute a soil family. A subdivision can be converted into '**great families**' and '**small families**' depending upon whether a simplified particle size or the geomorphological property is considered. For mapping, a classification of materials can be drawn up which serves as the basis for the identification of the family.

In the French classification system and soil taxonomy, a soil family is the fifth category. Thus, for hydromorphic leached soil with pseudogley and clayey, the family is 'clayey'; for an aridic Argiustoll, fine-loamy and thermic, the soil is 'fine loamy, thermic'. In the U.S. classification system, there are 4500 families identified.

Soil fertility

Soil fertility is an inherent capacity of the soil to supply adequate nutrients. It is a discipline of science that integrates the basic principles of soil biology, chemistry and physics to develop the practices needed to manage nutrients in a profitable and environmentally sound manner. The aspects concerning plant growth include adequacy, toxicity and balance of plant nutrients. An assessment of soil fertility can be made with a series of chemical tests.

For soil fertility to have an effect on crop yields, the presence or absence of plant nutrients has to be seen in conjunction with various environmental, chemical, physical and biological factors. The optimum management system specifies such factors as planting date, fertilization, irrigation schedule, tillage, cropping sequence and pest control.

Plants needed for food, fiber, animal feed, forage, medicines, industrial products, and aesthetically pleasing environment can be grown in a fertile and productive land. Soils exhibit a variable ability to supply mineral nutrients needed by plants. This property allows soils to be classified according to their fertility level, which can vary from deficiency to sufficiency or even toxicity of one or more nutrients. A serious deficiency of even one essential nutrient can greatly reduce crop yield. Several soil properties are important in determining the inherent soil fertility. One property is the adsorption and storage of nutrients on the surfaces of soil particles, also known as cation exchange; the quantity of nutrient cations that a soil can adsorb is its **cation exchange capacity**. The negative charge in the soil is associated with clay particles, but sometimes it can arise from organic matter (humus). The proportion of the cation exchange capacity arising from mineral clays and organic matter depends on their proportions in the soil.

The amount and kind of acids on the cation exchange sites can substantially influence the perceived fertility of the soil. Soils become acidic when (a) crops are harvested, exchangeable bases are removed along with the crop and move with water drainage below the crop root zone, and (b) a high nitrogen fertilizer application is done. Poor crop growth on acidic soils may be due to Al or Mn toxicity, Ca and/or Mg deficiency, etc.

Biological factors can be both beneficial and harmful. The beneficial factors include mycorrhizal fungi which in association with plant roots enhance the phosphorus-uptake. *Rhizobium* bacteria in the root nodules of legumes fix the atmospheric nitrogen and many microbial populations which decompose organic residues to recycle the nutrients. Conversely, soil-borne pathogenic organisms decrease the yield. Physical factors, such as soil, soil volume explored by roots and soil's water holding capacity are of importance. Chemical factors include nutrient status, soil pH and soil organic matter. Therefore, it is necessary to distinguish the natural or actual fertility from the acquired or potential fertility, as also from the chemical and physical fertility. Soil fertility assessment is useful for deciding fertilizer application rates, which is the main function of soil testing. Fertilizers are needed when soil fertility is low.

Soil fertility is to be differentiated from soil productivity which is the soil's capacity to produce crop yields with optimum management, keeping all related factors in mind.

Soil fertility evaluation

The evaluation of soil fertility helps to (a) estimate the ability of the soil to supply nutrients required for optimum plant growth, (b) identify such characteristics of the soil as its acidity, elemental toxicity and phytotoxicity, all of which affect soil productivity, and (c) determine soil impact on the quality of the environment.

Soil fertility is evaluated from observations and tests, and is used to predict the plant response in terms of the yield. Fertility evaluation involves the use of an impressive array of field and laboratory tests, and some sophisticated empirical and theoretical models.

The laboratory tests include chemical and biological soil tests, visual observations of plant growth for nutrient deficiency or toxicity symptoms, and chemical analysis of plant tissues. New techniques include remote sensing and **geographic information systems** (**GIS**) that facilitate the landscape-scale and site-specific assessments of soil fertility. It also includes qualitative or quantitative assessments of plant performance (yield, composition, quality, color, health, etc.) in order to rapidly adjust soil management practices for the most efficient use of nutrients. Generally, the fertility levels of soils are given as: very low, low, medium, high and very high.

In future, soil fertility evaluation will play a greater role in global agriculture for identifying new lands to be brought under cultivation and for maximizing the production from the existing soils. For example, horticultural systems, disturbed lands needing reclamation and soil conservation and remediation practices, all benefit from an in-depth evaluation of soil fertility.

The criticality of soil fertility differs with the intended use of the soil. For instance, for a specific purpose of soil conservation, where the goal is a stable vegetative cover, it may often be met by a low to moderate soil fertility. Soil needs to be evaluated with agronomically optimum nutrient values when the objective is to attain maximum yield. Finally, the need to ensure an optimum soil fertility in the soil remediation programs is a new, but increasingly important aspect of soil fertility, whether the goal is of enhancing microbial degradation of organic contaminants (like oil spill) or of **phytoremediation** of an inorganic contaminant (for example, Cd, Pb or Zn) from soils near industrial sites.

Environmental quality is inextricably linked with soil fertility. Soils must be managed to optimize plant productivity and minimize pollution. Nitrogen causes human and animal health problems, if nitrate-nitrogen (NO_3-N) leaches to ground waters and is used for drinking. Ammonia-nitrogen volatilized from fertilizers and animal manures causes soil acidification in forest ecosystems. Nitrogen oxides produced by denitrification are implicated in ozone depletion and global warming. **Eutrophication** of surface waters is caused by the entry of phosphorus and nitrogen in the run-off, erosion and aerial deposition.

Recycling of wastes or nutrients can affect the environmental quality, directly or indirectly. The use of municipal bio-solids (**sewage sludge**, composts, etc.) as soil amendments, beneficial in recycling nutrients and building the soil organic matter, is carefully regulated in most countries to limit non-essential and potentially toxic elements from impacting the health of humans or animals. Paper mill sludge, municipal composts, wood ash, flue gas desulphurization, gypsum and coal fly ash have some beneficial effects, but often create soluble salts, acidity or alkalinity, and immobilization of nutrients.

Soil fertility evaluation is more complex today as it is necessary to balance productivity and environmental protection for a wider and more diverse range of land uses.

Improvement of soil may be carried out on the basis of how the soil fertility has been evaluated. For soil improvement, major techniques in use involve tillage, drainage irrigation, and application of mineral or organic fertilizer and liming.

Soil formation

Soil formation or **soil genesis** is the process of creating soil from non-soil (that is, the parent material). Soil formation includes reducing the size of the parent material particles, rearranging the mineral particles, adding organic matter, changing the kind of minerals, creating horizons and producing clays. It is a continuous and slow process.

The factors controlling the rate of soil formation and the final product are the (a) parent material, (b) climate, (c) biota, (d) topography, and (e) time. These factors come together in infinite combinations to produce an array of soils. Physical, chemical and biological processes transform parent materials to soils, reduce the parent material size and convert the individual minerals to new minerals or to soluble products that are carried out of the soil. Jenny, H. J. put forward a soil-forming equation which states that soil is formed by the combination of five independent soil-forming factors:

$$S = f(P_m, C, R, B, T)$$

where S is the soil property which is a function of the parent material (P_m), climate (C), relief or topography (R), biota (B) and time (T). Physical weathering by freezing and thawing, shrinking and swelling, abrasion and heating breaks the large particles into smaller ones. Chemical weathering through hydrolysis, hydration, carbonation, oxidation-reduction, chelation, etc. changes individual minerals into new materials or molecules that can recombine to form new minerals, or are removed from the pedon by leaching. The process of soil formation produces soil horizons over time as a result of differential changes in one soil layer as compared to another. (See also Soil horizons.)

Soil genesis: See Soil formation

Soil horizons

Soil is a creation of nature and consists mostly of minerals and very little organic matter. It has usually two or more horizontal layers, which can be seen from a vertical cross-section of the soil, called **soil profile**. The horizontal layers of the soil, with their own texture and color, are called soil horizons. The thickness and composition of horizons distinguish one soil from another. Each horizon has a distinct identity (Fig.S.16).

There are three distinct horizons namely, the **plow layer**, the **leached layer** and the **accumulation layer**. The plow layer is rich in organic matter and plant nutrients which are readily-soluble. The leached layer or **eluvial layer** (horizon) is that from which soil materials and soluble salts are removed by the downward moving water. The accumulation zone or the **illuvial layer** has a fairly high clay content. Underneath these three layers lies the parent material from which the soil is developed.

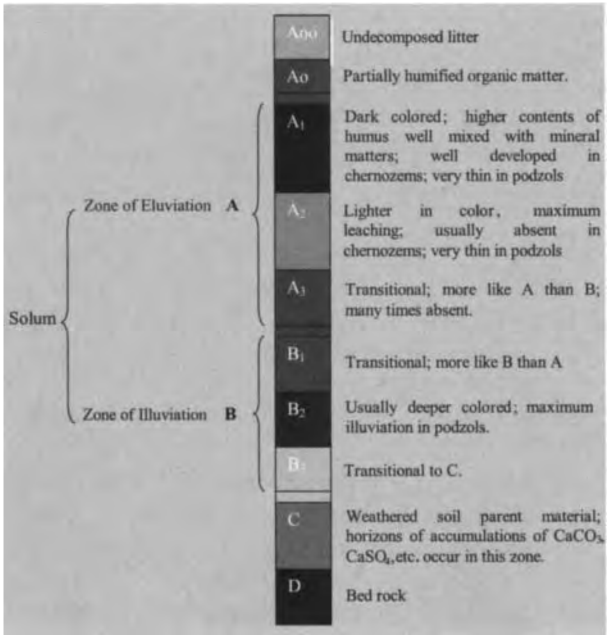


Fig.S.16: A diagrammatic soil profile showing all distinguished horizons.

A soil horizon can restrict plant growth because of its (a) inadequate thickness, (b) physically impervious layers known as **hard pans**, and (c) chemically impervious layers, such as root-damaging aluminum levels in very acidic soils. A careful examination of the soil profile is the first step toward the proper use of soil.

Soil volume is made up of only four components, namely organic matter (0.5 to 5.0%), minerals (45 to 50%), water (25%) and air (25%). Water and air occupy the **pore spaces** or **voids** in the soil.

Several factors are responsible for **soil formation**. Humus accumulation and percolating water, for instance, help form the horizon. A humus-accumulated horizon is dark in color. The percolating water takes away some clay and humus to a deeper section of the soil, which makes it a **leached horizon**. The accumulation of clay also differentiates various horizons. Accumulated secondary minerals make lime zones or hard pans.

Soil is depth-wise non-uniform and consists of several horizons which are identified by a letter and a number code. The names for master horizons begin with capital letters **O**, **A**, **E**, **B**, **C** and **R**, whereas transitional horizons that are found between the **master horizons** are designated by two capital letters. **AB**, **EB**, **BE** and **BC** are the terms used for **transitional horizons** between A to B, E to B, B to E and B to C, respectively. The lower case subscripts are used to subdivide the master and transitional horizons (creating subordinate horizons) and to designate their important properties (e.g., O_e, O_i).

The upper part of a **pedon**, which is a three-dimensional soil body, and most influenced by the roots, rainfall and micro-organisms, is known as **solum**. The part below the solum is the parent material from which the solum is developed. Normally, there are one or more A horizons of high biological activity at the surface, where humus accumulates and darkens the soil. In addition, the A horizon is a zone of leaching. The rainwater, as it enters and moves down, dissolves soluble components and picks up colloidal particles. These dissolved and suspended materials move downward slowly into the lower subsoil horizons. If there are more than one A horizons in the soil, these are numbered sequentially as A_1, A_2, A_3, etc. The E horizon, (E representing the word eluvial), is the one from which particularly large amounts of constituents, such as clay and iron, are removed. **Eluviation** is the translocation of weathered products out of one horizon to a lower horizon. The color in the E horizons is lighter than that either in the overlying A or the underlying B horizons.

The O horizon is a surface horizon, which is predominantly organic and less mineral. A soil composed entirely of the O horizon is an organic soil. O horizons are numbered consecutively from the surface. The mineral soils, which may also have organic soil horizons, are differentiated on the basis of three degrees of decomposition of organic matter - slight (Oi), intermediate (Oe) and high (Oa). The slightly decomposed organic horizons have plant remains that are easily distinguishable, which is not so in highly decomposed horizons. Generally, the organic soil has a high capacity to supply N, P and S.

The B horizon is a zone of illuviation below A, E or O horizons. Illuviation is the accumulation of eluviated materials. Eluviated clays, iron, aluminum, calcium carbonate, humus, silicates and salts, either alone or in various combinations, accumulate in the B horizon. In humid environments, where leaching occurs frequently, iron, aluminum and humus are eluviated from the O and A horizons to form the Bs (sesquioxides) and the Bh (humus) horizons. Sandy textures enhance leaching. Bt horizons are formed when clay is the main material accumulated. Horizons of carbonate (Bk), gypsum (By) and salt (Bz) accumulation are common in arid and semi-arid climates where insufficient salt leaching occurs. Bt horizons are found in moist climates. Some soils do not have zones of accumulation but have zones which develop a color or structure that is different from the overlying A and underlying parent material, and is called the Bw horizon.

The parent material is recognized as C, R and Cr horizons. The C horizon is affected little by the soil formation and lacks the properties of the horizons. The symbol R designates hard bedrock. Cr is used as a symbol for soft or weathered bedrock.

Geological material situated directly below the parent material of the soil is called the **D horizon** and is designated by the letters C and R. The material is actually lithologically discontinuous from the soil above.

Besides the capital letters, lower case letters and numerals, there exist a few descriptive names of the horizons. These are **diagnostic horizons**, divided into two categories: **epipedons** and **endopedons**. Epipedons are located at or near the surface. The six epipedon horizons recognized in soil taxonomy are **mollic**, **anthropic**, **umbric**, **histic**, **plaggen** and **ochric**. The epipedon is generally 20 to 30 cm thick, becomes saturated with water in some seasons and contains at least 20 to 30% organic matter. Endopedons are layers in the sub-surface horizons. The sub-surface diagnostic horizons may be part of the A or B horizon - more commonly part of the B horizon. There are seventeen sub-surface diagnostic horizons of which argillic horizon is one. Clay is accumulated in this sub-surface horizon. It is at least one-tenth as thick as the sum of all the overlying developed horizons.

Horizons designated by appropriate letters characterize the layers in sequence, in a particular profile. Diagnostic horizons require laboratory data for the verification of percentages of lime, salt, gypsum, etc.

It may be noted that not all horizons are present or apparent in every soil. In semi-arid savannah soils, for instance, the usually light colored A_2 horizon may not be evident. In some cases, neither the A_2 nor the B horizon is discernible. In general, the horizons most often observed are the O_2 (if it concerns forest land), the A_1 or A_2, the B_2 and the C horizon. Conditions of the soil formation determine the horizons and their properties.

Soil inoculation

Soil inoculation involves inoculating the soil with microbial inoculants or organic growth material to enhance the crop yield and/or improve the product quality. A small quantity of a suspension containing microbial inoculants is applied to the soil where seeds will be later sown. Inoculation of the soil or, say a legume seed with *Rhizobium* is a well-known practice.

Crops get nitrogen from bacteria through biological N-fixation. The selection of an appropriate microbial strain ensures extensive and efficient fixation but its efficiency depends on the level of competition of the native strains already facilitated by the existing soil conditions (like pH, moisture, phosphorus content, etc.). Other bacteria like ***Azospirillium, Azotobacter*** and **Cyanobacteria** are also used for the inoculation of soils and seeds. These bacteria stimulate root development through the production of plant hormones rather than by nitrogen fixation. Cyanobacteria are also used for the inoculation of paddy fields. Inoculating soils with some bacterial strains solubilizes soil phosphates.

Bacteria and fungi (e.g., ***Bacillus thuringiensis*** and ***Trichoderma harzianum***, respectively) are used as soil inoculants and as plant protection agents. Organic growth stimulants are used in small amounts (a few kg/ha) as inoculants which consist of humic acids, extracts of seaweed and plants, and amino acids.

Soil manganese

Manganese (Mn), which is a micronutrient, is vital to the growth of plants. Its major role is in activating several plant enzymes and in splitting the water molecule during photosynthesis. However, it is important to distinguish between the total soil manganese, and the total available soil manganese. For instance, throughout India, the manganese availability varies widely from as low as 37 ppm to around 11500 ppm; the actual plant-available Mn, however, depends on various factors.

It is important to understand the conditions under which Mn is available. The water-soluble Mn, which is the easily reducible form of Mn, and the exchangeable Mn account for 15 to 25% of the total Mn. The manganese content is the highest in semi-arid areas, humid conditions and acidic soils. Mn availability also increases in poorly drained, flooded/ponded soils and soils rich in organic matter. In fact, here Mn is available in such high quantities that it can lead to toxicity.

The oxides and hydroxides of iron and manganese are important reserves for iron and manganese, as well as other metals that co-precipitate along with the oxides of iron and manganese and get attached to their surfaces. The release involves desorption and dissolution of metal cations. It is favored by acidity and the presence of chelating agents that combine with these cations. The reducing conditions also contribute to the dissolution of metal cations. Iron oxides are partly reduced in flooded soils and manganese oxides are reduced even without flooding, if the organic matter supply and temperature favor microbial activity. Manganese is also present in non-silicate clay soils like sesquioxides.

On the other hand, the Mn availability goes down as the pH goes up. It is the lowest in calcareous and alkaline soils, and in arid regions. Sandy soils, leached soils, excessively limed soils are unfavorable to Mn availability. During cold winters and dry periods, Mn is sparingly available. Generally, field crops do not suffer from Mn deficiencies because of timely irrigation and incorporation of organic manure, etc. But fruit crops, such as apples, citrus, grapes, strawberries and other crops like beans, lettuce, peas, potato, radish, wheat, oats, sorghum and soybean commonly suffer from Mn deficiency.

A broad guideline for soil manganese test indices, based on extractable soil Mn and soil pH may be used to assess available Mn. If the value is >30, it may be concluded that soil Mn is adequate for field grown crops. However, if it is in the range of 16 to 30, it means that the soil Mn is approaching the deficiency level for oats, barley, soybean and wheat. Such findings suggest the need for Mn, followed by plant analysis. A value less than 16 indicates the need for a systematic Mn application program as Mn level is clearly deficient.

Soil map

There are two kinds of soil information – geographic data and point data. Both types are needed if soils are to be used properly. Geographic data is available as soil maps and they portray the arrangement of soils on the landscape as seen by the soil surveyor. Geographic information includes the distribution of soils on the landscape, current land use and potential uses. Soil map units describe soil pedons as they exist on the landscape. The map scale determines as to how the map can be used. Detailed maps of large scales are useful for a broad overview of an area.

Soil maps are made using satellite imagery, aerial photographs or traditional methods such as walking across the land, digging holes and observing pedon characteristics. The number of observations made by the soil surveyor determines the map's level of detail. Maps are a form of geographic data. Computerized storage, retrieval and interpretation of geographic data eliminate the laborious task of drawing and redrawing maps.

Soil microfauna

Microscopic living creatures in the soil are called **microfauna**. These include nematodes, protozoa, small spring tails and mites which feed on soil microflora (algae, bacteria, fungi) and cause mineralization (Fig.S.17). Macrofauna also contribute to nutrient cycling. Attention to soil fauna tends to be concentrated on earthworms, which feed on plant residues, fragment the waste and distribute it through the soil thus promoting its further mineralization.

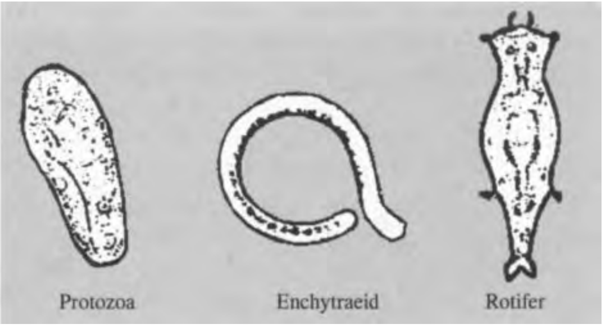


Fig.S.17: Soil microfauna.

Soil microflora

Microscopic vegetative growth in the soil is known as soil **microflora** which includes fungi, bacteria, actinomycetes, etc. (Fig.S.18). Estimates of the soil microbial biomass range from about less than 700 kg to more than 5000 kg dry weight/ha in the top 20 cm of soil. This is at least as large as the root biomass of a normal agricultural crop. However, both the population and activity of these microbes vary greatly with the soil type, nutrient and energy supply, temperature, oxygen and water supply, pH and the plant community. Microflora react quickly to changes in their environment and hence soil bioactivity is not constant.

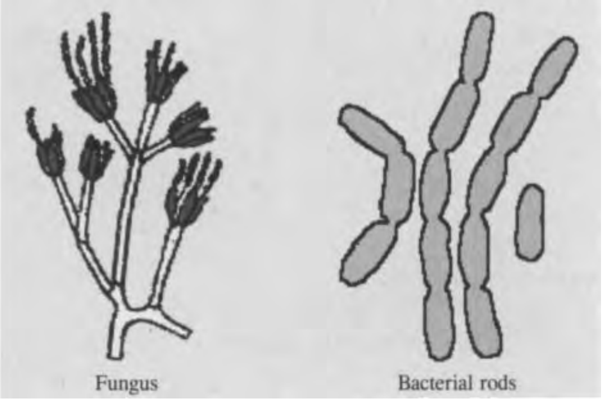


Fig.S.18: Soil microflora.

Urea and ammonium fertilizers can influence bacterial population and activity through soil acidification and the suppression of methane oxidation. Some bacteria directly influence nutrient availability in the soil by (a) immobilizing and mobilizing nutrients, (b) converting nitrogen into various forms, and (c) producing plant growth hormones that promote root development.

Soil mining

Most agricultural soils contain large amounts of nutrient reserves which become available to plants through slow processes. These processes include weathering of soil minerals and the mineralization of soil organic matter. In natural ecosystems, various nutrients (except nitrogen) are recycled with small losses, but agricultural nutrients are removed from the field with the harvested crop. When nutrients are removed from the soil and not replenished naturally or artificially, the situation is known as soil mining. Soil mining in arable agriculture is also seen as the reduction of soil organic matter to a level at which the soil structure deteriorates, diminishing the capacity of the soil to hold nutrients and water.

Soil mining is widespread where fertilizer use is the lowest, as in sub-Saharan Africa and to some extent, in Asia. In these regions, conservation of soil productivity is a major challenge because fertilizer supply and distribution are problematic and expensive. Economic returns from fertilizer use here are often too low and too erratic to make the use of fertilizers viable even on staple crops.

The growing population, along with the need to increase incomes, has resulted in deforestation and waterlogging. This has also led to agricultural waste being used as fuel, leading to soil mining. Nutrient mining is most severe in small land holdings where, despite more intensive land use, farmers continue to replenish the land primarily with recycled manure and crop residues. In sub-Saharan Africa, the average loss of nutrients/ha was found to be 22 kg nitrogen, 15 kg potassium and 2 kg phosphorus.

The following measures generally reverse the soil mining phenomenon: (a) planting trees and grasses to control wind erosion and digging channels for drainage, (b) liming to remove soil acidity, and (c) introducing crops like clover, in rotation, to increase the nitrogen supply.

Soil moisture regime

Soil moisture regime refers to the presence or absence of water in the soil or specific horizons at a tension less than 15 bars. When the tension is equal to or greater than 15 bars, most mesophytes (land plants requiring an average supply of moisture) cannot survive.

A soil is considered to be dry when the **soil moisture tension** is at least 15 bars, and moist when the tension is less than 15 bars. Moisture regimes are decided considering the time periods during which the soil is either moist or dry. The temperature is taken at a depth of 50 cm in the soil, which is the **soil control section**. For loamy soil, the control section exists at a depth of 10 to 30 cm.

Moisture regimes are of many types, such as aridic, aquic, torric, **udic**, **ustic** and xeric.

Soil moisture tension

The strength with which water is held in the soil is the pressure (measured in bars) required for forcing the water off the soil. The opposite of pressure, namely, **moisture suction** or tension is also used for measuring soil moisture; it is measured in atmospheres of suction or tension. Soil water potential is used to measure the availability of water in soil. **Tensiometers** are used to measure the matrix potential of soil moisture. These are useful in scheduling irrigation. Principal limitations of tensiometers are that these are effective only from 0 to 85 bars and can be better used in measuring moisture in sandy soils, than in fine textured ones.

Soil nutrient index

Chemical analysis of a soil sample is the first step in soil nutrient management. The nutrient content of soil and its availability to a crop determine **soil productivity**. The distinction between the available nutrients, and those present but unavailable, is not marked. The interaction of physical, chemical and microbial processes affects the nutrient availability. The overall soil nutrient index (**SNI**) of an area for a nutrient is calculated as follows:

$$\mathrm{SNI} = \frac{(N_l \times 1) + (N_m \times 2) + (N_h \times 3)}{N_t}$$

where N_t is the total number of samples analyzed, N_l is the number of samples having a low nutrient value, N_m is the number of samples having a medium nutrient value and N_h is the number of samples having a high nutrient value.

The value of SNI below 1.67 shows a low fertility, between 1.67 and 2.33, a medium fertility, and 2.33 and above, a high fertility. This provides basic information about the adequacy of the soil nutrient content.

Integrated nutrient management involves maintenance and adjustment of soil productivity and plant nutrient supply to achieve a given level of crop production. This is achieved by optimizing the benefits from all possible sources of plant nutrients.

Many laboratories classify soil fertility level as very low, low, medium, high and very high, based on the exact quantity of the nutrients extracted. This classification is in vogue with the grower. However, crops differ in their nutrient requirements; what is low for potatoes may be high for small grains and what is low for clay-loam soils may be high for sandy-loam soils. Some laboratories also use the **fertility index** which expresses the relative sufficiency as the percentage adequate for optimum yields. The lower the fertility index, the higher the crop response to fertilization. Crop response is seen to be very highly probable in case the soil tests are very low on rating (with the fertility index of between 0 and 10). Similarly, crop response is possible when the soil test rates are low or medium. (I.e., the index of 10 to 25 and 25 to 50, respectively.) As soil test rating goes on increasing (to high and very high), crop response becomes increasingly unlikely.

Soil order

Soils are classified based on characteristics and interrelationships. Such classifications facilitate systematic and scientific grouping of similar soils separated by particular morphological (visible) characteristics for study. Soil order is the most general soil category.

All soils in the world are divided into 12 orders on the basis of properties resulting from major processes and pathways of soil formation. While broad groups exist, there are also more specific smaller groups - **suborders**, **great groups**, subgroups, **families**, **series**, etc.

Soils in each order share one or more diagnostic horizon or feature formed by similar soil-forming processes. The knowledge of the specific processes or the rationale behind the categorization of a soil into an order is not as critical as the results of the processes.

The degree of profile differentiation is one characteristic that separates the orders. Those undifferentiated profiles that do not require subsurface diagnostic horizons are entisols, vertisols and mollisols.

Soil orders are as follows: (a) **Entisols**, (b) **Inceptisols**, (c) **Andisols**, (d) **Histosols**, (e) **Aridisols**, (f) **Mollisols**, (g) **Vertisols**, (h) **Alfisols**, (i) **Spodosols**, (j) **Ultisols**, (k) **Oxisols**, and (l) **Gelisols**. (See also Soil taxonomy.)

Soil organic matter

Soil organic matter comprises decomposing plant and animal residues, as well as the cells and tissues of soil organisms. The decomposition rate of various organic compounds in these residues varies. For instance, lignin, waxes and cellulose decompose very slowly, while sugar, starch and proteins decompose quickly. The decomposition process has five end products namely, CO_2, heat, water (a result of oxidation of carbon compounds by enzymes), plant nutrients (N, P, K, S, Mg, Ca) and soil humus. Soil organisms provide nitrogen to the soil, and help to increase the decomposition rate.

Organic matter is a source of 90 to 95% nitrogen in unfertilized soil and is the source of available phosphorus and sulphur when humus is present. Chemically, soil organic matter contains carbohydrates, fats, waxes, lignins and proteins.

In temperate regions, mineral soils typically have 1 to 4.5% organic matter. The plow layer (the top 20 to 30 cm of soil) is richer in organic matter than the lower soil layers.

The content of soil organic matter tends toward the equilibrium level, depending on the (a) soil type, (b) climate, (c) amount of organic material added as manure or retained in the crop residues, (d) the rate of microbial breakdown of the added organic matter, and (e) the method and frequency of tillage. In general, annual inputs of organic matter to the soil are large in grasslands and forests compared to agricultural land. There is a minimum level of organic matter in the soil below which crop rooting, access to water, growth and yield are adversely affected. This level may differ from one type of soil to another and from one crop to another crop. Soils unsuitable for arable cropping, owing to low organic matter content, can be made more productive by including grass leys in rotation.

Organic matter helps the soil in (a) supplying N, P, S and many micronutrients to the plant, (b) improving its structure by reducing the effect of compaction, (c) acting as a chelate to solubilize micronutrient metal ions (by forming stable complexes with Cu^{2+}, Zn^{2+}, Mn^{2+}, etc), (d) increasing exchange capacity, (e) reducing soil crusting and increasing infiltration, (f) providing carbon and energy to microbes, (g) buffering the soil against the change in acidity, alkalinity and salinity, (h) increasing the water-holding capacity of soil by protecting it from atmospheric heat, (i) releasing carbon dioxide, (j) stabilizing soil structure and improving tilth, and (k) providing surface protection, thus reducing crusting while increasing infiltration.

The organic matter on soil surface reduces erosion and protects soil moisture. When virgin soil is cultivated, organic matter decreases rapidly during the first 10 years and reaches its lowest point after about 30 to 60 years. Intensive tillage, fallowing, low crop productivity and erosion cause organic matter to decrease over the years. An increased soil organic matter requires that tillage be reduced, and the amount of carbon dioxide fixed by plants be increased.

Cropping systems contribute to varying amounts of plant residues whose nitrogen content is related to the quantity of organic matter in the soil. Corn, fertilized with nitrogen, contains more than 0.75 to 1% nitrogen in the stover. Plant residues returned to the soil increases soil organic matter.

A variety of soil organisms affects the breakdown of residues of higher plants and animals and their subsequent conversion into soil organic matter. Neutral to slightly alkaline pH increases the rate of decay, whereas the acid medium reduces the breakdown of organic matter.

The other parameter influencing decomposition is the carbon/nitrogen (C/N) ratio. Increasing the crop residues increases the soil nutrient availability. The higher the yield of the produce, the more extensive and deep is the root system, and hence, the more widely distributed, the organic matter. The latter contains approximately 50% organic carbon which is used to estimate the available soil nitrogen.

Organic matter of soil influences many biological, chemical and physical properties as well as nutrient availability. The dark colors that organic matter renders to the soil facilitate warming of the soil. Organic matter has significant amounts of water (in the range of 15 to 20 times its weight). This property improves soil moisture, thus reducing its drying and shrinking capacities.

Organic matter is a source of energy and carbon, for both healthy and diseased organisms. Excessive organic matter in soil hinders planting and may be difficult to manage. The organic matter is rendered harmful by the phytotoxins produced by some plant residues. Toxins resulting from decomposed plant residues inhibit the growth of other plants.

Increased inputs of crop residues, roots and root exudates may not be enough to maintain the soil organic matter content at a satisfactory fertility level in arable land. For this purpose animal manures are more efficient. However, best results are achieved with a combination of manures and mineral fertilizers.

To make up for nutrient deficiency, appropriate fertilizers are applied to these soils to enhance the breakdown of organic matter. Similarly, good drainage is provided and care is taken to prevent structural deterioration.

Soil phase

Soil phase is a mapping unit of the soil series. Mapping is useful in allocating soil areas for farming, municipal or country zoning. Phases are subdivisions of **soil series**. Terms like surface soil texture, thickness, percentage slope, stoniness, saltiness, erosion and other conditions are called soil phases. (See also Soil taxonomy.)

Soil phosphorus cycle: See Phosphorus cycle

Soil phosphorus, managing of

If finely divided soluble phosphate is broadcast and/or mixed with soil, it enables the phosphate to be fixed on a much larger area than would be possible by banding. Band placement reduces the surface contact between the soil and fertilizer with a consequent reduction in the amount of fixation. Granulation of soluble phosphate fertilizers tends to have a similar effect, particularly in the case of larger granules such as those of 4 to 10 mesh size. Band placement generally increases the plant utilization of water-soluble phosphates such as superphosphates and ammonium phosphates. There are, however, other phosphatic fertilizers which are water-insoluble; their utilization by plants is higher when mixed with soil, than when applied in bands without mixing with soil. (See also Management of soil phosphorus.)

Soil-plant atmosphere continuum: See Total soil moisture stress

Soil population

All living **fauna** and **flora** of the soil are collectively known as the soil population.

Soil porosity

Porosity is one of the physical properties of soil. Pore spaces are occupied by air or water. Pore spaces may be caused by the irregular shapes of primary particles, the arrangement of solid particles within the soil, the penetrating roots and activity of soil organisms.

It should be noted, however, that pores are of different sizes and shapes. Sands have large pores, whereas clays have very small ones. Generally, the finer the soil texture, the greater is the surface area and the total pore space. Thus, clays have the highest percentage of pore space (50 to 60%) and sands have the lowest (20 to 30%), while loams fall in between (30 to 50%). The movement of air and water through the soil depends upon the pore space, which in turn influences plant growth. Pores filled with water block air movement. If pores are smaller than 3 mm, the soil retains water within the fine pores, leading to waterlogging and poor aeration. In some clayey soils, air exchange is inadequate for plant root growth. In sands, however, the water and air movement is very rapid. To growing plants, the pore size is more important than the total pore space. The best balance between water retention time and adequate air and water movement is found in medium-textured soil, like loam.

The proportion of small pores in sandy soil is very low and hence its water-holding capacity is low. In fine-textured soils, however, the proportion of small pores is high in the total pore space (low bulk density) with a large proportion of micropores, which gives the soil a high water-holding capacity. In moist, well-drained soils, the macropores are usually filled with air and are called **aeration pores**. Micropores which are usually filled with water are called **capillary pores**.

Root development is closely linked with soil porosity and bulk density. An increase in the porosity not only enhances the aeration and permeability of water but also reduces the mechanical resistance to the penetration of roots. Most soils have bulk densities ranging from 1.50 to 1.70 g/cm^3 and an average porosity of 42%.

The **bulk density** and the particle density of soil are used in the calculation of soil porosity. The mass per unit volume, including the pore space, is the bulk soil density. With an increasing soil compaction, its bulk density increases. The particle density varies from 2.6 to 2.7 g/cm^3. Its porosity is calculated as follows:

$$\text{Porosity (\%)} = [1-\frac{\text{bd}}{\text{pd}}] \times 100$$

where bd is the bulk density and pd is the particle density. Optimum porosity values differ; those reported in literature are 6 to 10% for Sudan grass, 10 to 15% for wheat and oats, and 15 to 20% for barley and sugar beet.

Soil potassium management

The management of potassium in soil warrants (a) maximizing the efficiency of the added potassium and maximizing the use of natural potassium sources, and (b) minimizing the excess absorption of potassium by plants.

For the most efficient use of potassium (added or natural), the soil pH is maintained at 6 to 6.5 with lime when potassium losses from leaching are reduced. The addition of crop residues and manure amounts to increasing the potassium availability.

It is the small and split applications of potassium fertilizers that prevents its excessive uptake by plants (and not so much its heavy applications).

Potassium can significantly correct adverse effects of excess nitrogen to plants. Indeed, appropriate proportions of nitrogen and potassium are beneficial to plant nutrition.

Soil potential

Soil potential is defined on the basis of usefulness of the site for a specific purpose using the available technology at a cost expressed in economic, social and environmental terms.

Soil potential assumes that the use of the soil must be both cost effective and environmentally sound. It is intended to be an interpretative soil classification which does not indicate the cost of using the soil.

Potential is determined locally, based on a relative ranking (100 for the best soil) and is not expected to be a national rating. Soil potential is determined by (a) the soil properties, (b) effects of any unfavorable properties of the soil, (c) devising practices that can overcome the problem areas, both for immediate application and from the point of view of reclaiming the soil, and (d) the costs involved in the process. Soils are ranked from the best to the worst for each use. The best soil is rated 100 and all others are rated less than that depending on their potential problems.

The soil potential index (SPI) is given by

$$\mathrm{SPI} = \mathrm{P} - (\mathrm{CM} + \mathrm{CL})$$

where P is the locally derived index of performance or yield, CM is an index of costs of measures to overcome or minimize the effect of soil limitations and CL is the index of continuing costs caused by limitations. For soils with SPI 100, CM and CL are zero.

The best soils will have (a) the lowest initial cost, and (b) the lowest operating or maintenance cost while maintaining the environment. The worst soil will naturally have the highest costs, and the index values P, CM and CL will vary proportionately with the relative costs.

Knowledge of soil potential helps the planner to identify the limitations of a soil and device methods to overcome them. Such extensive data is unfortunately not available for a multitude of soils, and so, soil potential and SPI cannot be used so widely.

Soil productivity

Soil productivity is the capacity of the soil to produce a specified plant or crop under a specified system of management and a given environment. It is a product of soil and non-soil factors that influence crop yields.

Soil productivity, therefore, depends on both natural and acquired fertilities. It also describes the soil's ability to support the production of crop biomass. The productivity of a soil for cotton is expressed in kilograms per hectare or bales per acre, assuming the use of an optimum management system which considers all such relevant factors as planting date, fertilization, irrigation schedule, tillage, cropping sequence and pest control.

Soil scientists determine productivity ratings of soils for various crops by measuring yields (including tree growth and wood production) over a period of time.

During the development of a region, soils are grouped according to productivity classes on the basis of clear specifications since a soil cannot produce all crops with equal success, nor can a single management system have the same effect on all soils.

Soil productivity depends on the climate, topography, seeds, fertility, applied nutrients and complex interactions among many factors that contribute to the biological, chemical and physical properties of the soil. Many of these properties change comparatively slowly and should be used to achieve the maximum crop production.

Soil productivity index

The productivity index (**PI**) of a soil, developed in USA, is used to evaluate productivity in the top 100 cm of the soil, with reference to the potential productivity loss due to soil erosion. The productivity index evaluates the soil on its sufficiency for root growth based on the (a) potential of the available water storage, (b) bulk density, (c) aeration, (d) pH, and (e) electrical conductivity. A value from 0 to 1 is assigned to each of these properties, depending on its importance for root development. The product of these 5 index values describes the fractional sufficiency of any soil layer for root development.

Pierre *et al.* modified the soil productivity index to include the assumption that with invariant climate management and plant differences, nutrients are not a limiting factor for productivity. In another approach, PI of soil is given by:

$$\mathrm{PI} = \mathrm{f}(\mathrm{H.D.P.T.N}\ (\mathrm{or\ S}).\mathrm{O.A.M})$$

where H is the soil moisture, D is the soil drainage, P is the effective soil depth, T is the soil texture or structure, N is the base saturation, S is the soluble salt status, O is the organic matter content, A is the cation exchange capacity or nature of clay and M is the mineral reserves.

Soil profile

Soil profile is a vertical section of the soil. It is a sequence of values corresponding to significant characteristics of the soil arranged vertically from the top to the unchanged parent material beneath, showing the various horizons.

Soil profile is a newly prepared pit extending from the soil surface to the substratum. The characters observed in the profile are derived from the generic development. The profile comprises a succession of layers or horizons, resulting from transformation, migration or displacement (generally vertical) of certain constituent elements of the soil.

The following are some specific aspects of the soil profile: (i) **Cultural profile** is a section of the soil in a cultivated land extending from the surface of the soil to the depth reached by a majority of roots (generally, 1 m). It comprises a succession of earth layers, individualized by the intervention of agricultural implements, plant roots and natural factors reacting with them. (ii) **Moisture profile** indicates variations in the moisture content of the soil at a given point and time. By varying the time, and by selecting the characteristic moisture contents, it is possible to draw up the soil's moisture diagram. (iii) **Thermal profile** represents fluctuations of the soil temperature in various seasons, obtained by plotting temperatures along the X-axis and the depths along the negative Y-axis. By varying the time and selecting the characteristic temperatures, one can get a thermal diagram of the soil. (iv) **Physico-chemical profile**: By plotting the values of the soil depths along the negative Y-axis and the variables along the X-axis, one can get a profile of all the constituents and soil properties, such as the acidity, porosity, nitrogen content, organic matter content, calcium carbonate content, particle size distribution, etc.

Profiling of soil consists of digging a pit in a soil to enable the enlisting of all observations indispensable for a detailed study of that soil and to collect samples for laboratory analysis.

Soil reaction

The behavior of different organic and chemical compounds with each other and with the soil population is referred to as soil reaction. Soil reaction depends on the pH of the soil. Soil reaction influences nutrient availability. For example, manganese (Mn) precipitates in alkaline soils when it has a +2 charge, but not when it has a +7 charge. In acidic soils, which are rich in iron and aluminum, availability of phosphorus is reduced.

Generally, most nutrients available in the soil are with a near-neutral pH. Some of the indicative pH values for soil reaction are (a) less than 4.5 for extremely acidic, (b) 4.5 to 5.0 for very strongly acidic, (c) between 5.1 and 5.5 for strongly acidic, (d) between 5.6 and 6.0 for medium acidic, (e) between 6.1 and 6.5 for slightly acidic (f) between 6.6 and 7.3 for neutral, (g) between 7.4 and 7.8 for mildly alkaline, (h) between 7.9 and 8.4 for moderately alkaline, (i) between 8.5 and 9.0 for strongly alkaline, and (j) higher than 9.0 very strongly alkaline. Certain soil-borne diseases are influenced by soil pH. For example, neutral or alkaline conditions favor Scales of Irish potatoes, pox of sweet potatoes and black root rot of tobacco. The knowledge of soil reactions can be used to the grower's advantage, especially since they can be easily altered.

Soil sample preparation

For laboratory analysis, soil samples are air-dried at room temperature. The sample can be dried at 50°C in a forced air cabinet dryer for 24 to 48 hours, but not longer than 72 hours. After drying, the sample is ground to pass a 10 mesh (2 mm) screen.

Soil sampling

A process by which true representatives of soils are collected from an area for analysis and interpretation is called soil sampling. Since soils are extremely heterogeneous, true representatives are very difficult to gather, making the sampling exercise very critical.

Any recommendation for amendments or fertilization depends on (a) how the soil sample is representative of the area from which it is taken, (b) the accuracy of the laboratory analysis, and (c) correct interpretation of the laboratory results.

Samples are taken from the top few centimeters of the soil as most immobile nutrients remain in the top layers. During sampling, surface and subsurface soils are kept separate for individual analysis and interpretation.

Sampling depth depends on the nutrient mobility and on the crops to be planted. Mobile nutrients such as nitrate, sulphate and borate, should be sampled to a depth of about 60 cm and a sample taken when the biological activity is low. For immobile nutrients like K^+, Ca^{2+} and Mg^{2+}, sampling to tillage depth is satisfactory. For a pasture crop, a 10 cm depth is normally sufficient, while for field crops a depth of 15 to 20 cm is recommended.

Soil samples should be taken in a zigzag manner, the path of which can be decided on the basis of the number of samples required from a given area. For example, if 10 samples are desired, the field is divided into 10 equal blocks.

A representative soil sample is composed of 15 to 20 sub-samples from a uniform field, without major variations in slope, drainage or fertilizer history. If cultivation is intensive, sampling should be done annually to evaluate the fertility status; otherwise, sampling once in three years is sufficient if the field is planted with one crop per year.

Each field is treated as a sampling unit and if the various locations within the same field are different in their appearance, slope, drainage, soil texture, color or pest treatment, each location is separately sampled. Larger fields are divided so as to obtain each sample from not more than three hectares.

Samples are taken using soil tube, auger, harrow or narrow-bladed hand hoe and put in clean containers. Samples from non-representative areas like bunds and marshy regions are avoided. Sampling is done after plowing, and generally three months after the application of lime, fertilizer or ash. Clods or lumps are broken and the sample dried before packing.

The variance, from more than 8 core samples, does not substantially reduce the determined soil test parameter. It is better to create composite samples (of 4 to 16 individual core samples) for fewer areas and submit more multiple composites for laboratory analysis so that the mean of the analytical results, as the soil test value, is accompanied by the variance.

Some scientists recommend at least one composite per 2 hectares, while others suggest one composite per 40 hectares. It is best to divide the land into equal-sized sections of no more than 4 hectares each and gather a composite from each section.

The recommended procedure is to core to the plow depth of soil, occupied by most plant roots in unplowed soils. The surface and subsurface layers should not be mixed. Both horizons should be kept separate for analysis and interpretation. Generally, subsurface analysis is not done. Deep soil profile samples are used for tests, such as for nitrate-nitrogen (NO_3^--N).

The best time to collect samples is just before the end of summer when seasonal effects are minimal. However, taking samples at the same time each year (so that the results can be tracked), ensures the best sampling.

For field sampling, the following procedure is recommended: In plowed fields, core to plow depth; in the case of unplowed, planted or to-be-planted fields, core to the depth at which at least 75% of the plant roots are found. Samples are usually air-dried to prevent changes during storage, but freezing or freeze drying is better if the soil is to be analyzed for nitrate, manganese or other constituents that change during ordinary drying. (See also Test sample of soil.)

Soil science

The study of soils as a natural resource is called soil science. Soil science includes areas relating to soil formation, soil classification and mapping, geography and the use of physical, chemical and fertility-related properties of soils and those properties in relation to their use and management.

Soil separates

Soils are made up of particles of varying sizes. Particle-size groups less than 2 mm in equivalent diameter, ranging between specified limits, are called soil separates. The names and size limits of separates, recognized in the United States are very coarse sand (1 to 2 mm), coarse sand (0.5 to 1 mm), medium sand (0.25 to 0.5 mm), fine sand (0.1 to 0.25 mm), very fine sand (0.05 to 0.1 mm), silt (0.002 to 0.05 mm) and clay (less than 0.002 mm).

Soil sequence

A complex unit of soils, the succession of which is constantly found in a defined order without any apparent link between them, is called a soil sequence. The reason for regular soil succession is the preponderance and sustained influence of one of the factors of soil formation. When the predominant pedogenetic factor causing the differentiation is (a) the climate, the sequence is called **climosequence**, (b) the time, it is **chronosequence**, (c) the relief or topography, the sequence is termed **toposequence**, (d) the original material, the soil sequence is called a **lithosequence**, (e) the biological material (human, animal, etc.), it is termed **biosequence**, and finally (f) the color, it is called **chromosequence**. (E.g., on gentle slopes in tropical areas, we see a reddish color in a well-drained soil and a yellowish color in a less well-drained soil.)

Soil series

Soil series is one of the soil categories in the US system of soil taxonomy. The basic unit of classification and mapping consists of soils that are identical in all the main profile characteristics (except the surface texture) and predominantly confined to one parent material. A soil series is the subdivision of a family with each family having several series.

Soil series are differentiated on the basis of clearly visible soil characteristics such as color, texture, pedon structure, consistency and chemical properties. The names of soil series are based on the river, town or area from where they were first recognized.

For example, the **Yolo series** is defined as having certain horizons each with a specified color, structure, texture, as well as other properties. For a soil to belong to the Yolo series, it must have all the properties of a modal Yolo soil, and be within the acceptable range of each property. The central or modal Yolo pedon has two horizons, A and C, and is 100 cm thick, (or ranging in thickness from 80 to 120 cm). A soil like the Yolo in every other property, but less than 70 cm thick or thicker than 120 cm, would not qualify as Yolo. In this way, an infinite variety of individuals can be categorized into numerous units that are understandable and useful.

The term soil phase is not a soil taxonomical category but is referred to along with the term soil series to identify areas within a soil series. A soil phase is a mapping unit within a series. (See also Soil taxonomy.)

Soil sickness

Soil sickness refers to the deterioration of soil health due to excessive loading of the sewage sludge or accumulation of toxic materials. This leads to anaerobiosis and imbalance of carbon-nitrogen and carbon-phosphorus ratios.

Soil solution

A solution is generally a liquid, made by dissolving a relatively small solid component, called **solute**, in a major liquid component, called **solvent**. The aqueous liquid phase, in equilibrium with the soil at a particular moisture tension, is called the soil solution. The aqueous liquid phase of the soil and its solutes consisting of ions dissociated from the surfaces of soil particles and of other soluble materials is also known as soil solution.

In a soil solution, the solvent is water and the solutes are ions, most of which are found in plant ash. A permanent exchange phenomenon exists between the ions retained by the adsorption complex (exchangeable ions) and the ions existing in the soil solution. The equilibrium between various ions is not static and, even during the equilibrium phase, exchange continues between the adsorbed ions and those in solution at any given instant.

A soil solution can be made by watering slowly over a column of soil or in the field by draining from a lysimeter buried in the soil. The soil being an open system, the composition of its solution is influenced by many factors namely, the atmosphere, biosphere, hydrosphere and the energy between soils.

It is also influenced by climatic and biological factors, vegetation on the soil and soil minerals. In cool and humid atmosphere, the soil solution may be constantly renewed by precipitation. In cold winter months, there may be little biological activity to influence the composition of the soil solution. In the warm humid tropics, the soil solution is influenced by the biological activity brought about by warm temperatures. Thus, soil solution compositions vary with regions.

A normal soil solution contains 100 to 200 different soluble complexes. Acid soils tend to contain free metal cations and protonated anions, whereas alkaline soils contain carbonate or hydroxyl complexes.

The simplest method for determining the chemistry of soil solution is to extract a sample of the soil solution and determine the constituents in the laboratory. In one method, a soil sample is collected from the horizon of interest and saturated with water. The soil solution, known as the saturation extract, may be analyzed for its constituents. In another method, the soil solution is obtained directly from the field using porous disks.

Soil sterilant: See Fumigants

Soil structure

Soil structure is a morphological property of soil and is determined by the arrangement of soil particles and pore spaces in the aggregates. The shrinking, swelling, freezing and thawing of soil push or pull soil particles and cause the formation of aggregates. The principal forms of soil structure are determined by the kind of soil aggregates. Calcium, clay, iron, aluminum oxides and organic matter are among the important factors in the formation of the aggregate.

The soil structural units (peds) have three main characteristics: the type, the class and the grade. The type indicates the shape of the **ped**, that is, whether it is angular blocky, sub-angular blocky, columnar (prisms with rounded edges), granular, platy, prismatic, etc (Fig.S.19). The class specifies the size of the ped - whether very fine, fine, medium, coarse or very coarse. The grade evaluates the distinctness, stability or the strength of the ped.

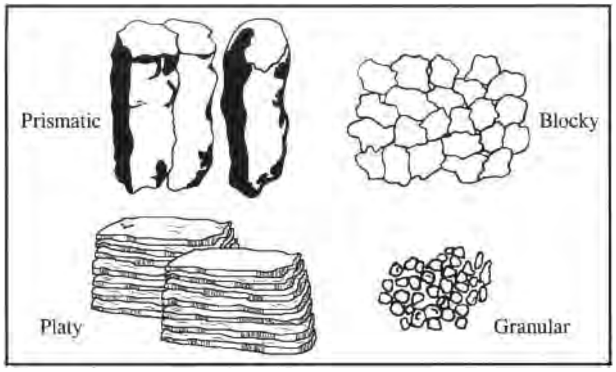


Fig.S.19: Types of soil structure.

Soil structure influences many soil properties, such as the rate of infiltration. Some soils are structureless, that is single-grained (each grain by itself) or massive (conglomerated particles without any regular cleavage). A massive, structureless pedon is a coherent mass of material. Sands and sand dunes are the unconsolidated mass of such grains.

A well-structured arable soil consists mainly of small aggregates or crumbs, separated by voids or pores which are large enough to allow the seedling to emerge easily and to provide a ready supply of water and oxygen to the plant roots. If the soil aggregates are not strong enough, they may be broken down by the impact of raindrops. Then a crust may be formed, which may prevent the emergence of seedlings and water infiltration, and also lead to surface run-off and erosion. Hence, the size, stability and internal porosity are important for the soil structure.

Soil organic matter plays a major role in soil aggregation. The soil structure increases the soil aeration and its water holding capacity, and facilitates microbiological activities. The structural development in a soil greatly affects its agricultural productivity. A loose, friable, freely draining soil is easier to cultivate than a heavy, compact soil. Wetting and drying, tillage and biological activities contribute to a continuous build-up and breakdown of soil aggregates. The structure of the arable layer is heavily influenced by the cultivation practices and so, one should encourage cropping systems which allow greater aggregation.

Soil subgroup: See Soil taxonomy

Soil suborder

In **soil taxonomy**, soil is classified into orders, suborders, great groups, families, etc., on the basis of its characteristics.

Soil suborder is the division of the **soil order**. The suborder name has two syllables. The first connotes something of the diagnostic properties of the soil, and the second syllable is the formative element or syllable for the order. For the suborder aqualfs, aqu is derived from the Latin word aqua, meaning water, and alf from alfisol. Thus, aqualfs are alfisols that are wet; they have an aquic soil moisture regime. The suborder is the most common category used in the discussion of soil geography and in the legends of soil maps.

The variations in moisture and temperature of the soil lead to the formation of additional horizons within the same order. The chemical and textural features cause orders to be divided into suborders. For example, the suborders within mollisols separate it from different climates or moisture regimes. The suborders of mollisols are albolls, aquolls, rendolls, borolls, udolls, ustolls and xerolls. Rendolls-mollisols formed on limestone may be found in many climatic regions, and have distinctly separate properties from other mollisols and so form a suborder. There are around 50 identified suborders of soil.

Soil subsample

Soils, fertilizers, plants, sediments, etc. are bulk and non-homogeneous materials that contain particles of different composition, which are not uniformly distributed within the material. In this case, a number of increments are taken randomly from points in the bulk material so that each part has an equal chance of being selected. The combination of these increments forms the gross sample or composite sample, which is generally large for direct analysis and hence divided further to get a subsample. For example, in soil analysis, 20 to 25 locations are identified in a field to get a representative composite sample from which the subsample is taken. (See also Sample.)

Soil taxonomy

Soil taxonomy is a **soil classification** system which defines its characteristics and inter-relationships, to facilitate the systematic and scientific grouping of similar soils from the most general categories to the most specific ones, with the ultimate aim of improving plant productivity and human environment. Soil taxonomy classifies and arranges such natural individual soil characteristics as horizons, soil color, soil texture, soil mineralogy, soil structure, soil moisture regimes and soil temperature regimes.

Most countries accept the US system of soil classification; a few have their own systems. The US system groups the world's soils into 12 orders, 54 suborders, 238 great groups, 1922 subgroups, families and series as described below.

Soil order is the most general soil category. All the soils in the world are placed under 12 orders based on the properties resulting from major processes and pathways of soil formation. Many features of the soil formation, which have taken a long time to develop, are stable in a pedological sense, and are mainly static, historically.

The soil orders are: (1) Entisols. (2) Inceptisols. (3) Andisols. (4) Histosols. (5) Aridisols. (6) Mollisols. (7) Vertisols. (8) Alfisols. (9) Spodosols. (10) Ultisols. (11) Oxisols. (12) Gelisols. Among these 12, the following 5 orders exist in a wide variety of climates: (i) **Histosols**: These are organic soils formed in water or under water, in which the minimum organic carbon content is 12% (with no clay in the mineral portion) and the maximum is 18% (with clay in the mineral portion at 60% or above). (ii) **Entisols**: These are little developed soils distinguishable by the lack of distinct, naturally developed (pedogenic) horizons. Entisols can constitute deep sandy areas or river-deposited clays or volcanic ash deposits or dry lakebeds. (iii) **Inceptisols**: While more developed than entisols, inceptisols are still only weakly developed soils, some of which are young soils of a comparatively recent origin causing the inceptisols to lack the development of a profile and horizon. In the US, inceptisols were earlier known as **Brown forest**, humic gley, **Ando** and Sol Bruns Acide. Water is available to plants for more than half the year or more than 90 consecutive days during the warm season. (iv) **Andisols**: These are mostly weak to moderately developed soils, with the majority formed from volcanic ejecta during the last 5000 to 10000 years. They have andic soil properties like low bulk density, amorphous clays, low soil strength and susceptibility to erosion by wind and mechanical disturbances. (v) **Vertisols**: These are mostly clay soils which stick and swell significantly. These are neither easy for cultivation nor ideal for constructing roads and buildings on.

The six orders developed in microclimate over a long period of time are: (i) **Mollisols**: These are usually fertile soils which are slightly leached and occur in semi-arid to sub-humid climates or under grasses of broad leafy forests. (ii) **Alfisols**: These are fertile soils in good moisture regimes with a base saturation higher than 35 percent. It is moist enough during the growing season to make it an intensively cultivated soil. (iii) **Ultisols**: These are not highly fertile but are probably the most productive soils because they are formed in areas with long frost-free periods and warm climate. (iv) **Oxisols**: These are formed in hot wet tropics and often exist in climates that are good to excellent the whole year round. Oxisols have to be carefully fertilized and limed for good yields of cultivated crops. (v) **Spodosols**: These are acidic sandy soils found in cool climates and are the poorest soils for cultivation; but, when properly managed, they can be used for cool season crops. (vi) **Aridisols**: Aridisols in the arid region have an aridic moisture regime, a chryic epipedon and other pedogenic horizons, but no Oxic horizon. **Gelisols** is the 12th and the most recent soil order found in the non-vegetated to continuously vegetated tundra. The suborders of the Gelisols are histels, turbels and orhels.

Suborder: The variations in moisture and temperature of the soil lead to the formation of additional horizons within the same order. The chemical and textural features cause the orders to be divided into suborders.

Great group: Great group is a subdivision of the suborder. The great groups may have the same arrangement as that of horizons and may also have a comparable temperature and moisture range. But the accumulation of clay or iron and/or humus changes the feature of the suborder, creating pans or hard zones, which interfere with water movement or root penetration. The characteristic features of soils belonging to the great groups are self-mixing properties of clays (expansion and contraction), soil temperature and differences in the content of Ca, Mg, Na, K, gypsum and other salts.

Subgroups: Each great group is divided into three subgroups: the first represents the central segment of the great group; the second has properties of the inter grades toward the other orders or suborders; and the last has an extra grade with properties different from the first two.

The subgroup denotes whether or not the soil is typical for the great group. Soils that are not typical of the great group are indicted as being intergrades.

Family: Within a subgroup, families are divided according to the important properties required for plant growth or for engineering use. The texture, pH and the average temperature of that soil determine the family.

Series: Each family has several soil series with a prominent feature like the presence of a river or town, and distinct characteristics that can be observed and mapped. Soils in the same series have very similar color, texture, structure, consistency, thickness and pH.

Soil phase: This is not a soil category but a mapping unit of the soil series. The mapping is useful in allocating the soil areas for farming, municipal or country zoning. Phases are subdivisions of series. Terms like surface soil texture, thickness, percentage slope, stoniness, saltiness, erosion and other conditions are called soil phases.

The advantages of soil taxonomy over the earlier classifications are that (a) it is based on the observable soil properties rather than the processes of soil formation, (b) it focuses on soils as natural bodies, (c) it permits the classification of soils of unknown origin, and (d) it is flexible and open to modification as knowledge about soils increases.

Soil taxonomy does not grant equal importance to all soil characteristics. Three special zones or layers have been defined in soil taxonomy for purposes of classification: epipedons, subsurface diagnostic horizons and the control section. These layers may constitute either one or more horizons.

Soil temperature

The sun gives out heat which is not absorbed equally by all soils. Soil temperatures, therefore, differ greatly and influence plant growth. In the tropics, soil surface temperature varies from around 28°C to beyond 45°C. It has a profound influence on biochemical and physical processes of soil formation as well as on the microbial activity and must, therefore, be regarded as a critically important property. Thus, the knowledge of soil temperature is essential before sowing, harvesting, etc.

Absorption of heat by soil depends upon the (a) angle of sun rays to the earth, (b) season of the year, (c) slope of the soil, (d) quality of soil water, (e) soil color, and (f) soil compaction. Soil temperatures higher than 35°C may reduce crop growth even when the crop species are well adapted; for example, there is a reduction of cassava growth for every 10 degree rise of temperature beyond 35°C. Generally, the higher the organic matter and the moisture, the higher is the specific heat. Therefore, wet soils or soils rich in organic matter may be cooler than those which are dry and low in organic matter. Dark colored soils absorb more heat than light colored ones. Subsoil temperatures are important for seedlings and for influencing fungal diseases.

The **standard soil temperature** (SST) is measured at a depth of 50 cm from the soil surface, but the average **annual soil temperature** (AST) is measured at a depth of either 90 cm or 180 cm.

The season and the soil temperatures at a particular location are the basic inputs for crop planning. Two practical steps can be taken to change the soil temperature. Wet soils can be drained to remove water, and mulches can be applied on the soil surface to alter the energy relationships.

If the cover is transparent to solar radiation, it can lead to a large increase in soil temperature. A transparent cover lets sunshine in but impedes loss of energy by long wave radiation, evaporation and conduction to the air. Variations in this practice include full scale green houses, smaller scale hot frames for raising seedlings and laying plastic films directly on the ground. In fact, leaving a clear plastic film in place for several weeks of hot clear weather can kill enough weed seeds, nematodes and other pests, to provide a worthwhile improvement in the crops.

The use of mulches and various shading devices can reduce the (a) solar radiation absorbed by the soil, (b) heat loss by radiation, and (c) water infiltration and evaporation losses. Modern materials and techniques help get over temperature effects. For instance, in cold regions, transparent plastic covers are used to increase the soil temperature whereas in hot regions, black polyethylene mulches are useful because they transmit less heat through the soil. Mulches act as insulation and retard warming.

Lowering the soil temperature is sometimes desired. The roots grow poorly when soil temperatures exceed 40°C, or even 30°C in sensitive species. Such temperatures are achieved, albeit briefly, in exposed soils. Several effective controls for reducing the radiation reaching the soil include shading, mulching with non-transparent materials, establishing the plant cover early and maintaining the cover at critical times. Keeping the soil wet helps to cool it by increasing the heat capacity, heat conduction and evaporation.

Soil test concentration: See Mehlich No. 1 extractant

Soil testing

Soil testing concerns itself with chemical or physical measurement. Its main objective is to measure the nutrient status and natural characters of that soil. Such measurements help to decide proper amendments (such as lime requirement for acidic soils, or gypsum for sodic soils) for remunerative farming.

Soil samples, their collection, preparation, laboratory analyses, calibrations and interpretation are all necessary for soil testing, evaluation and management of soil fertility.

A routine analysis involves the determination of pH, P, K, Ca, Mg, and of Al for problematic soil acidity. The determination of organic matter and micronutrients is done under specific conditions but not routinely.

Soil testing, apart from being a useful diagnostic tool for evaluating the soil fertility and for recommending the fertilizer dose, helps prevent environmental degradation by providing guidelines for minimizing the nutrient loss to surface and ground waters.

Soil samples are taken with an auger (a soil corer) and collected after harvest, but before any manure or fertilizer is applied. Patches, where heaps of compost are stored, or where there are hedges, marsh spots, etc., are excluded for sampling.

Soil testing consists of two important steps - extraction of plant nutrients from the soil by a liquid, and analysis of the resulting solution. A number of extraction methods have been developed for each nutrient. The results are compared with those from field experiments to ascertain the nutrient availability.

As nitrogen and sulphur are part of a dynamic system, involving rapid transformation between various forms, they are not always included in standard soil testing. However, soils are often analyzed for mineral nitrate and ammonium just before a nitrogen fertilizer is applied. Soils can also be tested for secondary nutrients and micronutrients. However, the availability of micronutrients is judged readily from the analyses of the plant material.

Soil tests help the farmer to scientifically know what nutrients need to be supplemented, and hence may effectively reduce the total fertilizer cost without affecting the yield. He can also allocate the same total costs toward fertilizers by readjusting the N, P and K proportion on the basis of nutrients present in the soil, thereby increasing the yield as well as the net profit.

Soil test kits

Soil test kit is a portable kit, containing chemicals and simple equipment like a pH meter and conductivity meter to carry out quick soil tests on the field itself (without the test samples having to be brought to the laboratory). The quick analysis can be confirmed later on in the laboratory.

Soil, test sample of: See Test sample of soil

Soil Tex G1

Soil Tex G1 is polyacrylamides that are used alone or with starch to promote water storage in soils. The water holding effect, however, varies with the pH value, water hardness and dissolved substances.

Soil texture

Particle size groups or **soil separates** determine the soil texture which is an important soil characteristic. In this classification, only such mineral particles that are less than 2 mm in diameter and with no organic matter, are considered.

Soil texture can be classified under the sand, silt and clay categories. The particle size of sand is the coarsest, that of silt, medium and clay, the finest. Soil that does not show properties of any of these groups predominantly is called the loam which has more or less equal properties of **sand**, **silt** and **clay** (Fig.S.20).

The U.S. Department of Agriculture (USDA) has classified and established the limits of variation in the size of soil separates. The classification of soil separates according to the USDA is given in Table-S.5.

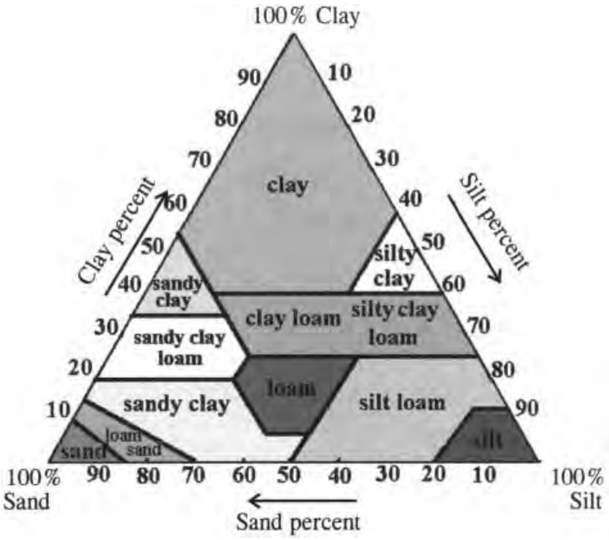


Fig.S.20: Triangle of soil textural classification for particles less than 2 mm size.

Table-S.5: Classification of soil separates.

Particle diameter range (mm)	Classification
0.5 - 2.0	Coarse sand
0.25 - 0.5	Medium sand
0.05 - 0.25	Fine sand
0.002 - 0.05	Silt
< 0.002	Clay

The rate of many important chemical reactions in the soil is governed by the soil texture because the latter offers the available surface area for reaction. Soil texture critically influences the crop response to fertilization. There are about 12 textural classes graded from coarse-textured, easily worked soils (light or sandy), to very fine textured, not easily worked soils (heavy clayey). The proportion of particle sizes decides the textural class of that soil. A fraction of the dominant size is the base of the texture of that soil. A 'light' or 'coarsely' textured soil is considered **sandy**, while the 'heavy' or 'fine' textured soil is considered to be of high clay content. A soil with more than 40% organic matter is usually termed 'organic' peat soil.

Soil texture is only a guide for cultivators. For instance, light soils are relatively easy to cultivate, while heavy soils are difficult. Young soils tend to have a similar texture in each horizon. Soil texture is determined by the **international pipette method** that is based on the rate of fall of solid particles in a liquid medium as per the Stokes' law. Assuming the average particle sizes of sand, silt and clay as 50, 5 and 2 μm, respectively, the number of particles falling through is estimated and the textural class, determined. The texture can also be assessed by a finger touch. A rough and quick method (the **feel method**) determines *in-situ* soil texture, as shown in Table-S.6. The water intake rate, the water storage in soil, the ease of tillage and the amount of aeration are assessed from the soil textural class.

Plasticity, water permeability, ease of tillage, fertility and productivity are all closely related to soil texture.

Table-S.6: Determination of soil texture by the feel method.

Texture class	Feel of fingers	Ball formation	Stickiness on fingers	Ribbon
Clay	Very smooth	Hard ball, when dry, cannot be crushed by fingers	Definitely stains	At appropriate moisture, squeezes out into 2-7 cm long ribbon
Silty clay loam	Very smooth	Moderately hard ball when dry	Definitely stains	Flaking on ribbon surface similar to silt loam
Clay loam	Slightly gritty feel	Moderately hard ball when dry	Definitely stains	Ribbons on squeezing, breaks early
Loam	Neither gritty nor smooth	Firm ball	Definitely stains	No ribbon
Silt loam	Smooth or 'buttery' feel	Firm ball	Definitely stains	Slight tendency to ribbon with flat surface
Sandy loam	Moderately gritty	Fairly firm ball, but easily broken	Definitely stains	No ribbon
Loamy sandy	Very gritty	Easily breakable ball	Stains very little	No ribbon
Sand	Very gritty	No ball	Does not stain fingers	No ribbon

Source: "Analysis of Soil Physical Properties", 2000, by S. P. Mujumdar and R. A. Singh. Agrobios (India). With permission.

Many clay soils expand and shrink with wetting and drying, causing cracks in the walls and foundations of buildings. Conversely, many red colored tropical soils have clay particles composed mainly of kaolinite and oxides of iron and aluminum. These particles have little tendency to develop stickiness and to expand and contract on wetting and drying. Such soils can have high clay content and show little evidence of stickiness when wet, or of expansion and contraction with wetting and drying.

There are many established relationships between plant growth and soil texture for particular geographic areas and particular crops. Coarser textured soils bring out even better yields from pine than for corn. The greatest growth of red pine occurs on soils with sandy loam texture where integrated effects of nutrients, water and aeration are most desirable. Loam soils offer the greatest productivity for corn.

Soil types

There are six types of soil zones in the world. They are as follows:

(i) **Tundra soils**: These are soils found in the tundra regions, 'tundra' meaning a treeless plain. Tundras are very cold regions and include the Arctic, Antarctic and alpine tundras. The tundra soil supports dwarf shrubs, mosses, grasses and lichens. Most of the vegetation has a short growing season.

Some tundra soils have been considered important because of the significant pool of carbon present in the form of humus and peat. Such accumulation is related to the low decomposition rates in the cold and waterlogged conditions of the tundra regions.

(ii) **Podzolic soils:** These are found in humid, temperate and broadleaf forests. Such soils are moderately leached and clayey with some iron content (usually a result of eluviation). The humus layer is generally 50 cm thick. Occasionally, the iron and clay form a laterite layer.

(iii) **Chernozemic soils**: These dark colored soils exist in sub-humid, semi-arid, temperate climates and develop under xerophytic or mesophytic grasses. The soil surface has an Ah, Ap horizon and a B or C horizon which has high base saturation.

(iv) Latsolic soils are typical of humid and wet or dry tropical and sub-tropical climates.

(v) **Desertic soils**, considered aridisols, form in arid climates and have a high mineral and low organic content. Commonly, these soils form gravelly and sandy layers with calcium carbonate and other salts.

(vi) Stony mountain soils may have any one of the above characteristics.

Each soil zone or belt consists of many soil types. In a sub-tropical country like India, for instance, approximately 25 types of soils are recognized: those extensively studied the world over are the **red soils, laterite soils, black soils** and **alluvial soils**. In Russia, a level of soil classification system offers about 71 known soil types.

Soil water

Water is held in soils, and is available to plants, depending on the content of soluble salts. It is this water that plants take up before water from rains or irrigation canals becomes available. Water is held in soils as films on particle surfaces and in small pores. Water held in large pores drains off by gravitational flow, whereas small pores retain it by capillary force. Clayey soils and soils with high humus hold a good deal of water. Compaction affects the water content in the soil adversely.

Water can be present in the soil above the water table and be held with varying degrees of tension, ranging from free-flowing water to that held firmly on the surface of the soil particles. Soil water is classified into two categories: water that plants can use, and that which they cannot use. On the basis of water movement, soil water is classified as gravity water, capillary water, hygroscopic water and plant-available water.

Gravity water or **vadose** is that water which is present in soil above the water table and which drains away under gravity. **Capillary water** is retained by the soil during the infiltration of rainwater in medium and fine pores ($< 10\ \mu m$). It creeps above the water table, moves upward and evaporates at the surface, leaving behind dissolved salts. **Hygroscopic water** is the film of water that adheres to soil particles by molecular attraction. **Plant available water** is the stored soil water that can be used by plant roots. The **wilting point** (or **permanent wilting point**) is the quantity of soil water that the plant roots cannot absorb for their needs, causing them to wilt and not recover. It is the lower limit of available water. The **field capacity** is a measure of the maximum amount of water that a soil can hold, when there is complete wetting and free drainage.

The force of attraction between the positively charged hydrogen atoms of water and the negatively charged ions (like oxygen in soil minerals) causes the soil to hold water. The bond between hydrogen atoms and negatively charged atoms is called **hydrogen bond**. Hydrogen bonding between water molecules produces another important characteristic of water - surface tension, as water molecules attract each other more strongly than do air molecules. The two hydrogen atoms of water bond themselves to the surface oxygen atom, which makes this a surface-attractive force. So, soils with more surfaces adsorb more water. Negative and positive pressures, the pH scale and the water potential all indicate how strongly the water is held in the soil.

Infiltration is an important soil water process. Water moves in the soil in three ways: (a) as saturated flow, (b) as unsaturated flow, and (c) as vapor transfer. In both the saturated and unsaturated cases, water flows under a hydraulic gradient. In saturated flow, the hydraulic head is the most important factor, while in unsaturated flow, the matric potential (or head) is most important.

Water moves within the soil and from the soil to the roots as a result of the water potential differences. Water movement is directly related to water potential differences and inversely proportional to the distance of flow. The rate of water flow is also directly related to the soil hydraulic conductivity. Hydraulic conductivity decreases rapidly as soils dry up. The plant uptake of water reduces the water content of the soil and greatly decreases the hydraulic conductivity. Thus, as the soil dries, the movement of water to the roots becomes slower. Plants wilt when the movement of water is too slow to satisfy the plant's demand for water.

Water in the soil is referred to as soil solution. It contains solutes which include cations and anions, organic and inorganic compounds, some micro fauna and gases. Frequently there are small, suspended particles (such as clay) in the soil solution. Fresh water, before entering the soil, comes into contact with vegetation and removes some cations and anions in the vegetation by means of leaching. Soil water is not static. It changes in composition, whether or not new water is added to the soil. The composition is influenced not only by vegetation on the soil and the soil minerals, but also by the climate and the time of the year. The soil water content is expressed in several ways, such as being relative to the (a) mass of soil solid, (b) total volume, (c) total mass of the soil, (d) volume of solids, and (e) volume of pores.

Soil water belt

Soil water belt refers to the **root zone**. The volume of the soil in which roots grow actively during the life of the crop is known as the **root zone** which is generally 50 to 100 cm deep depending on the crop and the soil type.

Soil water potential

Soil water potential, also called **water potential**, is defined as the chemical potential of water in the soil (or the biological system) minus the chemical potential of pure water at the same temperature and pressure.

Soil water potential is the amount of work (usually given in kilopascals, kPa) that must be done per unit quantity of pure water in order to transport reversibly and isothermally, an infinitesimal quantity of water from a pool of pure water, at a specified elevation and atmospheric pressure, to the soil water.

Sola

Sola is the plural of **solum**.

Sole

Sole is another term for **pan**.

Solid

Matter in its most highly concentrated form is solid. In a solid, the atoms and molecules are much more closely packed than in gases and liquids. Hence it is more resistant to deformation.

The normal condition of solid state is a crystalline structure with an ordered arrangement of ingredient atoms, in a framework called lattice. Crystals are of many types, and normally have defects and impurities that profoundly affect their applications, as in semiconductors. The geometric structure of solids is determined by x-rays, which are reflected at characteristic angles from the crystal lattices, which act as diffracting gratings.

Some materials that are physically rigid, such as glass, are regarded as highly liquid because they lack a crystalline structure. All solids can be melted by heating, and are thus converted to liquids. For ice, this occur at 0°C; for some metals the melting point may be as high as 3300°C.

The **solid-state chemistry** deals with the study of the exact arrangement of atoms in solids, especially crystals, with particular emphasis on imperfections and irregularities in the electronic and atomic patterns in a crystal, and the effects of these on electrical and chemical properties.

Solid-state chemistry: See Solid

Solid wastes

Solid wastes can be dry (rubbish, scrap) or wet (garbage, sewage, industrial wastes suspended or dissolved in water). Solid wastes are classified according to the source of the waste (agricultural, mining, industrial and municipal).

Agriculture and mining activities produce about 90% of all solid wastes.

Agricultural solid wastes consist of crop residues and animal waste. Crop residues are returned to land as manure. Animal wastes, especially those generated in feed lots and slaughter-houses, are often discharged into water or burnt. Mining wastes generally accumulate near the extraction site.

Most industrial solid waste is disposed on the generator's property; 10 to 15% of it may be hazardous, reactive, corrosive, ignitable, infectious, radioactive or toxic and requires a "cradle to grave" management technique. The greatest danger from hazardous waste is contamination of water supplies – either by leaching into ground water or by surface run-off into streams. Hazardous waste may contaminate the land as well.

Municipal solid waste from residential, commercial and institutional sources are generally collected and disposed of by local governments either directly or through private contractors. About 75% is disposed of in open dumps, 13% as sanitary landfills and 8% by burning. Open dumping poses health problems. Space for dumping is scarce in urban areas, making it critical for each community to manage its own waste.

Sanitary refills, where each day's deposit of waste is covered with a layer of soil, are more costly than dumps but in some cases refills may upgrade the low-quality site for recreational and other uses. However, in recent times, it has been discovered that even sanitary refills can be a source of heavy metal leaching into underground water as well as methane gas which can explode if not drawn off.

Organic wastes, which constitute 75% of municipal solid wastes, can be readily burnt, incinerated or used as fuel in specially adapted electricity generating plants.

Solifluction

The slow flow of material in the form of mud over frozen subsoil, particularly in cold climates (as in Greenland) and high mountains, is known as solifluction or **soil creep**. The speed of the flow is 5 to 50 cm/year. Alternate thawing and freezing of snow in rock crevices breaks the rocks. Soil erosion by the action of snow is known as **nivation**.

Solonchaks

Solonchaks are one of the 106 groups of a special soil classification designed by the Food and Agricultural Organization (FAO). Solonchaks are a group of **saline soils** with a greyish crusty appearance and form a part of **saline-alkali soils** with the pH around 8 to 8.5. Their diagnostic horizons include an A horizon, a histic H horizon, a cambic B horizon, a calcic horizon or a gypsic horizon. Solonchaks are also classified as aridisols and belong to the great group in soil taxonomy.

Solonchaks can be orthic, mollic, takyric or glyric, containing active lime. Soils found mainly in arid and semi-arid climatic regions or on the sea coast under more humid conditions may be solonchaks. These are formed where hot arid conditions cause the evaporation of soil moisture, leading to dissolved salts being deposited on the surface.

Solonetz

Solonetz is one of the 106 groups in the special soil classification designed by the Food and Agricultural Organization (FAO).

Solonetz and **solonchaks** are classified as aridisols and are differentiated at the great group level in the soil taxonomy. Solonetz forms a group of the B horizon **sodic soils** and also a part of the saline-alkali soils. These soils have a natric B horizon without an albic E horizon, characterized by hydromorphy (at least in a part of the horizon) and not exhibiting any abrupt textural change.

Solonetz can be orthic, mollic, haplic, calcic, gypsic, stagnic or gleyic. The pH of the surface layer is close to 7, while deep down it is 9 to 10. These soils are also called **black alkali soils**.

Solubility

The tendency of a substance to mix uniformly with another substance is known as solubility, like in the case of solid in liquid, liquid in liquid, gas in liquid or gas in gas.

The solubility of a solid in a liquid varies from 0 to 100%, depending on the temperature and chemical nature of the two substances. Solids lose their crystallinity and become molecularly or ionically dispersed in the solvent to form a true solution. Examples are ammonium, sodium and potassium fertilizers in water. Liquids and gases are often said to be **miscible**, rather than soluble, with other liquids and gases. Nitrogen, oxygen and carbon dioxide are freely miscible and air is a solution. The chemistry of solubility is a complex mathematical subject in which electrolytic dissociation, diffusion and thermodynamics play a vital role.

Solubilization

Solubilization is a process by which the constituent elements of primary minerals are released to a soluble or pseudo-soluble liquid state. This release of elements of primary minerals takes place during their biochemical weathering These elements either retain their form, or are lost through natural drainage, or slowly turn into amorphous or para-crystalline gels, mostly after undergoing redistribution in the profile.

Soluble nutrient

Plant nutrients that are more soluble than gypsum (with a solubility of 0.241 gm/100 ml of water at 0°C) are called soluble nutrients. Nutrients are absorbed either as simple compounds or as ions. For example, carbon and oxygen enter plants as carbon dioxide through the leaves; water enters plants through the roots, as do all nutrients, either as positively charged cations such as ammonium (NH_4^+), calcium (Ca^{2+}), potassium (K^+) or as anions, as in nitrate (NO_3^-), sulphate (SO_4^{2-}) or phosphates ($H_2PO_4^-$, HPO_4^{2-}). (See also Soluble salts.)

Soluble salts

Inorganic chemicals that are more soluble in water than gypsum are called soluble salts. They are made up of cations of sodium, calcium, magnesium, etc and anions of sulphate, bicarbonate (HCO_3^-) etc. Soluble salts are usually a result of weathered minerals.

During the chemical analysis of a soil sample or a nutrient, the total quantity of salts or nutrients extracted by diluting or saturating the sample in water or in a specific medium under specific conditions (soil to water ratio of 1:10 or 1:5) is known as **soluble nutrients**. The value of the water extract or a saturation extract is approximate. If the total soluble salts are more than 2 g/kg, a complete analysis of various ions is undertaken.

Soluble salts and their composition can determine the productivity of soils and crop yields. The evidence of soluble salts is seen in the development of major problem soils the world over, namely, **saline soils**, **sodic soils** and **saline alkali soils**.

Soluble starch

Soluble starch is obtained by heating ordinary starch with 10% hydrochloric acid (HCl) for 24 hours and then precipitating it with alcohol.

Solubor

Solubor is a type of borate containing 20.3% boron. It is chemically a polyborate, similar to borax, and is represented as $Na_2B_2O_7{\cdot}5H_2O + Na_2B_{10}O_{16}{\cdot}10H_2O$. It is a finely-ground, white product specially designed for foliar, liquid or dust applications, to correct boron deficiency.

Solum

The upper part of the soil profile above the parent material, which is most influenced by roots, rainfall and micro-organisms is the solum (plural:**sola**). Each of the A, E and B horizons, for instance, is a solum. (See also Soil horizons.)

Solute

Solute is a substance that dissolves in a solvent forming a solution. In a sodium chloride solution, for instance, sodium chloride is the solute and water is the **solvent**. The quality of solute is mostly such that it does not saturate or over-saturate the solution, and is uniformly dispersed in the solvent.

In plants, water movement is dominated by the solute (osmotic) potential, caused by salts and organic solutes found in the cell water. The difference in solute concentrations can be maintained with a cell membrane that restricts solute movement but allows water to pass through. Also, when a cell is inflated with water, the cell wall gets stretched. This develops a moderate pressure potential called **turgor pressure**. Turgor pressure helps to expand the growing cells and stiffen the plant tissue. Loss of turgor is known as **wilting**. (See also Soil solution.)

Solution

Solution (in chemistry), is a **homogeneous mixture** of two or more substances (solid, liquid or gas). A solution is commonly made of a solid and a liquid, and has uniform properties throughout. The two parts of a solution are called phases. The liquid component is termed solvent and the component dissolved in it is called the **solute**. The proportion of substances in a solution depends on their limits of solubility. The solubility of a solute, in a given solvent at a particular temperature is usually given as the mass that dissolves in a 100 g of the solvent to give a saturated solution.

Solutions showing no change in internal energy on mixing and a complete uniformity are known as **ideal solutions**, and they follow Raoult's law. Solutions are involved in many chemical reactions, refining and purification, activities industrial processing and biological phenomena. **Solubility** generally increases with temperature.

Air is a solution consisting of a mixture of gases. Wine is a complex liquid solution. Brass is a solid solution of copper and zinc. Two common examples of solutions include vinegar (being a solution of liquid acetic acid in water) and sugar syrup (being a solution of sugar in water).

A solution containing the maximum amount of solute that can be dissolved at a given temperature and pressure is known as **saturated solution**. Super saturation is also possible. Different weathering mechanisms contribute to the dissolution of minerals in a soil solution.

Most common minerals have a limited solubility in pure water. However, acidification of soil solution by carbon dioxide, dissociation of the hydrogen ions (H^+) and decomposition of organic matter (to release organic acids) increase the solubility of most inorganic compounds. Even since soil formation began thousands of years ago, repeated removal of dissolution products have only led to further dissolution.

Solution of ammonia: See Aqua ammonia

Soluviation

Soluviation is a geochemical weathering phenomenon. It is a combination of **solubilization** and **eluviation**. It differs from **cheluviation** which is a combination of chelation and eluviation. In soluviation, the weathering liquid does not contain chelating substances, acids or water, to correspond to hydrolysis.

In soluviation, aluminum is not eliminated whereas silica is, to a varying extent.

Solvation

The process by which molecules of a solvent surround the solute particles is referred to as solvation. It is the process that causes ionic solids to dissolve and the released energy to be used up for breaking down the crystal lattice. It is also applied to the action of plasticizers on resin dispersion in plastisols. When the solvent is water, the process of solvation is called **hydration**.

Solvay process, modified

The modified Solvay process is an industrial process named after the late 19th century Belgian chemist, Ernest Solvay. Several methods are used to produce ammonium chloride. The most important is the **dual-salt process** or the modified Solvay process, wherein ammonium chloride and sodium bicarbonate are produced simultaneously using common salt and anhydrous ammonia as the principal starting materials. The reactions are:

$$2NH_3 + H_2O + CO_2 \longrightarrow \underset{\text{Ammonium carbonate}}{(NH_4)_2CO_3}$$

$$(NH_4)_2CO_3 + CO_2 + H_2O \longrightarrow \underset{\text{Ammonium bicarbonate}}{2NH_4HCO_3}$$

$$NH_4HCO_3 + NaCl \longrightarrow \underset{\substack{\text{Sodium}\\\text{bicarbonate}}}{NaHCO_3} + \underset{\substack{\text{Ammonium}\\\text{chloride}}}{NH_4Cl}$$

The addition of sodium chloride to ammonium bicarbonate yields sodium bicarbonate and ammonium chloride.

Solvent

Solvent is a substance in which a solute is dissolved to form a solution at the molecular or ionic level. Usually, the quantity of solvent is more than the solute so that no solute remains undissolved in the solution. In a sodium chloride solution, for example, water is the solvent.

There are two types of solvents: polar and non-polar. **Polar solvents**, like water and liquid ammonia, have dipole moments and high dielectric constants and they dissolve ionic or covalent compounds that ionize. Non-polar solvents, such as carbon tetrachloride, benzene, etc., do not have permanent dipole moments and they easily dissolve non-polar covalent compounds, but not ionic compounds.

Solvents are further classified according to their proton donating and accepting properties, into **amphiprotic** and **aprotic solvents**. Amphiprotic solvents like water, self ionize and hence can act as proton donors and acceptors, whereas aprotic solvents like carbon tetrachloride neither donate nor accept protons.

The main uses of organic solvents are in coating surfaces (paints, varnishes and lacquers), industrial cleaners, printing inks, extractive processes and pharmaceuticals. Many solvents are inflammable and, therefore, a fire hazard. Some solvents may also be toxic, in which case they contribute to air pollution. Aqueous solutions of nutrients are used for foliar applications. Plants also take up nutrients from the soil aqueous solutions. (See also Soil solution.)

Solvent extraction

Solvent extraction is a process of selectively separating a desired constituent from a mixture, by dissolving the mixture in a solvent in which only that constituent is soluble, and not the others.

Solvent extraction, as a process, is used in chemical and oil industries. The solvents used vary with the nature of the products involved. Widely used solvents are water, hexane, acetone, isopropyl alcohol, furfural, xylene and tributyl phosphate.

After the extraction of oil from seeds, the cake is used as a fertilizer. The solvent-extracted cake is better than the one extracted by the country ghani (oil-mill or oil expeller), in that the solvent method extracts most of the oil from the seeds.

Sombric horizon

Sombric horizon is an illuvial horizon (endopedon). The sombric horizon contains well-drained mineral soils from cool mountainous regions and high plateaus. The horizon is also present in tropical and subtropical regions. Its humus has a low exchange capacity and saturation percentage, but does not contain aluminum or sodium. The values of the exchange capacity and the saturation percentage or chroma, or both, are lower than those in the underlying horizon. Often the sombric horizon contains more organic matter than the overlying horizon; the organic matter is not uniformly distributed but is concentrated on the faces of the peds and in pores.

Sombric horizons are associated with inceptisols, oxisols and ultisols.

Somerville process for phosphoric acid: See Phosphoric acid production processes

Sorption

Sorption is absorption and adsorption viewed as a single process. It, therefore, means the collection of one substance on the surface of another substance, and/or the penetration of one substance into another. Sorption is thus adsorption and absorption taking place jointly or separately. A high soil pH adversely affects the sorption behavior of elements in the soil. Heterogeneous catalysis very often involves gaseous reactants being adsorbed on the surface of a solid catalyst. An important example of heterogeneous catalysis occurs in the hydrogenation of unsaturated hydrocarbons. Typically, heterogeneous catalysis involves the (a) sorption of reactants, (b) migration of adsorbed reactants on the surface, (c) reaction of the adsorbed substances, and (d) escape or desorption of the products.

Sour soil

An infertile acid soil, as distinct from a 'sweet' or fertile alkaline soil, is called sour soil.

Southern leaf blight in corn

The southern leaf blight is a pathogenic attack on the corn plant caused by *Bipolaris maydis*. It can cause damage to the crop, if it is not controlled in time.

SPA

SPA is short for **superphosphoric acid**. Phosphoric acid, with more than 54% phosphorus (as P_2O_5), is superphosphoric acid. It is a mixture of orthophosphoric acid and polyphosphoric acid, and is made from green phosphoric acid. The salts of green phosphoric acid are used as fertilizers.

Space formula: See Formula

Speciality fertilizer

Speciality fertilizer is a commercial fertilizer produced and distributed primarily for such non-farm uses as home gardens, lawns, shrubbery and nurseries.

Speciality fertilizers are developed to amend soils for nutritional enhancement of a wide variety of crops. These fertilizers include ammonium thiosulphate, potassium thiosulphate, ammonium polysulphide products and triazone-based slow-release nitrogen liquid fertilizers, like urea-triazone formulations.

Sometimes, micronutrients are mixed with major nutrients to form speciality fertilizer formulations.

Speciation

Speciation is the act of forming new and distinct species from the existing species.

A **species** is defined as a group of living organisms comprising similar individuals capable of interbreeding or exchanging genes, and is the main natural taxonomic unit. A species possesses characters distinguishing it from other units within a genus. The name of the species is designated by a biennial nomenclature, for example, *Aspergillus niger*, which consists of a generic name followed by an epithet.

Speciation is part of the whole process of organic evolution. The modern period of its study began with the publication of the theory of evolution by natural selection (Charles Darwin and Alfred Russell Wallace).

Environmental pathways and toxicity of an element depend on the speciation of the element concerned. For instance, hexavalent chromium is more toxic than the trivalent form; methyl mercury, formed in aquatic environments due to bacteria, is far more toxic than metallic mercury. Methyl mercury in fish is considered as the most important pathway of mercury. Aluminum is mobilized in soil and water, under conditions of acid rain.

Species: See Speciation

Specific adsorption

Specific adsorption is adsorption, usually chemical, that is selective for a particular ion or substance. Specific adsorption and desorption processes control the levels of the dissolved P, Mo, B, Cu and Zn in most soils. These processes resemble precipitation or dissolution from surfaces. (See also Adsorption specific.)

Specific gravity

Specific gravity or relative density of a material is the ratio of its density to that of water at a specified temperature (4°C), or air (for gases) at standard conditions of temperature and pressure. Specific gravity being dimensionless, is often more convenient to use (than density) as its value is the same in all systems of units. Thus, a solid or a liquid with a density of 1.5 g/cc has a specific gravity of 1.5.

Specific gravity of soil is always more than the **bulk density** or apparent density, as the latter is simply the soil mass divided by the whole soil volume.

Specific surface area

Specific surface area of a material is the surface area per unit mass of the material measured in m^2/kg and is indicative of the extent of fineness of the material. The higher the surface area, the finer is the particle size and greater the volume of adsorption of gases and vapors.

The surface area of clay and humic substances is high, whereas that of sand particles is low. This concept is particularly useful in determining the fineness of phosphate rock and phosphogypsum in the phosphoric acid production process. The data can also be used to predict reaction efficiencies and filtration rates.

Since activity at the surface (being the interface with the environment) is very high, it would follow that the larger the surface area of a given substance, the greater is its reactivity. Thus, reducing the particle size is a way to increase the efficiency of both the chemical and physical reactions. For example, the coloring effect of a pigment is increased by reducing its size. Carbon black, being a very fine powder, has a very large surface area and when used as filler, increases the strength and abrasion resistance of rubber.

The surface area of particles of known linear dimensions can be calculated. The linear dimensions of dispersed particles can be determined by electron microscopy.

The most widely used method for the determination of specific surface area is based on the adsorption of gases, vapors or liquids, and uses the **Brunaur-Emett-Teller (BET) adsorption isotherm equation**:

$$\frac{1}{V\left(\frac{P_o}{P}\right)} = \frac{1}{V_m C} + \frac{C-1}{V_m C} \times \frac{P}{P_o}$$

where V is the volume of gas adsorbed at pressure P, V_m is the volume of gas adsorbed when the surface of the solid is completely covered with a monolayer of adsorbed molecules, C is the BET constant dependent on the gas, P is the adsorbate gas pressure and P_0 is the saturation pressure.

Catalysts for chemical reactions have high surface areas. The specific surface areas of some common catalysts are as follows:

Catalyst	Specific surface area (m^2 / kg)
$SiO_2 - Al_2O_3$ (cracking catalyst)	$(2-5) \times 10^5$
Fe (for NH_3 system)	$(0.4-1.1) \times 10^4$
Active Al_2O_3	1.15×10^5

Specific surfactant

Surfactant is a compound that reduces the surface tension when dissolved in water solutions or which reduces interfacial tension between two liquids or between a solid and a liquid. Surfactants are molecules made up of a lyophilic or hydrophilic portion, and a lyophobic or hydrophobic portion. The lyophilic portion consists of long-chain hydrocarbons or benzenoid ring structures which are low in water solubility but high in organic solvent solubility. The hydrophilic end has high affinity for water. Specific surfactants can be used in many ways, such as wetting agents, dispersing agents, emulsifiers, foaming agents, detergents, etc.

A **wetting agent** is added to herbicides to cause spray droplets to spread over the surface of the leaves. Phospholipids are the example of a specific surfactant present in cell membranes. (See also Adjuvant.)

Specific yield

Specific yield is the volume of water drained by gravity divided by the total volume of a saturated aquifer sample. The specific yield of most unconfined aquifers ranges from about 10 to 30%. A good water-bearing formation from which **groundwater** is derived, should have a high hydraulic conductivity and a high drainable porosity, which is called specific yield.

Speckled yellows: See Manganese

Spent mushroom substrate

Spent mushroom substrate is another term for **dried slurry**. (See also Peat.)

Sphalerite

Sphalerite, which is zinc sulphide with some Cl, Mn and Fe, is the principal ore of zinc mineral. It is yellowish brown in color.

Sphericity

Sphericity is a measure of the extent of roundness of the particle and, in the case of solid fertilizers, is determined by the ratio of length to diameter of the particle.

The efficient packing of any material depends on its shape and size, which is not easy to measure. Sphericity is one such parameter which, along with some other parameters and measurements, can give an idea about the particle shape.

To determine sphericity, granules are distributed over an inclined moving belt. While the spherical ones roll down the inclination and collect at the bottom, the irregular and broken ones are carried up and discharged at the top of the belt.

Sphericity is also referred to as the ratio of the surface area of an equivalent sphere to the actual surface area.

$$\text{Sphericity} = \frac{\text{Surface area of equivalent sphere}}{\text{Actual surface area}}$$

Splash erosion

The removal of soil particles by raindrops is referred to as splash erosion. Soil gets eroded when raindrops detach and move particles from soil clods (Fig.S.21). The loosened material is transported by turbulent run-off rain water (known as **run-off erosion**). Erosivity depends on the property of rainfall, namely, its drop size, velocity distribution, direction, intensity, frequency, magnitude, duration and sediment content.

Fig.S.21: Raindrops cause splashing of soil particles and may lead to soil erosion.

Split application of fertilizer

Split application is the breaking up of the total dosage of fertilizer intended for a crop, in two or more instalments. This practice is followed for nitrogen and in some cases for potassium. Fertilizer applications are generally split into basal dressings or top dressings. This practice is observed to improve fertilizer use efficiency.

Spodic horizon

Spodic horizon is an illuvial horizon usually located below an albic horizon. It contains active amorphous materials (with a high cation exchange capacity, specific surface area and water retention capacity) and is composed of organic matter and aluminum (with or without iron). This horizon must have a certain minimum thickness and also have some carbon, extractable iron and aluminum, the actual quantity being dependent on its clay content.

Spodic horizons are associated with **spodosols**. Spodosols, one of the twelve soil orders, are soils that develop in cool climates. They are mineral soils having either a spodic horizon or a placic horizon cemented by iron, overlying a fragipan and meeting all requirements (except thickness) of a spodic horizon. These are acidic, sandy and mostly unsuitable for cultivation. If properly managed, crops like grains, strawberries, raspberries, pastures, etc. can be usefully grown in the cool season.

Spodosols are classified into suborders, namely, aquods, ferrods, humods and orthods. Spodosols provide a life-supporting medium for the world's largest contiguous expanse of boreal vegetation, where the dominant economic activities are forestry and agriculture. They are also well-suited for root crops, especially potato and sugar beet.

Spodosols: See Spodic horizon

Spoon feeding of crops

Liquid fertilizers are used either as a solution or suspension. Most nitrogen solutions are directly applied, broadcast or applied in bands.

One of the methods of applying non-pressure nitrogen solution and other fluids to irrigation systems (such as sprayers, sprinklers, gated pipes and drip tubes) is called spoon feeding. The spoon feeding method involves applying these fertilizers through irrigation water, several times a day during the growing season of the crop.

Spray drift

Spray drift refers to the tendency of a spray of fine droplets, (produced by a low volume nozzle) to drift with the air from the intended field of application to other fields. Such drifts may damage other crops, and, if toxic, can poison grazing animals or bees. Drift damage is minimized by spraying in suitable weather conditions and by using agents, like adjuvant oils, to increase the viscosity of spray mixes. Large nozzles and low pressure reduce the spray drift owing to the formation of larger spray droplets which are less prone to drift.

Sprayer

Sprayer is a machine used to spray a liquid through a nozzle under pressure. Field crop sprayers are classified according to their application capacity, as shown in Table-S.7.

Table-S.7: Classification of capacity of sprayers.

Volume	Litre/ha
Low	Less than 220
Medium	220 to 660
High	More than 660

A sprayer consists of a tank from which the liquid is pumped into nozzles, fitted at regular intervals along the boom. The nozzles may be like a fan (used for low and medium volume sprayings) or like a cone (used for high volume spraying), as shown in Fig.S.22.

Fig.S.22: Types of sprayers.

The flooding nozzles emit droplets of about the same size as an average raindrop. They are used to broadcast fluids, mixed fertilizers and suspensions. Sprayers with tanks of up to 450 liters capacity may be tractor-mounted; those of a larger capacity of up to 1800 liters are trailer-mounted on a 4-wheel-drive vehicle. These large applicators are capable of applying fertilizer solutions at a rate of about 0.5 ha/min.

Common types of spray nozzles produce a wide range of droplet sizes. These are sprayers which use high-speed spinning nylon discs with fine-toothed margins to produce droplets of a uniform size (**control droplet applicator**) in the range of 250 to 300 microns. These sprayers use the spraying material economically and give a good crop cover without as much of drift. Other sprayers designed to apply small volumes of liquid (less than 5 liters/ha), called the **ultra low volume** or **ULV sprayer**, use a droplet size of 60 to 70 microns which can be carried by wind to give a thorough crop cover. The ULV sprayer is prone to spray drift and hence not used for applying herbicides or toxic chemicals. **Electrostatic ULV sprayers** produce positively charged droplets of a controlled size (about 50 microns), which behave fairly predictably in terms of the area covered and fall mainly on the uncharged target crop. **Aerial spraying** using aeroplanes or helicopters may also carry out spraying on a large area.

The application of a fluid fertilizer or any other solution to a crop in the form of fine droplets is known as spray application. Pesticides and insecticides are also sprayed on crops.

Spray-tower ammoniation for producing ammonium sulphate: See Ammonium sulphate production processes

Spring wheat: See Wheat

Sprinkler irrigation

Sprinkler irrigation is a time-saving **irrigation method** in which the flow of water can be closely controlled. Fertilizer is added to water and then applied to the land, even when the land is not uniform in its slope. It is used widely for irrigating lawns (Fig.S.23).

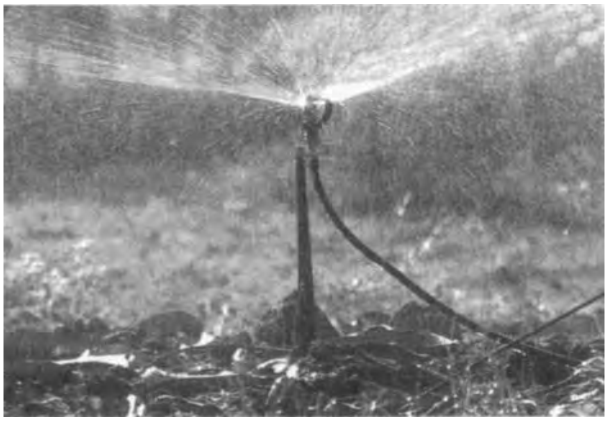


Fig.S.23: Sprinkler irrigation method.

Sprinkler irrigation wets plant leaves and the soil surface and may affect the surrounding air temperature. The high specific heat of water makes sprinkling an effective means of reducing frost hazard. Sprinkler irrigation has been used for protecting winter vegetables against frost.

However, sprinkler systems are expensive and ineffective in windy conditions. (See also Irrigation methods.)

Sputter-ion pump

In physics, an **ion pump** is a vacuum pump that passes a beam of electrons through the residual gas in a container to reduce the pressure to about 1 nanopascal. The gas is ionized and the positive ions are attracted to a cathode in the container where they remain trapped.

The ion pump is useful only at a very low pressure, (below 1 micropascal) and has a limited capacity because the absorbed ions eventually saturate at the cathode surface. A more effective pump can be made by simultaneously sputtering a film of metal so that a fresh surface is continuously produced to trap positive ions, which is known as a sputter-ion pump.

SQ

SQ is short for **soil quality**. (See Productivity index.)

SSP

SSP is short for **single super phosphate**

SST

SST is short for **standard soil temperature**.

ST

ST is short for **2-Sulphanilamide thiazole**, a well-known nitrification inhibitor.

Stability index

Stability index is a number that indicates the extent of changes in weed numbers of a given cropping system. It can be found by summing the percentage changes in the numbers of individual weeds. The index has a predetermined time specification.

Stabilizer

Stabilizer is a substance which helps to keep a compound, mixture or solution retain its form or chemical nature.

Stabilizers retard the reaction rate, preserve a chemical equilibrium, act as antioxidants, keep pigments and other components in emulsion form, or prevent particles in a colloidal suspension from precipitating.

Staining

Stains are organic protective coatings similar to a paint, but with a much lower solid content. Stains are used for both exterior and interior coating of wood, furniture, flooring, etc.

Stains are also used to color cells or tissues of organisms for microscopic examination. Examples of such stains are osmium tetroxide, uranyl acetate, etc.

Staining is a technique in which a normally transparent cell or thin section of a biological tissue is immersed in one or more colored dyes to make it clearly visible through a microscope.

Staining improves the contrast between various components of the cell or tissue. It facilitates the observation of a substrate by introducing differences in optical density or light absorption between the substrate and its surroundings or between different parts of the same substrate.

Colored dyes, also called stains, are usually organic salts with positive and negative ions. If the color comes from a negative ion (organic anion), the stain is described as an **acidic stain** (e.g., eosin). If the color comes from a positive ion (organic cation), the stain is called a **basic stain** (e.g., haematoxylin). **Neutral stains** have a colored cation and a colored anion (e.g., Leishmans' stain). The cell components are classified as **acidophilic** if they are stained with acidic dyes, basophilic if receptive to basic dyes and neutrophillic if receptive to neutral dyes. **Vital stains** are used to color constituents of living cells without harming them. **Non-vital stains** are used for dead tissues.

Counter staining involves the use of two or more stains in succession, each of which imparts colors to different cells or to tissue constituents. **Temporary staining** is used for an immediate microscopic observation of material - the color soon fades and the tissue is subsequently damaged. **Permanent staining** which does not distort the cells, is used on a tissue that is first killed, to be preserved for a considerable period of time.

Electron stains, used in the preparation of material for electron microscopy, are **electron-dense stains** and interfere with the transmission of electrons. Lead citrate, phospho-tungstic acid, osmium tetroxide and uranyl acetate are electron-dense stains.

A method used for mounting a bacterial culture for examination through a microscope is called **Gram staining**. The latter shows differences in the properties of permeability of the bacterial cell walls. Depending on the stain properties, the cells are divided into two groups: Gram positive and Gram negative named after the Danish physician **Hans Christian Gram**, who perfected the staining method.

Bacteria are heat fixed, stained first with a basic crystal violet dye, then with an iodine solution, followed by rinsing with alcohol or acetone. The **Gram-negative bacteria** lose the initial color of the Gram stain and then take on the color of the final stain (light pink), as in *Rhizobium*. Some bacteria absorb the initial color of the Gram stain and become deep purple because they do not take on the color of the final stain and are called **Gram-positive bacteria**, an example of this being *Bacillus*.

Stains: See Staining

Stamicarbon's recycle, stripping and finishing processes in urea production: See Urea production processes

Standard curve

For fertilizer-related matters, a standard curve is a calibration curve or a graph generated during the estimation of fertilizers or fertilizer ions using instrumental methods, such as photometry, titrimetry, atomic absorption spectrometry, fluorimetry, etc. It is also termed as the **reference** or **calibration curve**. For example, Nessler's reagent estimates ammoniacal nitrogen by colorimetric technique in fertilizers, using varying quantities of ammonium chloride. Here, the absorbance is estimated at 525 nm, and a standard calibration graph under the same standard and experimental conditions is generated. The absorbance of standard solution (A) against its concentration (c) is plotted. From the knowledge of absorbance of the test sample, its concentration is determined by comparing the graph with the help of the standard curve.

Standard curves generated during the estimation of fertilizer cations or anions using such instrumental methods are calibration curves with varying slopes, which reflect the sensitivity of the response. In photometric determination, the curve always satisfies the equation $A = kc + b$, where the size of the blank value b is based on the intersection with the ordinate and the scatter of the individual values. Subtracting the blank value from the measurement forces, the line moves through the origin (0, 0).

This standard curve is used for further determination of constituents under the same experimental conditions. When the absorbence is directly proportional to the concentration, only a few points are required to establish the line. When the relation is non-linear, a large number of points are necessary and the standard curve should be checked at certain intervals of time.

When plotting the standard curve, it is customary to assign 100% transmission to the blank solution (reagent solution plus water), which represents a zero concentration of the constituent. Some colored solutions have an appreciable temperature coefficient of transmission; hence a control of temperature is required during the generation of the standard and experimental curves.

The calibration method is sometimes modified to counter the matrix effects, and is performed by adding known quantities of the substance to be analyzed. The concentration after this addition is plotted on the abscissa and the zero value corresponds to the sample's measured value. The intersection of the dotted line with the abscissa yields the concentration in the sample.

Standard deviation

Standard deviation (SD), which is a term commonly used in statistics, is a measure of the dispersion of data. In analytical chemistry, this term is commonly called the **root mean square deviation (RMSD)**. It is the square root of the mean of the sum of the squares of differences between the values and the mean of the values. RMSD is important in situations falling in normal distribution curves. For example, if we have a series of observations, $x_1, x_2 \ldots x_n$, the mean is given by

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{N}$$

where N is the number of observations.

The spread of the measured values is given by the standard deviation

$$SD = \sqrt{\frac{(x_1-\bar{x})^2 + (x_2-\bar{x})^2 \ldots\ldots (x_n-\bar{x})^2}{N-1}}$$

or simply

$$\sqrt{\frac{\Sigma(x_i-\bar{x})^2}{N-1}}$$

The square of standard deviation is called the **variance**. **Relative standard deviation (RSD)** is given by

$$RSD = \frac{SD}{\bar{x}}$$

The percentage of this RSD is also known as **coefficient of variation (CV)**.

$$CV = \frac{SD}{\bar{x}} \times 100$$

The greater the number of measurements (n), the closer the sample average approaches the true mean value. When there is a reasonable amount of data, which is symmetric about the mean, one can be reasonably sure that (a) 68% of the data lies within the one σ value from the mean, (b) 95% data lies within the two σ value from the mean, and (c) 99.7% data lies within the three σ value from the mean.

Standard deviation is useful for making predictions. For example, if we know that the average monthly rainfall for the last 10 years is 10 cm and the standard deviation is 2.5 cm, then there is a 68% chance that any given month will have between 7.5 and 12.5 cm of rainfall. Approximately 32% will have rainfall above or below this range.

If a sample is taken from a '**population**' (or an aggregate), and a statistical measure such as sample mean, sample median or sample standard deviation is calculated, its standard error (which is a measure of its precision) is calculated by considering conceptually all possible samples from the same population and finding the desired statistical measure from each of them and then calculating the variation (using standard deviation) among all of them. In practice, this can be done by using the theory of probability. Thus, if $\bar{x}$ is the mean of a sample, its standard error is $\frac{S}{\sqrt{n}}$, where n is the sample size and S is the standard deviation of the sample observations.

Standard deviation is considered to be the best measure of dispersion. There is, however, one difficulty with it. If the same unit of measurement of variables of two series is not the same, then comparing the values of standard deviation cannot compare their variability. A relationship between quartile deviation (QD), mean deviation (MD) and standard deviation (SD) is 6 QD = 5 MD = 4 SD.

Standard error

Standard error is another term for **standard deviation**.

Standardization of sampling procedure: See Plant sample

Standard knife

The side dressing application of nitrogen, very common for corn, sorghum, cotton and other crops, is done with an implement called the standard knife or **point injector applicator**. This implement can be used for both solid and fluid fertilizers.

Standard soil temperature

The standard soil temperature (**SST**) is the temperature measured at the rock or hard-pan, or at a depth of 50 cm (unless the soil itself is 50 cm deep in which case SST has to be measured at a lower depth). Daily temperature fluctuations seldom affect soil deeper than about 30 to 40 cm. Below one meter, the temperature changes slowly, from season to season. (See also Annual soil temperature.)

Standard solution

A solution of a known concentration used in volumetric analysis is a standard solution. The success of a titration depends upon knowledge of the concentration of the standard solution which must be prepared with care and accuracy.

The concentration of a standard solution is known either (a) directly, by dissolving an accurately weighed quantity of the pure reagent and making up the solution to an exact volume, or (b) indirectly, after titration of a solution containing a weighed quantity of the pure compound with the reagent solution of a known concentration.

Standard solutions are of two types: (i) **Primary standard**: A substance in a 100% pure stable form should be available for weighing and preparing the standard solution. For example, potassium hydrogen phthalate is a primary standard for acid-base titrations. (ii) **Secondary standard**: A substance, which is not available in a 100% pure form, should itself be standardized with a primary standard. For example, sodium carbonate is a secondary standard for acid-base titrations.

Starch

Starch is reserve carbohydrate usually stored in the seeds, roots or stems of a plant. It is the second largest source of carbohydrates, next only to cellulose. Although starch is widespread in plants, only a few sources are abundant enough to make the extraction commercially feasible. The general sources are arrowroot, barley, corn, maize, potato, rice, sago, sorghum, tapioca and wheat. Arrowroot, barley, potato and wheat are commercial sources of starch, available as loosely packed granules of varying shapes and sizes.

There are two basic types of starch molecules - the linear starch polymer and the branched starch polymer. Starch is a polysaccharide consisting of various proportions of the two glucose polymers, namely, amylose and amylopectin (Fig.S.24).

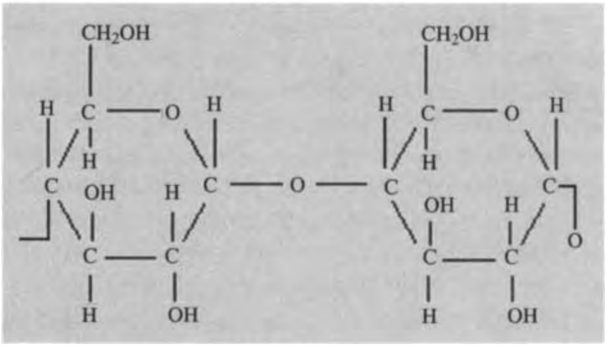


Fig.S.24: Chemical structure of starch repeat unit.

Amylose consists of an unbranched chain of 200 to 500 glucose units, whereas amylopectin consists of chains of 20 glucose units joined by cross links to give a highly branched structure. Most natural starches are mixtures of amylose and amylopectin; potato and cereal starches are 20 to 30% amylose and 70 to 80% amylopectin.

Amylum is the ordinary starch found in all green plants. A molecule of starch is built out of a large number of α-glucose rings joined through oxygen atoms, thus making starch a major energy source for animals.

Starch is a tasteless, odorless, colorless, white amorphous powder insoluble in water. It turns iodine solutions intensely blue, and is used as an indicator in certain titrations. An expert can tell the source of a starch by its appearance in a grain under the microscope. Starches in the form of rice, potato, wheat and some cereal products, supply about 70% of the world's food. **Soluble starch** is obtained by heating ordinary starch with 10% hydrochloric acid for 24 hours and then precipitating it with alcohol.

Natural starches are used as thickeners in food.

Starter dose

A small quantity of a nutrient fertilizer provided to a crop during its preplant stage to give additional stimulus to the plant's growth is known as the starter dose of fertilizer or **starter fertilizer**, **pop-up fertilizer** or **planting fertilizer**. These water-soluble stimulants, in solid or liquid form, are high in P or K and are applied near or along the seed to enhance seedling vigor, especially in cold and wet soils. In cool temperatures, the early available nutrient supplies may be inadequate because of the slow mineralization of N,P,S, etc., from the soil organic matter. The inadequacy is also due to the restricted-release of plant nutrients from soil minerals, reduced diffusion of phosphorus and potassium, or limited absorption of phosphorus, potassium and other nutrients by the plant. The starter dose stimulates root growth and shoot formation. This early root growth helps the plant to take up more fertilizer from the soil for healthier growth and an early yield.

The application of 20 to 25 kg/ha of nitrogen fertilizer to a grain legume helps increase its growth. Generally, low amounts of fertilizer are applied to avoid damage to the seedlings or to the process of germination.

A **starter solution** contains NPK fertilizer which reaches plant roots quickly and provides readily-available nutrients for the early growth of a transplant or emerging seedling. It is applied to the plant at the time of transplanting or directly on, below or beside the seed. Such an application is made because early nutrient supplies available in the soil or growing medium may be inadequate. Most starter solutions are high in phosphorus which promotes the root growth.

The advantage of early stimulation depends on the crop and seasonal conditions. This may be seen from the following examples: (i) A fast growing young plant is usually more resistant to disease and insect attacks. (ii) Vigorous and early crop growth reduces weed competition and improves the effectiveness of herbicides. (iii) An early crop is very important for vegetables, since a delay of 3 or 4 days can considerably affect the price of a perishable commodity.

Starter fertilizer: See Starter dose

Starter solution: See Starter dose

Steamed bone meal

Bones are among the earliest known sources of phosphate. Bones, treated with steam (to remove the residual fat before grinding), yield steamed bone meal or **bone flour meal**. However, steamed bone meal contains only 2% nitrogen as against untreated bones which have 4 to 6%. It is similar to tricalcium phosphate [$Ca_3(PO_4)_2$], contains 22 to 30% phosphorus (as P_2O_5) and is superior to rock phosphate as a source of available phosphorus.

Home gardeners continue to ask for bone meal for use on their flowers, shrubs and lawns because it can be used without the fear of salt burn.

Steam stripping: See Stripping

Steinberg effect

Under severe deficiency, rapid increases in the yield with an added nutrient can cause a small decrease in the nutrient concentration. This is known as the Steinberg effect which results from a dilution of the nutrient in the plant. (See also Critical value.)

Stem and root succulents: See Leaf succulents

Stem melanosis

Stem melanosis is a disease that occurs in certain beet varieties due to **copper deficiency**.

Stem rot in rice: See Rice, major diseases of

Stem rust in wheat: See Wheat, common diseases of

Stem succulents

Stem succulents are a type of xerophytes, which store water in specialized, modified spongy tissues.

Stengel process for granulation of ammonium nitrate: See Ammonium nitrate production processes

Sterile land

A non-fertile land is called a sterile land.

Steroids

Steroids belong to the class of lipids, called **simple lipids**, which are devoid of fatty acids. Steroids are derived from a saturated compound, called cyclopentanoper-hydrophenanthrene.

Steroids include sterols, bile acids, vitamin D, sex hormones, etc.

Sterols, which are present in animals, plants and fungi, are a kind of lipid, which have a hydrocarbon side-chain of 8 to 10 carbon atoms. They are also a kind of alcohol and exist as esters of fatty acids or as free sterols.

A major sterol in plants is called beta-sitosterol. Cholesterol, notorious as a substance deposited on the walls of arteries and as the chief constituent of gall stones, is a sterol. Ergosterol is an important plant sterol (phytosterol).

Sterols: See Steroids

Stevia

Stevia (*Stevia rebaudiana*) is a perennial, semi-bushy plant which originated in Paraguay. It is robust in nature and is tolerant to a range of climatic and soil conditions. For its growth, the temperature should ideally be between 15°C and 30°C, and the pH range between 6.5 and 7.9. It grows to a height of around a meter and bears white flowers. Cultivated stevia needs regular irrigation and fertilization.

The leaves of stevia produce an extract called **stevioside**, which contains crystalline diterpens glycosides. Stevioside is a non-caloric, non-fermentable, non-discoloring natural sweetener. It is more than 200 times sweeter than sucrose. The leaves are ready for collection about 4 months after transplanting. The quantity and quality of stevioside is best just prior to flowering. In addition, the leaves have been tested to contain Vitamin C, beta carotine and fiber. Once the plant matures, the leaves can be plucked every month. Stevia is prescribed in diets tailored for diabetics and over-weight patients.

The plant is best propagated by cuttings which become ready for transplanting in 1½ months. Transplantation may be done in mid-May, maintaining row spaces of 50 to 60 cm., thus accommodating around 100,000 plants per hectare. The leaf yields can go up to 3 tons/ha with a stevioside content of about 15%.

Drying, threshing and packaging of stevia leaves render them a long shelf life. The leaves are increasingly used in cooked/baked products, processed foods and beverages. With the US FDA allowing the use of this natural product in the production of processed foods (1995), it is likely that the production and use of this plant will get a boost.

Stevioside : See Stevia

Sticker

A substance or a binder added to (or sprayed on) materials to improve their adhesion is known as a sticker or a sticking agent. For example, coal tar helps in sticking neem cake powder to urea in a slow-release fertilizer formulation. Coal tar is used as a binder (for the coating) to stick to urea granules. Sugar solution is used for coating *Rhizobium* inoculums on seeds. A number of polymers like polyethylene, PVC, polysulphides and polyvinyl acetate act as sticking agents in water-dispersible powders.

Sticky limit

Physical and geo-technical properties of a soil are based on the grain size, mineralogical composition, chemical composition and moisture content. For a rough estimation of the quality of soil and the need for fertilization, **puddle tests** are put into use. These tests are simple to carry out, although they are qualitative in nature.

Terzaghi and Peck have designed the sticky limit test. Clay is mixed with water in such a way that it is plastic and sticks to a dry spatula blade. The clay is then allowed to dry. The moisture content at the point when the tool can no longer pick up the clay is the sticky limit.

Sticky rice: See Glutinous rice

Sticky soil

The consistency of a soil varies with its water content and degree of cementation. If the soil adheres to other materials it is considered a sticky soil. There are degrees of stickiness like slightly sticky, sticky or very sticky. (See also Consistence soil.)

Stimulant fertilizer

A stimulant fertilizer, also known as a **catalytic** or **indirect fertilizer**, does not contain any essential nutrients, and yet has a beneficial influence on the plant. Plant growth regulators, such as **auxins**, **gibberellins** and ammonium compounds are examples of indirect fertilizers.

Stocking rate of trees: See Timber and range site indices

Stock nitrogen

Nitrogen present in animal feces, as distinct from that in artificial fertilizers, is known as stock nitrogen.

Stoichiometric point: See Volumetric analysis

Stokes' law

Viscosity is the quality of being glutinous, sticky or not free flowing. Stokes' law, discovered by Sir George Gabriel Stokes, expresses the rate of fall of solid particles in the liquid medium.

$$V = \frac{2}{9} \times \frac{r^2 g\,(p-d)}{\eta}$$

where V is the rate of fall in cm/sec, p is the particle density, d is the density of the liquid, r is the particle radius, g is the acceleration due to gravity, η is the coefficient of viscosity of the medium.

Stokes' law predicts the frictional force (F) on a spherical ball moving through a viscous medium. The law provides a theoretical basis for the particle size analysis, and is used in determining sedimentation of solids, creaming rate of particles in milk, etc. (See also Viscosity.)

Stoma

Stoma (plural stomata) is a pore in the leaf through which a plant can absorb moisture, oxygen, carbon (as carbon dioxide) and nutrients. Stoma also means, apart from the pore, its associated guard cells.

Stomata are present in the epidermis of leaves (especially under the surface) and young shoots, and function as a gas exchanger between the plant and the atmosphere. Each stoma is bordered by two semi-circular guard cells (specialized epidermal cells), the movement (due to changes in water content) of which controls the size of the aperture (Fig.S.25).

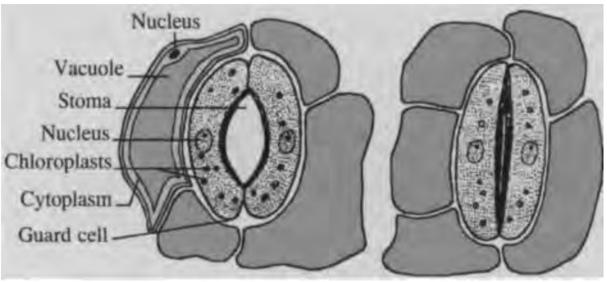


Fig.S.25: Stomatal movements: Open stoma and closed stoma.

Stomatal frequency is the number of stomata per unit leaf surface area. The greater the stomatal frequency, the greater is the rate of transpiration. The stomatal frequency increases with dry conditions and decreases with humid conditions. It is represented as:

$$I = \frac{S}{E + S} \times 100$$

where I is the stomatal frequency, S is the number of stomata/unit area of leaf and E is the number of epidermal cells in that area.

Stomatal frequency is also expressed as **stomatal index** (SI) and is given by:

$$SI = \frac{\text{Number of stomata per unit area}}{\underset{\text{per unit area}}{\text{No. of stomata}} + \underset{\text{per unit area}}{\text{No. of epidermal cells}}} \times 100$$

Stomata

Stomata is the plural for **stoma**.

Stomatal frequency: See Stoma

Stomatal index: See Stoma

Storage

Storage is the act of preserving raw materials, chemicals, food products, fertilizers and energy, before being used, transported or consumed. Storage of a few kinds of substances are considered below:

(i) Raw materials: Storage of raw materials should be done in suitably protected and well-ventilated interior areas at ambient temperatures. Some raw materials such as logs assigned for pulpwood, and certain bulk solids received in metal fiber drums are stored outdoors. Storage of flammable liquids (like gasoline and fuel oil) in large underground tanks is a standard practice. Hygroscopic materials (such as paper and salt) should be kept in a humidity-controlled environment. Combustible materials that tend to build up internal heat on long storage at high temperatures (cellulosics such as paper, hay, grain, bulk wool and certain vegetable oils) should be stored in well-ventilated areas.

(ii) Chemicals: Materials which may react to form hazardous products in the event of spillage, should be kept well-separated. Oxidizing agents (ammonium and potassium nitrates, peroxides, perchlorates, etc) should not be stored near reducing or combustible materials. Heat-sensitive materials should be kept away from hot pipes or any other heat source. This is especially true in the case of flammable liquids. Chemicals that will ignite in air spontaneously or react with water vapor require special storage conditions to keep them out of contact with air. Reactive organic monomers that tend to polymerize at room temperature, for instance, styrene, must contain an inhibitor when stored or shipped.

(iii) Food products: Long shelf-life at or near room temperature is highly desirable for processed foods. This is achieved partly by the use of anti-oxidants and other preservatives and partly by processing techniques. Refrigerated storage at temperatures near 4 to 5°C is used for meats, eggs and other dairy products. Meats and other frozen foods can be stored indefinitely below or at minus 18°C. Unprocessed fruits and vegetables are stored under controlled-atmospheric conditions to retard post-harvest ripening.

(iv) Energy: The conventional method of storing energy is by means of primary and secondary batteries. The growing need for energy conservation has stimulated research on new and more effective methods of storing energy, even in the case of solar and wind energy which are intermittent or non-uniform in nature.

Two methods are commonly used for storing energy, although they have limited uses. One (for electric power plants) involves compressing air with off-peak electricity and storing it in subterranean cavities, from which it can be withdrawn when needed. The other (for domestic use) involves electrically heating refractory bricks at night at off-peak rates. The stored heat is given up during the day with 90% energy recovery.

A number of other techniques are in experimental stages. Glauber's salt has seven times the heat capacity of water.

Storage and transportation of ammonia: See Ammonia production processes

Storage and transportation subsidy: See Subsidies in agriculture

Stored soil water

The quantity of soil water originating from rains or snowfall, which partly or fully meets the plant requirement, is the stored soil water. Although most of the water absorbed by plants is through the roots, some water is also absorbed through leaf stomata.

For optimum water use, it is vital to know how (a) water enters and moves through soil, (b) soil stores water, (c) plants absorb it, (d) nutrients are lost from soil by percolation, and (e) soil water content and its losses are measured.

Soil water is classified (depending on the plant requirement), as **gravity water**, **plant available water**, **field capacity** and **permanent wilting point**. As soil water is held in the form of a film on particle surfaces and in small pores, the soil content (as in humus) and soil texture greatly influence the amount of water stored. Soil water content is measured gravimetrically and also by using tensiometry, electrical conductivity and radioactive devices.

The used soil moisture has a pronounced effect on the nutrient uptake by plants. A low water level in the root zone retards the nutrient availability as it impairs processes like **diffusion**, **mass flow** and **root interception**. Recommendations for nitrogen supply in some areas are based on the assessment of stored moisture and residual nitrate nitrogen in the soil profile.

Fertilizers have an indirect effect on the amount of stored water in the soil profile. A response to fertilizer is shown by an increased vegetative cover which retards the run-off and increases the infiltration.

Storie index rating of fertility

The Storie index, developed by Earl Storie in 1937, is a system of rating land for cultivation. It is a numerical index from 0 (for non-agricultural soils) to 100 (for the best agricultural soils). It is a parametric system developed in California and is given in Table-S.8.

Table-S.8: Storie index grades.

Storie index (%)	Storie grade	Land quality
80 - 100	1	Excellent
60 - 79	2	Good
40 - 59	3	Fair
20 - 39	4	Low
10 - 19	5	Very poor
less than 10	6	Non-agricultural

The four factors in Storie's system are as follows: (i) The soil profile factor is based on the degree of profile development and the kind of parent materials (A). (ii) The surface texture factor (B). (iii) The slope factor (C). (iv) The soil management factor (X).

The soil management factor X has several parts: drainage, salinity, alkali level, nutrient level, acidity, erosion and micro relief. Each part is evaluated for any soil and is then multiplied to determine the X factor.

Within each factor, there is a range of values from 0 to 100. The range is divided by 100 and the four values are multiplied to obtain a product which in turn is multiplied by 100 to yield the Storie index rating for the soil:

$$\text{Storie index} = \left[\frac{A}{100} \times \frac{B}{100} \times \frac{C}{100} \times \frac{X}{100}\right] \times 100$$

Storie grade 1 soils are well-suited for intensively cultivated crops. The next soil, grade 2, is good but usually has a less permeable subsoil and a gravelly or fine textured surface layer. Soils assigned grade 3 have only moderate soil depth, restricted drainage, low fertility, and they are usually acidic. Grade 4 soils have shallower depths and steeper slopes than grade 3. These soils are sandy, gravelly or clayey on the surface and are acidic in nature.

Grades 5 and 6 represent soils with extreme limitations from an agricultural point of view. These soils find utility as pasture lands, wood lands, watershed and as protective habitats.

Storie index has also been created to determine suitability of land to timber cultivation. Factors such as the soil depth, texture, permeability, drainage, climate, erosion, etc. are used to rate soil for intensive timber production on a rating of 0 to 100.

Weaknesses of the Storie index are seen in situations where soils with a low index rating produce high yields of some crops. Another disadvantage of the Storie index is that it does not consider factors like location, access to water (irrigation systems), etc.

Stout-Arnon's criteria of essentiality of plant nutrients

Stout-Arnon's criteria of essentiality of plant nutrients help determine whether a plant needs a nutrient or not. The essentiality criteria assume that (a) the deficiency of an element makes it impossible for a plant to complete its life cycle, (b) the deficiency is specific to the element in question, and (c) the element is directly involved in the nutrition of the plant, as a constituent of an essential metabolite required for the enzyme activity.

Based on the above three criteria, 17 elements are considered essential for the growth of higher plants. These are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, copper, zinc, molybdenum, boron, chlorine and nickel. (See also Arnon's criteria of *essentiality of plant nutrients*.)

Stover

Dry and mature plant remains (ie. stalks and leaves) of corn, sorghum and pearl millet, after the removal of grains, are called stover. **Corn stover** is used as feed, bedding or surface mulch. It is also incorporated into the soil. Stover residues from corn and sorghum are coarse and pithy left unattended in the field. As a result, they may add to the complexity of tillage operations, reduce the effectiveness of herbicides and delay warming of the soil at high latitudes.

Straight fertilizer

Fertilizers containing only one primary plant nutrient are known as straight fertilizers or straights. Ammonium nitrate, superphosphate and muriate of potash, for instance, are straight fertilizers.

Occasionally, straights may comprise a mixture of ingredients and may still supply only one nutrient. For example, some phosphatic fertilizers contain a mixture of water-soluble and water-insoluble phosphates, but still supply only phosphorus. The equivalent term for straight fertilizers in Thailand is **single fertilizer**.

Straight-line method of depreciation: See Fixed costs

Straight phosphatic fertilizer: See Phosphatic fertilizer

Straight-run gasoline: See Gasoline

Straight run naphtha

Naphtha is the raw material for hydrogen and contains C_4 to C_{12} hydrocarbons. Naphtha is obtained by distilling petroleum crude and collecting the required fraction. This method of processing naphtha is known as straight run naphtha. The strait run naphtha is preferred over another distinct process known as **cracking** where higher molecular fractions are degraded to required size of C_4 to C_{12} atoms. The naphtha obtained by the cracking process contains sulphur which contaminates the hydrogen produced from it. (See also Naphtha.)

Stratified random sampling

The method of sampling in which the soil population is divided into strata, each of which is randomly sampled, with samples from different strata pooled together, is called stratified random sampling. (See also Sampling.)

S/T ratio

The S/T ratio is the ratio of the saturation of exchangeable metallic cations (S) to the total exchange capacity (T) of the soil absorption complex expressed as:

$$V = \frac{S}{T} \times 100$$

Straw

The dry residue of fine-stemmed cereal crops after the grain is removed is called straw (Fig.S.26). It is a fibrous cellulosic component (1 to 1.5 m long), similar to that found in hardwood. It can be pulped by the alkaline process to yield speciality papers.

Straw is a major component of **farmyard manure (FYM)**. It has N, P and K in small quantities. Dry straw is almost fully organic, carbonaceous (with a carbon to nitrogen ratio of 40-80:1) and contains only small amounts of nutrients (0.4 to 0.5% nitrogen, 0.25 to 0.4% phosphorus and 0.35 to 0.45% potassium). If straw is plowed back into the soil, it decomposes to release nutrients and occasionally, undesirable organic acids and ethylene gas. Incorporating straw into wet soil is not advisable since it creates waterlogging and retains herbicide residues.

Fig.S.26: Straw is a major component of FYM and is also used as mulch, folder and as a soil organic amendment.

If straw is burnt, its organic matter and N are lost but K and P return to the soil. Straw may serve as clean, dry, bedding material, providing comfort to animals and conserving their excreta.

Straw when incorporated directly into the soil decomposes slowly. In fertile aerobic soils with sufficient (but not excess) water, however, straw can make considerable contribution to the **soil organic matter**, especially in areas of intensive cereal production. The other favorable conditions for effective decomposition of carbon in straw are the availability of nitrogen in the soil or plant and a pH regulated by lime. In this way, it helps to increase the water holding and nutrient retention capacities of the soil, improve soil structure and reduce insidious erosion which happens when the soil organic matter level falls below the critical point.

The management of straw incorporation is not simple and warrants that the following rules be followed. (i) Because of the bulky nature of straw, addition must be chopped into short lengths for easier incorporation and increased speed of decomposition. (ii) Because of high carbon to nitrogen ratio of straw, additional fertilizer nitrogen becomes necessary. (iii) Great care must be taken to get a good spread of straw through the topsoil. When wrongly incorporated, it will decompose anaerobically, giving an obnoxious odor, and prove toxic to roots.

Straw fiber has many commercial uses in industries dealing with paper, fuel, chemicals, single cell protein, boards and crafts.

Strip cropping

Strip cropping is a technique in which bare, fallow or row crops like corn or soybean are grown in conjunction with grass or a legume hay crop. Soil erosion tends to occur in the corn rows or fallow areas, but the grass or hay crops reduce the soil loss by trapping the soil as it moves downhill.

Strip cropping thus involves growing commonly cultivated crops along with a sod forming crop in alternate strips simultaneously in a systematic arrangement of bands; the contours should be wide enough for the two crops not to interact agronomically.

Strip cropping around a slope on a contour is particularly helpful because the furrows retain water and slow down its flow along the slope. This cropping method helps to control erosion and is particularly beneficial when tall crops are planted in strips at right angles to the wind direction to provide a shelter. This practice has received considerable attention in the USA, where corn is used to shelter sugar beets. The width of each strip should be in multiples of the width of the machinery used to plant and harvest the crops. Other determinants of strip-width are (a) rainfall intensity, (b) soil erodibility, (c) slope length, (d) slope gradient, (e) crop type, and (f) field condition, whether terraced or not. For a slope of 5/100, the typical strip widths are 10 m for a sod crop and 25 m for a cultivated crop.

Strip fertilization

Strip fertilization is a method of applying fertilizers. It is a modification of banding and broadcasting, and involves placing the fertilizer in strips so that there is a broad concentrated strip along the crop row. This method ensures a more concentrated application than **broadcasting**. But it is not as dense and localized as **banding**.

Wide strip application of fertilizers encourages more extensive root development compared to banding. In the strip fertilization method, a lesser amount of fertilizer is lost by fixation than when done by broadcasting.

Strip mulch

The practice of placing an impermeable strip of plastic or other material in the shape of an inverted U over a banded fertilizer in rows is called strip **mulch** (Fig.S.27). The strip mulch system is an economical and effective method to prevent the fertilizer from being washed away from plant beds, especially during heavy rainfall.

Fig.S.27: Strip mulching using plastic sheets in tomato plantation.

Stripping process

Stripping means removal of relatively volatile components from a mixture of gasoline or other liquids by distillation or evaporation, and passing air, steam or gas through the liquid mixture.

The stripping operation is important in many industrial processes which employ absorption to purify gases and recover valuable components from the vapor phase. In such processes, the rich solution from the absorption step must be stripped to recover the absorbed solute and recycle the solvent. Stripping may lead to pressure reduction and be accompanied by the application of heat or inert gas. Many processes employ a combination of all three – distillation, evaporation and absorption.

When steam is used as a stripping medium for a system not miscible with water, the process is called **steam stripping**.

Stripping also means quick removal of color from an improperly dyed fabric or fiber by chemical reaction. Compounds used for this purpose in vat dyeing or in discharge printing are termed discharging agents. Substances commonly used as strippers are sodium hydrosulphite, titanous sulphate, sodium and zinc formaldehyde sulphoxylates.

Stripping process plants for urea production: See Urea production processes

Strong electrolytes

When an aqueous salt solution conducts electricity, the salt is a strong electrolyte. The classes of strong electrolytes are (a) soluble salts such as sodium chloride, potassium chloride and ammonium chloride, (b) strong acids such as hydrochloric acid, sulphuric acid and nitric acid, and (c) strong bases, such as sodium hydroxide and potassium hydroxide. Strong electrolytes dissociate completely in an aqueous solution.

$$\mathrm{NaOH\ (aq)} \longrightarrow \mathrm{Na^{+}(\ aq)} + \mathrm{OH^{-}\ (aq)}$$

(See also Electrolyte.)

Structural formula: See Formula

Structureless soil

Soils having no structure are known as structureless soils. Such soils are divided into two groups – massive-grained and single-grained. A massive structureless condition means that all of the particles are stuck together but there are no aggregates. The entire soil pedon may be one coherent mass of material. By contrast, sand dunes and beach sands are single-grained, each particle acting as an individual. (See also Soil structure.)

Stubble mulch farming

Stubble mulch farming is a way of erosion control (Fig.S.28). In this method, crop residues are not removed after the harvest but are mostly left standing in the soil. A part of the crop residue is mixed with the soil. Stubble provides a rough cover on the soil. This vegetative cover is important in controlling wind erosion, the effectiveness of which depends on the quantity of the plant residue, its roughness and height.

There are two types of tillage equipment used. The first type includes such equipment as disks, chisel plows

Fig.S.28: Stubble mulch farming.

and field cultivators, which mix crop residues with the soil. The other type of tillage equipment includes sweeps or blades and rodweeders, which cut beneath the surface without inverting the soil. The primary goals of stubble mulching are to achieve maximum moisture efficiency and a reduced wind erosion especially when the land is left barren (fallow). Stubble mulch also helps reduce the impact of raindrops, and protect top soils.

Student's t-test

The origin of the name Student's test in statistics is that William Gaussett, who suggested this test, wrote under the pseudo-name 'Student'. It was originally intended to test whether the sample mean of a number of observations from a **population** is in agreement or is significantly different from a theoretical or hypothetical true mean of the population. The formula proposed by him is:

$$t = \frac{(\bar{x}-\mu)\sqrt{n}}{S}$$

where $\bar{x}$ is the sample mean, S is the sample standard deviation, n is the sample size and μ is the hypothetical true mean. The values of t with which the above value of t is to be compared for determining whether $(\bar{x} - \mu)$ is significantly large or not, are available from standard tables in statistics books. The value from the table is looked under, what are known as, the degrees of freedom and are $n-1$ in this case.

Later this t-test was found to be useful in many other statistical problems, such as comparing the means of two samples, testing the significance of a regression or correlation coefficient, etc.

Sub-artesian well: See Artesian well

Subbiah and Asija method for estimating available nitrogen in soil

Subbiah and Asija (S and A) method gives the amount of available soil nitrogen that can be oxidized in an alkaline medium. Most soil nitrogen is ammonium (NH_4^+), nitrate (NO_3) and organic substances. The S and A method determines the N-content present in the soil.

Sub-bituminous coal

The coalification process has various intermediates, referred to as the **ranks of coal**. Mainly, power generation stations use sub-bituminous coal which is one of the ranks of coal.

Sub-irrigation method

Sub-irrigation method is a process by which water is applied in open ditches or tile lines so that the water table is raised sufficiently to wet the root zone of the soil. This method is effective on land containing sand peat or muck.

Subsidies in agriculture

Subsidy is the financial assistance granted by a government or a public body to keep the commodity prices down. This, unlike credits, is not required to be repaid by those who avail of it. It is a device to lower the input costs of commodities such as seeds, fertilizers, pesticides, etc., to a farmer.

A favorable **fertilizer to crop price ratio** can give high economic returns. If the crop prices cannot be raised for the benefit of the farmer, the fertilizer prices can be subsidized for him.

The most common forms of subsidy are (a) **direct fertilizer subsidy**, (b) **storage and transportation subsidy**, and (c) **purchase credit subsidy**. Subsidies, mainly for nitrogen fertilizers, are common in many countries. This has helped to increase the yield, but has also sometimes led to a disproportionate use of the subsidized fertilizer, resulting into soil mining of other naturally present nutrients that are not subsidized (like phosphorus and potassium).

An alternative to fertilizer subsidy is a crop price support. However, input subsidies are often preferred to output subsidies for a variety of techno-economic, accounting and administrative reasons. Reliance on subsidies regarding their form should, however, be minimal as this disproportionately increases the investment cost in productivity.

Given the high cost of producing fertilizers in developing countries, the view is that, subsidies on fertilizers are unavoidable. The value of the subsidy continues to grow with an increase in the volume of consumption and the cost of production. At the same time, the need for an increased use of fertilizers, even though they are subsidized, to augment the country's own food grain production rather than depend on imports, has been universally appreciated.

However, in view of the mounting burden of fertilizer subsidies and the extremely vulnerable resource position of many developing countries, their governments have initiated corrective steps. These steps which are farming subsidies include the introduction of low-cost technologies and cover measures aimed at improving the efficiency of fertilizer use. In some countries, increase in the price of fertilizers has also been resorted to as a short term palliative.

Subsistence farming

Subsistence farming is one in which farm operations are primarily meant to provide for farmer's (and his or her family's) needs, rather than for sale in the market.

The farming method practiced in many developing countries in which a farmer consumes the produce of his farm (which may include livestock) for the livelihood of his family, is called subsistence farming. This contrasts with undertaking farming for commercial purposes.

Subsoil

Subsoil is a portion of the soil which is not tilled during normal plowing. In geology, the term is used to designate an un-weathered rock, as against the soil. Subsoil begins at a depth of about 30 cm, and contains little organic material. The utilization of subsoil nutrients depends on the soil structure, its aeration, pH, drainage and root distribution.

In most humid regions, the subsoil is acidic and low in fertility. In semi-arid or arid areas, the subsoil may be calcareous and low in fertility.

Subsoiler

Subsoiler is a kind of heavy cultivator with long tines or 'chisels', 30 to 60 cm apart, drawn through the soil and used to break the compact subsoil without inverting it. This may cause deep cracks and fissures which improve the drainage, air and root penetration, and the soil structure.

Subsoiler is a type of plow without a mould-board, used to work the subsoil (Fig.S.29). It is sometimes shaped like a torpedo and advances horizontally.

Fig.S.29: Chisel plow is used to break compact soil.

Subsoiling

Subsoiling or deep tillage is the process of breaking up of compact subsoils without inverting them, with a special knife-like instrument (e.g., chisel) that is pushed through the soil 30 to 60 cm deep and 60 to 150 cm apart. When subsoiling or deep tillage is practiced on compacted soils, it increases the water infiltration rate, field capacity and root development. Therefore, crop yields are generally high.

Sub-standard samples

Samples not meeting the prescribed standards stated on their labels are known as sub-standard or adulterated samples. Urea, for example, should not contain more than 2% biuret or single superphosphate with more than 12% phosphorus (as P_2O_5); if it does, it is considered sub-standard or adulterated.

Sub-surface drainage system

Drainage refers to the artificial removal of water. There are two types of drainage systems - surface and sub-surface drainage. Sub-surface drainage has concealed or buried conduits, built by pieces of tiles or plastic tubing on specified slopes. Sub-surface drainage requires soil that is porous enough for water to seep into the buried material. The choice of the soil suitable for sub-surface drainage is very critical. **Tile drainage**, tube drainage, mole drainage and sump and dump drainage are among the main sub-surface drainage systems. Other techniques use pumped wells, inverted or recharge wells and relief wells. Poorly drained and wet lands can be made productive by these newly developed techniques. Water polluting effects of sub-surface drainage systems are high nitrate concentrations in tile drain effluents.

Tile drainage system uses sections of clay or concrete tiles or plastic tubes, which may be about 0.6 m long and about 0.3 m in diameter. If planned properly, this system can remain operational for very long periods. Placement of the tiles depends on the permeability of soil - the lesser the permeability, the shallower the placement and the closer the tiles to each other. Plastic tubes are cheaper to use and easier to install than non-plastic tiles. It should be ensured, however, that the pipe openings are protected from pests and from being clogged. Gravel, peat, lime and gypsum may be used as filters or screens.

Mole drainage system uses shallow drainage channels about 0.3 m deep, made in fine-textured soil by pulling a sharp object (a mole) through it. This system is useful in cases where temporary drainage is needed, for example, during rapid reclamation of salty lands. Redoing of channels is possible easily and cheaply in this method.

Sump and dump drainage system is used only in cases where water in an area does not flow out naturally and gets removed by gravitational force. This system is designed in such a way that excess water is pumped out from low lying areas (sumps) where water gets collected. This depression in the land should be reinforced at the sides for the system to be effective.

Ideally, agricultural land should be chosen keeping in mind the slope of the land, so that a natural flow of water is allowed.

Among the other techniques of sub-surface drainage are the following: (i) **Vertical sub-surface drainage**: Here, inlets are vertically dug into higher level terraces which are devoid of grass. Water moves into the sub-surface channels to a lower terrace. This prevents water run-off and helps to conserve the soil. (ii) **Inverted wells**: A hole is dug into the ground and excess water is directed into it. This works best when soil has low permeability. Also, the surrounding areas should not be contaminated with harmful organisms or chemical toxins, lest such water seeps in and causes the ground water to be polluted. Such a system is also ideal for areas with stagnant water. Each inlet may be around $2\frac{1}{2}$ meters deep and less than 0.3 m wide. (iii) **Pumped wells and relief wells**: These are used where there is excessive wetness due to a high water-table. Water from wells thus dug can be directly canalized into an irrigation system. Shallow wells are also built to remove seepage spots.

Sub-surface irrigation

Sub-surface irrigation is another term for **micro-irrigation**.

Successional cropping

Successional cropping refers to the practice of growing different crops successively in the same field and in the same season. Here, planting is initiated with a time differential so that a small portion of the crop ripens at a time, ensuring its gradual and continuous supply over a long period. Commercial vegetable growers located near cities follow the practice of successional cropping, which allows them to raise many crops a year.

Succulents

Succulents are plants that have swollen leaves or stems and are thus adapted to live in arid regions. Cacti are among the more familiar plants, but there are also other succulent families, notably the Granulaceae and Aizoaceae. Many succulents have attractive foliage and colorful, often short-lived flowers.

Sucker

A sucker is a young plantlet which grows from the basal nodes of the main plant (Fig.S.30). It has root initials and can establish itself easily as an independent plant when detached and replanted, like in case of the banana. (See also Root sucker.)

Fig.S.30: Suckers of banana plant can grow independently, if detached.

Sucrose

Sucrose or cane sugar, a disaccharide carbohydrate, is obtained from sugar beet, sugar cane and sweet sorghum. Table sugar is the most common form of sucrose. It comprises a glucose unit joined to a fructose unit. Honey consists of sucrose and its hydrolysis products.

Sucrose, glucose and fructose all exhibit optical activity. When sucrose is hydrolyzed, the rotation changes from right to left. This is called inversion, and an equimolar mixture of glucose and fructose is called invert sugar. The enzyme invertase hydrolyzes sucrose to glucose and fructose.

Sugar occurs universally throughout the plant kingdom in fruits, seeds, flowers and roots.

Sugar

Sugars are a sweet, soluble carbohydrate product of photosynthesis comprising one, two or more saccharose groups. **Monosaccharide** sugars (often called **simple sugars**) are composed of chains of 2 to 7 carbon atoms. One of the carbon carries aldehydic or ketonic oxygen which may be combined in acetal or ketal forms.

The most abundant natural monosaccharides are hexoses ($C_6H_{12}O_6$) and pentoses ($C_5H_{10}O_5$). Many different isomers of these sugars are possible and often have names reflecting their source or property. For example, fructose is found in fruits, arabinose in gum arabic, and xylose in wool.

Disaccharides contain two monosaccharides joined by an oxygen bridge. Their chemical and physical properties are similar to those of monosaccharides. Sucrose, lactose and maltose are among the most important disaccharides.

Sugars are known for their sweetness. If the sucrose sweetness is 100, that of glucose is 74, fructose 173, lactose 16, maltose 33, xylose 40, and saccharin, 55,000. The sweetness of sugar is correlated to its solubility.

Sugar crops

Crops, such as sugar cane and sugar beet, grown for producing sugar are called sugar crops. Swollen roots of sugar beets lead to the production of almost half of the world's sugar. Sugar beet is grown extensively in Europe. It is grown in all temperate areas, the cool summers of which ensure good sugar formation. A balanced and precise nutrient application at the correct time results into high quality sugar beet. It needs sufficient nitrogen at the planting stage to ensure rapid leaf development and an early closing of the canopy. Excess nitrogen at later stages of growth produces leaves rather than sugar. It also increases the content of amino acids in the roots, which interferes with the action of the crystallization of sugar, during processing. Sodium and potassium contribute to rapid leaf development and increased resistance to heat and drought. But, their excess also interferes with sugar production.

Sugar beet, fodder beet, garden beet and leaf beet are cultivars of *Beta vulgaris* and are genetically related. Sugar beet cultivation is done almost on a fully mechanized mode.

Sugar cane (*Saccharin officinarum*) is a tall plant of the grass family. It grows in tropical and semi-tropical regions throughout the world. The plant comprises a solid stalk with joints at regular intervals. Each joint is a single bud. Stalks grow to a height of 2 to 8 meters with a diameter of 3.5 to 5 cm. The color of the stalk ranges from yellow to green, and violet to red, depending on the variety. Long, thin leaves grow from the stalk. Sugar is generally extracted from sugar cane in large factories either by milling or diffusion. Juice processing is completed by (a) clarification, to remove non-sugar components, (b) evaporation, to remove the water, and

(c) high-speed centrifugation, to remove molasses. Bagasse and molasses are the principal by-products of sugar cane processing.

Sullage

Open drains of untreated **sewage** are called sullage.

Sulphatase

About 50% of soil sulphur is present as organic sulphate esters. Sulphatase enzymes hydrolyze these esters and release sulphate. This is an important step in the mineralization process:

$$R\text{-}O\cdot SO_3^- + H_2O \longrightarrow R\cdot OH + HSO_4^-$$

Hydrogen iodide (HI) reducible sulphate esters are the substrates for sulphatase enzyme activity. Soil moisture affects sulphatase activity, the rate of sulphur mineralization and the movement of sulphate ion (SO_4^{2-}) in the soil.

Sulphate of potash

Sulphate of potash is potassium sulphate which contains 48 to 50% potassium (as K_2O) and 17 to 20% sulphur. It is used mainly as a potassium source and is produced from the ore **langbeinite**, a double sulphate of potassium and magnesium. (See also Potassium sulphate.)

Sulphate of potassium-magnesia

Sulphate of potassium-magnesia, a double salt of potassium sulphate and magnesium sulphate, is a white, crystalline material available in a powdered or granular form. It is made by washing any double sulphate of potassium and magnesium (e.g., langbeinite) with fresh water to remove chloride salts. The product is dried, screened, ground and bagged. This double sulphate stores well.

Sulphate of potassium-magnesia is used in agriculture as a primary source of water-soluble magnesium and also as a supplementary source of sulphate of potash. It contains not less than 22% potassium (as K_2O), 23% sulphur (S) and 18% magnesium (as MgO). It produces a neutral reaction in soil.

Sulphate waters: See Water quality

Sulphur

Sulphur (S) is a yellow, non-metallic element belonging to Group 16 (formerly VI B) of the Periodic Table (Fig.S.31). It is a macronutrient required by plants in relatively large amounts. Potato, cereals and grasses require about 20 kg/ha sulphur, while its ideal dosage for the Brassiceae family of crops is 50 kg/ha.

Soil-sulphur reactions are similar to soil-nitrogen reactions, and are dominated by organic or microbial fractions in the soil. Approximately 90% sulphur required by plants is for the synthesis of amino acids (namely, cysteine, cystine and methionine) which are essential components of proteins and contain 6 to 8% S. One of the main functions of sulphur in proteins is to form sulphur-sulphur (-S-S-) bonds between polypeptide chains which are essential for the protein conformation relevant to its catalytic or structural properties.

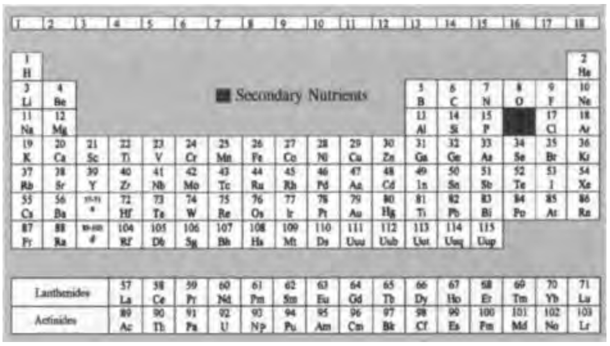


Fig.S.31: Position of sulphur in the Periodic Table.

Depending on their sulphur requirement, crops are divided into three groups. The first includes crops with a high sulphur requirement - in a range 20 to 80 kg/ha. Crucifers and Brassiceae fall in this group. The second group requires sulphur in a moderate range - 10 to 50 kg/ha and includes plantation crops. The third group needs sulphur in small quantities - 5 to 25 kg/ha and includes cereals, forages and other field crops. As a rule, sulphur requirement is 3 to 4 kg/ton of grains, 8 kg/ton of grain legumes and 12 kg/ton of oil seeds.

Soil can lose sulphur by (a) its removal by crops, (b) leaching and erosion, (c) sulphate adsorption and retention by clays, and (d) cultivation. Decomposition of organic matter is accelerated by cultivation, which improves soil segregation and aeration. The oxidation of organic matter causes a decline in organic sulphur.

Sulphur is needed for the synthesis of co-enzyme A, biotin, thiamine and glutathione. It is also present in substances like sulphur-adenosyl methionine, formyl methionine, lipoic acid and sulfolipid.

Sulphur plays an important role in chlorophyll synthesis. It is part of ferridoxins, a type of non-heme iron-sulphur (Fe-S) protein occurring in chloroplasts and involved in the reduction of nitrite and sulphate, and in the assimilation of nitrogen by bacteria.

Sulphur enhances the formation of oil in crops like soybean and flax. Plant roots absorb sulphur as sulphate ions. Small quantities of sulphur dioxide (SO_2) can be absorbed through plant leaves and used in the plant. The concentration of sulphur in plants is 0.1 to 4% which is equal to, or less than, the amount of phosphorus in wheat, corn, beans and potato but is more than the phosphorus content in alfalfa, cabbage and turnip.

There is a close relationship between organic C, total N and total S in soils. The C: N: S ratio in most well-drained, non-calcareous soils is approximately 120:10:1.4. Generally, the C: S ratio varies much more than the N: S ratio, the latter falling within a narrow range of 6 to 8.1. Sulphur may be immobilized in soils when the C: S or N: S ratio is large.

Much of the sulphate in the plant is reduced to the sulphur-sulphur (-S-S-) and the mercapto (-SH) forms, although some exists in the plant tissues and cell sap as well. Soil sulphur is present in organic as well as inorganic forms. The amount of sulphur in soil humus depends on microbial action and climate.

The principal sulphur-containing minerals are ores like gypsum, epsomite, pyrite and galena. Elemental sulphur deposits also occur on the earth. Another source of sulphur is the atmosphere, where sulphur dioxide (SO_2) accumulates from the combustion of coal and other sulphur-containing materials.

Adsorbed sulphate and sulphur is solution form represent the readily-available sulphur fraction utilized by plants. The sulphur cycle in soil, plant and atmosphere is similar to the nitrogen cycle. Concentrations of 3 to 5 ppm of sulphate in the soil solution are adequate for the growth of many plant species, although some crops like rapeseed and alfalfa require a higher concentration. The availability of readily-soluble sulphate varies with the depth of the soil and the season of the year.

The anionic nature and solubility of sulphates and nitrates make them easily leachable from the soil. Sulphur adsorbed on the soil, co-precipitated or co-crystallized with calcium carbonate, is not available to the plant. The chemical oxidation of elemental sulphur (and the sulphide ion) in the soil is much slower than microbial oxidation. Numerous soil transformations of sulphur occur as it converts back and forth (mineralization/immobilization) from the inorganic to the organic form by the action of micro-organisms.

Sulphur availability generally increases with organic matter. Crops grown in soil with less than 1.2 to 1.5% organic matter require sulphur fertilization. High yielding varieties, multiple cropping pattern, irrigation and heavier dosages of other plant nutrients accelerate sulphur withdrawal from the soil. Sulphur requirement is thus closely related to the amount of nitrogen applied to the plant.

Sulphur deficiency is characterized by stunted, thin-stemmed and spindly plants, these symptoms being similar to nitrogen deficiency. It has a pronounced retarding effect on plant growth. The symptoms of sulphur deficiency are seen first in younger leaves; the green veins are slightly more distinct than those with nitrogen deficiency (Fig.S.32). Sulphur fertilization improves crop quality through a better nitrogen to sulphur (N:S) ratio.

Sulphur deficiency, seen more in crops like tea, cotton and legumes, is likely to be higher in acidic soils and is estimated by evaluating soil texture and organic matter. It is exhibited by soil that is (a) sandy, (b) non-irrigated, (c) well-leached, (d) low in organic matter, and (e) far removed from industrialized areas.

Metal sulphates, except those of Zn, Cu and Mn, are applied to the soil surface after considering the cost per unit of sulphur applied. Yellow elemental sulphur, in a powdered form, is added to overcome sulphur deficiency. As the oxidation of elemental sulphur is slow, top dressing of the crops is not recommended. A blend of sulphur and bentonite, in the ratio 90:10 has gained acceptance as a plant nutrient. A suspension of sulphur in water is applied directly to the soil or is mixed with other suspension fertilizers.

Fig.S.32: Sulphur deficiency in leaves show symptoms like pale green leaves and still paler veins.

Ammonium thiosulphate in water is the most popular sulphur-containing product which is used to overcome sulphur deficiency in a soil with pH more than 5.8. Ammonium thiosulphate forms colloidal sulphur and ammonium sulphate. The sulphur must be oxidized to sulphate, in order to be available for a longer duration.

A red to brownish black solution of ammonium polysulphide containing 45% sulphur (and smelling hydrogen sulphide) is used as a fertilizer, and also to reclaim high pH soils. Ammonium polysulphide is also added to irrigation water to improve the penetration of sulphur into the soil. A mixture of urea and concentrated sulphuric acid is used as a nitrogen-sulphur (N-S) fertilizer and added to the soil either directly or through a sprinkler.

Elemental sulphur is incorporated into a N-S fertilizer to provide 5 to 20% sulphur. Sulphur is more easily oxidized in this mixture than when oxidized alone. Volatile sulphur compounds, such as di-methyl sulphide, carbon disulphide and methyl mercaptan are produced through microbial transformation under both aerobic and anaerobic conditions. Though the volatile matter in sulphur compounds is very small (0.05%), volatile compounds have significant side effects. Carbon disulphide, for instance, is a potential inhibitor of nitrification, while a few other sulphur compounds retard it. Volatile compounds, released by plants, affect the palatability and acceptability of the forage crop to grazing animals.

Many methods have been proposed to estimate available soil sulphur. The most common ones are: (a) $CaCl_2$ extractable sulphur, (b) heat-soluble sulphur, (c) mono-potassium or mono-calcium phosphate (500 mg phosphorus/liter) solution extractable sulphur, (d) Morgan's extract (sodium acetate-acetic acid buffer with pH 4.0), (e) 0.5N ammonium acetate + 0.25N acetic acid extractable, and (f) Olsen's 0.5M sodium bicarbonate extractable sulphur. (See also Mineralization of sulphur.)

Sulphur availability: See Sulphur

Sulphur bentonite

Sulphur bentonite is a sulphur-based fertilizer, containing 90% elemental sulphur and 10% bentonite. Sulphur bentonite is commonly blended with N-P-K based solid fertilizer materials. When such a blended fertilizer is applied to the soil, the bentonite part absorbs moisture, causing sulphur to disintegrate into finer particles which are easily oxidized to sulphate.

This sulphur-based fertilizer is applied 4 to 5 months before planting, as the process of the oxidation of sulphur to sulphate and the availability of the sulphate to the plant takes time. The application of this fertilizer, however, has accompanying dust problems due to the breakdown of the fertilizer formulation, followed by the release of fine sulphur powder.

Sulphur-coated urea

In order to get a slow release of nitrogen (over an extended period), urea fertilizers are coated with water-insoluble materials. Sulphur-coated urea (36 to 38% nitrogen), **crotonylidene diurea** (CDU, 30% nitrogen), and **isobutylidene diurea** (IBDU, 30% nitrogen) are examples of fertilizer formulations that enable slow release of nitrogen.

A sulphur coating is regarded as an impermeable membrane which slowly degrades in the soil through microbial, chemical or physical processes. Granular urea is sprayed with molten sulphur, followed by a wax coating and later, a clay film coating to improve handling. The rate of release is adjusted by the amount of sulphur applied as coating.

Sulphur-coated urea is administered in situations where multiple applications of soluble nitrogen sources are needed during the growing season under heavy rainfall or irrigation. Sulphur-coated urea is advantageous to sugar cane, pineapple, rice, fruits, forage, turf and ornamentals. Soil micro-organisms must oxidize the sulphur coating before urea is exposed and hydrolyzed.

Apart from effecting a slow nitrogen release, the sulphur-coated urea supplies sulphur to plants, though not in sufficient quantity. It is not effective as pellets on flooded fields because an insoluble coating of iron sulphide forms around each pellet, reducing its solubility and value.

Sulphur-coated fertilizers are commercially available as straight nitrogen grades. **Sulphur polymer hybrid coatings** combine the controlled-release performance of the polymer-coated fertilizer, at a low cost. The liquid monomers used in this process are di-isocynates such as MDI (4,4'- diphenylmethane diisocynate) and a polyol mixture of DEG (diethylene glycol) and TEA (triethanolamine). When applied sequentially onto the surface of hot sulphur-coated urea granules, they co-polymerize and produce a firm, tack-free, water-insoluble polymer-coated sealant which becomes an improved impact-resistant product. Commercial products in the USA contain 38.5 to 42% nitrogen, 11 to 15% sulphur and about 2% polymer sealant.

Sulphur cycle

Sulphur cycle entails the cycling of sulphur between the living (**biotic**) and non-living (**abiotic**) components of the environment. Most sulphur in a non-living environment is found in rocks, with a small amount in the atmosphere as sulphur dioxide (SO_2) produced by the combustion of fossil fuels.

The sulphate formed during the weathering and oxidation of rocks is taken up by plants and incorporated into sulphur-containing proteins. Sulphur in this form, is passed through the food chain to animals. It is returned to the living environment as hydrogen sulphide from the decomposition of dead, organic matter and feces by anaerobic, sulphate-reducing bacteria (Fig.S.33).

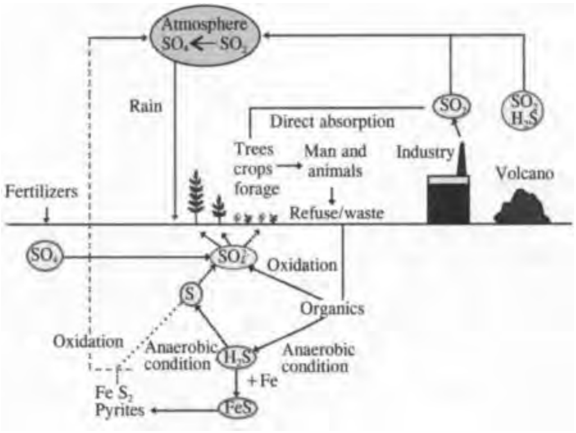


Fig.S.33: A sulphur cycle.

Hydrogen sulphide can be converted to elemental sulphur or sulphate by the action of different groups of photosynthetic and sulphide-oxidizing bacteria. Elemental sulphur gets incorporated into rocks.

Sulphur deficiency

Sulphur deficiency is characterized by stunted, thin-stemmed and spindly plants, the symptoms being similar to those in nitrogen deficiency (Fig.S.34).

Sulphur deficiency has a pronounced retarding effect on plant growth. It causes delayed maturity in cereals, poor nodulation in legumes (with reduced fixing ability) and improper maturing of fruits. Oil seeds deficient in sulphur produce low yields, with less oils in the seeds.

Both sulphur and nitrogen are essential for protein formation; research indicates that the nitrogen to sulphur ratio may vary from 15:1 to 18:1, depending on the plant. It starts with the appearance of pale yellow or light green leaves. Unlike the symptoms of nitrogen deficiency, sulphur deficiency symptoms appear first on younger leaves. Sulphur deficiency is usually seen when the soil has less than 10 ppm of soluble sulphur. (See also Sulphur.)

Fig.S.34: Sulphur deficiency. Healthy plants are shown on the right. Source: "Handbook on Fertiliser Usage" 1994, S.Seetharaman, et al, (Ed). The Fertilizer Association of India, New Delhi. With permission.

Sulphur polymer coating: See Coated fertilizer

Sulphuric acid

Sulphur, like nitrogen, is an important plant nutrient. It is a constituent of several amino acids, such as methionine, cysteine, cystine and essential constituents of proteins. Sulphur is provided to plants as sulphates made from sulphuric acid.

Sulphuric acid, also called **oil of vitriol**, is a colorless, oily liquid made by two processes, namely, the **lead chamber process** and the **contact process** which is currently used the world over. Both processes involve the burning of sulphur or sulphur ores, such as pyrites, to sulphur dioxide which is converted to sulphur trioxide in the presence of a catalyst, followed by absorption of the sulphur trioxide in dilute acid. The major difference between the two processes is in the (a) use of a catalyst in the oxidation of sulphur dioxide to trioxide, (b) design of the systems, and (c) strength of the acid to be used.

Main disadvantages of the chamber process are the limitations in throughput, quality and concentration, which allow only 78% sulphuric acid (H_2SO_4) to be obtained. The main reactions in the contact process are:

$$\underset{(Fe_2S_3/S)}{SO_2 + O_2} \xrightarrow[425^\circ C]{V_2O_5} SO_3$$

$$SO_3 + H_2O \xrightarrow{260^\circ C} H_2SO_4$$

And those in the lead chamber process are:

$$SO_2 + (NO)_x \xrightarrow{O} SO_3 + (NO)_x ;$$

$$SO_3 + H_2O \xrightarrow{\text{In lead rooms}} H_2SO_4$$

The contact process is economical since vanadium-pentoxide catalyst which is less susceptible to poisoning, replaces the platinum-based catalyst. Other advantages are that more than 98% concentrated sulphuric acid (H_2SO_4) of high purity can be produced directly in high capacity processing plants.

Sulphuric acid can also be made by the 'cat-ox' process, which is a proprietary, catalytic oxidation process for making sulphuric acid from flue gases and gypsum.

Handling and transportation of sulphuric acid must be done with care as it is a very strong and corrosive acid. Lead containers are used for acids of purity less than 95% while steel tanks, barges and containers are used to transport highly concentrated sulphuric acid.

Sulphuric acid, in addition to its use in the manufacture of fertilizers and intermediates (such as phosphoric acid, ammonium sulphate, etc.), is also used to manufacture certain chemicals, explosives, films, iron, matches, varnishes, paints, pesticides, pharmaceuticals, pigments, plastics, paper pulp, textiles and in petroleum refining. It is by far the most widely used industrial chemical. It is the highest volume chemical produced in the USA. It is a powerful dehydrating agent, capable of removing water from many organic compounds like anhydrides from acids or unsaturated compounds from alcohols.

Sulphuric acid is a strong dibasic acid forming two series of salts, sulphates and hydrogen sulphates. It is also used in the treatment of saline and alkali soils. The common sulphates used in fertilizers are $(NH_4)_2SO_4$, $MgSO_4$, $FeSO_4$, $CaSO_4.2H_2O$, $Fe_2(SO_4)_3$, K_2SO_4, $MnSO_4$ and $CuSO_4$, and double salts of metals with ammonium sulphate.

Sulphuric acid from elemental sulphur: See Sulphuric acid production processes

Sulphuric acid from pyrites or smelter operations: See Sulphuric acid production processes

Sulphuric acid production by chamber process: See Sulphuric acid production processes

Sulphuric acid production by contact process: See Sulphuric acid production processes

Sulphuric acid production by wet catalysis: See Sulphuric acid production processes

Sulphuric acid production from calcium sulphate: See Sulphuric acid production processes

Sulphuric acid production processes

The industry dealing with chemicals and fertilizers is, by far, the greatest consumer of sulphuric acid (H_2SO_4). This industry uses more than half of the sulphuric acid produced in the world.

Sulphuric acid is an important raw material for phosphate fertilizers and to a much lesser extent, for nitrogen (ammonium sulphate) and potassium fertilizers. Sulphuric acid is used also in steel works and the rayon and staple fiber industry. It is also used in the manufacture of alum and other inorganic chemicals and in petroleum refining, etc.

Sulphuric acid production is based on elemental sulphur (65%), pyrites (16%) and others (19%). It is also recovered as a by-product from smelting operations.

In general, sulphuric acid is produced by the catalytic oxidation of sulphur dioxide (SO_2) to sulphur trioxide (SO_3) which is subsequently absorbed in water to form sulphuric acid. In practice, sulphur trioxide is absorbed in sulphuric acid which is maintained at a controlled concentration of 98% by the addition of water.

The principal processes for the conversion of SO_2 are the chamber process and the contact process. The older chamber process is so named because the reactions that produce sulphur trioxide and sulphuric acid take place within a lead chamber.

Major disadvantages of the chamber process are that it has limitations in terms of the quality and concentration (about 78% H_2SO_4) of the acid. The process is now obsolete (although some older chamber plants are still in use) and all new plants use the contact process for the manufacture of H_2SO_4.

For the contact process, sulphur dioxide is converted to SO_3 in the presence of a metal or metal oxide catalyst. The procedure involved is termed as contact process on account of the fact that the SO_2 is absorbed on the surface of or in contact with the catalyst before its reaction with oxygen begins.

Platinum was used widely as a catalyst once, but because of its high cost and susceptibility to 'poisoning', it is replaced by vanadium pentoxide. Sulphur dioxide is first obtained either by burning molten sulphur in the presence of air or by roasting the pyrites. The reaction speed is dependent on the temperature, the activity of the catalyst and the time of contact with the catalyst.

When the reaction is complete, the SO_3 is rapidly piped out to the cooler to prevent reversing of the reaction. The SO_3 is passed through an absorption tower where it is absorbed in the recirculating concentrated acid.

There are many variations in the contact process depending on the type of raw materials used and engineering designs. The major advantages of the contact process are the high purity of the acid produced (>98%) and compactness of the plant.

$$S + O_2 \longrightarrow SO_2$$

or

$$4FeS_2 + 11O_2 \longrightarrow 2Fe_2O_3 + 8SO_2$$

$$2ZnS + 3O_2 \longrightarrow 2ZnO + 2SO_2$$

(reversible reaction)

$$2SO_2 + O_2 \xrightarrow{V_2O_5/Pt} 2SO_3$$

$$H_2SO_4 + SO_3 + H_2O \longrightarrow 2H_2SO_4$$

(I) Production of **sulphuric acid from elemental sulphur**: Elemental sulphur, whenever available at a reasonable cost, is the preferred source of sulphur. Sulphur of >99.9% purity with a low ash content is used in the production of H_2SO_4. The total heat released in this production is 1.3 x 10^6 kcal/ton of sulphuric acid. Recovery of a maximum portion of this heat is an important objective in this production technology.

Sulphur is burned in a refractory-lined combustion chamber with excess air at a temperature of 950 to 1100°C to produce a combustion gas containing 10% SO_2. The gas is cooled in a boiler to about 420°C (the desired inlet temperature of the catalytic converter). Combustion of sulphur produces some oxides of nitrogen (NO_x) which vary with the gas temperature.

The catalytic oxidation of SO_2 to SO_3 is usually carried out in three vanadium oxide catalyst beds. The gas is cooled between the steps to ensure that the temperature is within the desired range of 420 to 450°C. The cooling may be done by injecting cool air or by a heat exchanger to produce more steam. The cooled gas enters the absorption tower where SO_3 is absorbed in a recirculated stream of concentrated sulphuric acid. The H_2SO_4 is maintained at the desired concentration (usually 90% sulphuric acid) by water addition and in the desired temperature range of 70 to 90°C. For the single-absorption process, sulphuric acid produced is usually 97 to 98% pure and the remaining sulphur is discharged as sulphur dioxide into the atmosphere. However, since in most countries, letting out sulphur dioxide is prohibited, a double contact (meaning a double absorption) system is used. This system reduces the sulphur dioxide loss to less than 2 kg of SO_3/ton of H_2SO_4. Mist eliminators with high efficiency also help in reducing the loss of H_2SO_4 mist to less than 0.05 kg/ton of H_2SO_4. Thus, the recovery of sulphuric acid is better than 99.7% on sulphur.

The double contact, the double absorption process increases the plant cost by 10 to 15% compared to the single absorption process, with a higher energy consumption. The residual quantities of sulphur dioxide can be removed by scrubbing the stock gases with ammonia to get ammonium bisulphate/sulphite.

Operating the plant under pressure reduces the size of the plant, making it less expensive and less catalyst dependent. The pressure used is of the order of 0.5MPa. The conversion efficiency is found to be 99.80 to 99.85%. The CIL (Chemetics International Ltd., Canada) operates at 0.8 MPa pressure and uses a single-contact, single-absorption system. The CIL process has the advantage of a pressure process and reduction in the plant cost because of the single-contact and single-absorption equipment. The **Monsanto Enviro-Chem process** has 70% energy recovery (compared to 55% in the old methods) and steam production increases from

1.1 kg/kg to 1.35 kg/kg of acid made. A technological breakthrough was achieved by **Monsanto Enviro-Chem's heat recovery system**, which can recover 95% of the process heat as steam. This increases the steam production to 1.8 kg/kg of acid produced. In this process, the concentration of acid leaving the absorption tower corrodes the stainless steel equipment at an acceptably low rate at operating temperatures (190 to 200°C) and pressures (0.8 Mpa).

(II) Production of **sulphuric acid from pyrites or from smelter operations**: When the source of SO_2 comes from roasting of pyrites or other non-ferrous sulphide ores, the process of making sulphuric acid differs from that based on sulphur in respect of the following: (i) The burning-sulphur furnace is deleted. (ii) The incoming gas is cooled and scrubbed to remove all impurities to avoid poisoning of the catalyst. (iii) The gases must be dried in a tower containing sulphuric acid. (iv) The clean, dry gas is heated to the conversion temperature of 420°C. There is enough heat generated in the conversion step to preheat the incoming gas. (v) The concentration of sulphur dioxide in the gas is lower than that obtained from the burning of sulphur. To treat the large volume of gas, all equipments have to be larger, thus adding to the cost. The capital cost of the plant inclusive of the pyrite roasting step is about 2.6 times the cost of the sulphur-based plant. (vi) The amount of heat received as steam or in another useful form is somewhat lesser for a pyrite-based plant than for a sulphur-based plant.

Pure pyrite (FeS_2) contains 53.4% sulphur. However, unlike sulphur, pyrite ores contain numerous impurities and hence after mining and beneficiation, the pyrite ore contains only 40 to 50% sulphur. These ores may contain other elements, such as nickel, cobalt, cadmium, bismuth, arsenic and small quantities of gold and silver. The sulphuric acid manufacturing process from pyrites is the same as that from sulphur. In most locations during the manufacture, the stack gas is scrubbed or a second absorption stage is installed to reduce the atmospheric pollution.

The **Outokumpu process** of Finland consists of flash roasting pyrites in a non-oxidizing atmosphere in a fluidized bed. One half of the sulphur from the sulphides is recovered as elemental sulphur and the other as sulphide residue as called **pyrrhotite**. This residue can be roasted in an oxidizing atmosphere to recover the remaining sulphur.

(III) Production of **sulphuric acid by wet catalysis**: Unlike the conventional contact sulphuric acid process, the wet contact process uses a wet gas instead of dry sulphur dioxide/air mixtures. In this process, hydrogen sulphide is burned to sulphur dioxide and water. The sulphur dioxide is converted to sulphur trioxide which combines with steam to give sulphuric acid. Waste gases containing at least 10% H_2S can be converted to sulphuric acid directly. These may come from cokeries, mineral oil refineries, fuel gasification or low temperature carbonization plants, natural gas cleaning installations, carbon disulphide production plants and synthetic fiber plants.

The sulphur dioxide and water vapor containing the gases enter the converter at about 440°C when sulphur dioxide is catalytically oxidized to sulphur trioxide as in the contact process. The water vapor and SO_3 containing the gas flows into a condensation tower sluiced with sulphuric acid. The coolers remove the condensation and any other heat from the circulating acid. Some of the circulating acid is continuously discharged as a product. The concentration of the product sulphuric acid is 78%. By using the principle of hot condensation, sulphuric acid with 93% concentration can be produced from the wet catalysis process.

(IV) **Trends and technology improvements**: The growth of sulphuric acid industry depends on the production of wet process phosphoric acid. New plants will aim mainly at increasing the output from the production units, and maximizing the heat recovery and operational reliability of installations through precise selection of acid resistant alloys and non-corrosive materials.

(V) Production of **sulphuric acid from calcium sulphate**: Sulphuric acid can also be manufactured from calcium sulphate along with natural anhydrite, gypsum and phosphogypsum. Portland cement is a by-product of this process.

The process is carried out in a rotary kiln. When gypsum is used as a raw material, it is first dehydrated in a separate kiln. The rotary kiln is charged with a mixture of anhydrite or calcined gypsum and coke, silica and shale or other sources of iron and aluminum. The charge is mixed, ground and palletized to avoid dust losses. The kiln is operated just before the fusion point (< 1400°C). The sulphur is converted to SO_2 and comes out in the kiln exhaust gas along with O_2, N_2, CO_2, water vapor and a large quantity of dust. The gas is cleaned and cooled in a system of cyclones, dry electrostatic precipitators, wet scrubbers and wet electrostatic precipitators. Air is added to the purified SO_2 to give a SO_3 content of 5.5% at this stage. The gas is dried and taken to the conversion temperature of around 420°C and passed through H_2SO_4 as in the pyrites-based process. Sulphuric acid produced is in the concentration range of 96 to 98%. The over-all reaction is:

$$2CaSO_4 + C \longrightarrow 2CaO + 2SO_2 + CO_2$$

The process, which was in vogue in some European countries and South Africa, is obsolete now as it is uneconomical. It also produces approximately equal quantities of cement and sulphuric acid. Almost all plants are based on the use of calcium sulphate - either anhydrite or a mixture of anhydrite and phosphogypsum. No plant solely depends on phosphogypsum as it contains 15 to 20% free moisture in addition to 21% of combined moisture. Removal of this moisture means extra fuel compared to that in the anhydrite process.

The fuel requirement for cement production from the phosphogypsum process is 2.5 times that required when the production is from the usual raw materials. Another objection to the phosphogypsum based process is that the product contains radium or other radioactive substances.

The total capital investment for the combined process ranges from a ratio of 5:1 to 10:1, when compared with that of sulphuric acid from sulphur. The main advantage of sulphuric acid and cement from phosphogypsum is its easy availability from the phosphoric acid plant which also solves the disposal problem of phosphogypsum.

Science Ventures Inc. developed a process for recovery of sulphur from phosphogypsum in the form of H_2SO_4. This process is known as **Flash sulphur cycle** (FLASC). The pulverized coal is mixed with calcined phosphogypsum. Fluxing materials are sprayed onto a flame in a reactor resembling a copper smelter, where most desulphurization takes place. Excess fuel reduces $CaSO_4$ to CaO, releasing SO_2. Molten minerals drain from the reactor as molten slag. The slag is quenched to form a hard glassy mass. The SO_2 is converted to SO_3 in the usual way.

Sulphuric acid is transported in large containers by sea and from the port, by barge or rail. The tanks are made of mild steel lined with a plating of molybdenum-alloyed stainless steel or constructed entirely from this material. Small quantities of the acid are handled in porcelain or glass carboys.

Sulphuric acid, in addition to its use for fertilizers, is also used in the manufacture of chemicals, explosives, films, iron, matches, varnish, paint, pesticides, pharmaceuticals, plastics, paper pulp, textiles, vegetable oils and petroleum.

Sulphuric acid production, trends and technology: See Sulphuric acid production processes

Sulphuric acid, source of: See Phosphoric acid production processes

Sulphuric horizon

Sulphuric horizon is a horizon composed of mineral or organic soil materials with pH less than 3.5 and with yellow, jarosite mottles. This horizon is toxic to plant roots and is formed as a result of artificial drainage accompanied by the oxidation of sulphides.

Sulphuric horizons occur in entisols, histosols and inceptisols.

Sulphuric mineralization: See Mineralization of sulphur

Sulphur-polymer hybrid coatings: See Sulphur-coated urea

Sulphur production by Frasch process: See Sulphur production processes

Sulphur production processes

Sulphur-containing ores are usually excavated by conventional open-pit or underground mining methods. In the **Frasch process**, elemental sulphur is produced directly from the deposits by, melting them with hot water and pumping the molten sulphur to the surface. The recovered sulphur accounts for over 60% of the total world production of elemental sulphur. Most of the recovered sulphur originates from the processing of fossil hydrocarbons, especially natural gas, oil and coal. In natural gas, sulphur is in the form of hydrogen sulphide, but in oil and coal, it is present as organic compounds such as mercaptans and as sulphides, disulphides and heterocyclic compounds.

There are three processes for removing hydrogen sulphide from gas streams: sorption on a solid, reversible chemical and physical absorption in a liquid medium and absorption and oxidation in an oxidizing liquid medium. There are two methods by which this conversion can be achieved. One is called the wet Claus process in which the introduced sulphur dioxide reacts with the hydrogen sulphide as follows:

$$2H_2S + SO_2 \longrightarrow 3S + 2H_2O$$

The other type of direct conversion process uses an alkaline solution (sodium carbonate) containing one or more mild oxidizing agents that oxidize hydrogen sulphide to sulphur, and are then themselves regenerated by oxidation with air.

Non-ferrous metal ores such as copper, zinc, lead and cobalt sulphide, on roasting, are broken down to cuprous sulphide and elemental sulphur. Roasting and/or smelting sulphides under reducing conditions with coal, coke or a reducing gas, produces a gas mixture containing hydrogen sulphide and sulphur dioxide (H_2S and SO_2).

$$2H_2S + SO_2 \longrightarrow 3S + 2H_2O$$

These compounds can be converted to sulphur in a Claus plant. Reacting pyrite with sulphur dioxide can produce elemental sulphur and magnetite.

Sulphates are not currently a significant commercial source of sulphur because of economic factors. Large inputs of energy are required to reduce sulphates to sulphur.

Sulphur recovery by flash sulphur cycle process: See Sulphuric acid production processes

Sulphur suspensions

Suspension is a system in which very small particles (solid or liquid or semi-solid) are more or less uniformly distributed in a liquid or gaseous medium. If the particles are so small that they can pass through a filter membrane, the solution is called a **colloidal suspension**.

Sulphur suspensions contain sulphur and/or its compounds like elemental sulphur or gypsum. The addition of finely ground sulphur (which contains 2 to 3% clay) to water gives a suspension containing 40 to 60% sulphur. In regions where the effects of sulphur deficiency in the soil are more pronounced, the sulphur in fertilizers increases the yield and also improves the product quality. Tennessee Valley Authority (TVA) has manufactured a 29-0-0-5S **urea-ammonium sulphate** suspension (UAS) fertilizer in a pilot plant. The contents are urea (70% solution), sulphuric acid (93%) and anhydrous ammonia and water.

Sulphur volatilization

Sulphur is lost from the soil through the formation of volatile sulphur compounds under both aerobic and anaerobic conditions. The major compounds formed in the volatilization process are carbon disulphide (CS_2), methyl mercaptan (CH_3SH), dimethyl sulphide (CH_3SCH_3), and dimethyl disulphide $(CH_3)_2S_2$. Dimethyl sulphide accounts for more than 55% of volatilized sulphur. Sulphur volatilization in low organic soils is negligible but it increases with the increasing content of organic matter. Sulphur volatilization also occurs in soils treated with residues of a variety of cruciferous crops.

The possible sulphur loss from treated or untreated soils is small. Nevertheless, even this small loss has profound side effects. Sulphur compounds released from soils that are treated with cruciferous crop residues are known to control root rot in peas, beans and sesame.

Carbon disulphide (CS_2), methyl mercaptan (CH_3SH), dimethyl thioether, [CH_3SCH_3] and dimethyl disulphide [$(CH_3)_2S_2$] are potent inhibitors of nitrification. These compounds released by plants have unpleasant odors, and prevent animals from grazing on them.

Summer fallowing

Summer fallowing is an agricultural practice where no crop is grown and all vegetative growth is prevented by shallow tillage or herbicides for a period of time, in order to store water for use by the next crop.

After wheat is harvested, for instance, the land is left unplanted and weeds are controlled by herbicides or shallow cultivation. This minimizes the water loss by transpiration. There is greater water recharge during fallow periods than during the growth of plants. This additional water and the succeeding year's precipitation is used by wheat. The evaporation of water from the surface and its movement within the soil considered together, explains water storage in fallowed land.

However, evaporation of water from the area wetted in the spring results in accumulation of salts from the water. Thus, an area of salt accumulation, called **saline seep**, is formed. The osmotic effect of soluble salts reduces soil water potential, water uptake and yields. In some cases, soils become too saline for plant growth.

Saline seep may be controlled by: (a) reducing fallowing frequency, (b) increasing the use of fertilizer to enhance plant growth, and (c) intensifying the cultivation of deep-rooted perennial crops such as alfalfa, which remove soil water.

Sump and dump drainage system: See Sub-surface drainage system

Super-cooled liquid

Amorphous substances are some sort of solids with very high viscosity ($>10^{13}$ PaS) and are also called super-cooled liquids. Examples of super-cooled liquids are glasses, resins, some plastic substances and metallic glasses.

Super-granules: See Large granular urea

Superior spray oils

Superior spray oil adjuvant is the term used for **phytobland oil-water emulsions**. (See also Adjuvant.)

Supernatant liquid

Supernatant liquid lies above a solid residue after precipitation or centrifugation. For example, when an aqueous suspension of fine calcium carbonate is allowed to stand overnight or centrifuged, solid calcium carbonate settles at the bottom, leaving behind water that contains traces of calcium carbonate. The overlying aqueous layer is the supernatant liquid.

Superphosphate

Superphosphate is obtained by treating phosphate rock with sulphuric acid, phosphoric acid, or their mixture. Rock phosphate mixed (a) with sulphuric acid (H_2SO_4) gives **single superphosphate** (9% phosphorus), and (b) with phosphoric acid gives **triple superphosphate** (20 to 22% phosphorus).

Equal weights of finely ground rock phosphate and sulphuric acid are mixed in cast iron pans, equipped with a stirring mechanism. The fluid mixture is dropped into a 'hot den' where it solidifies. 15 to 30 minutes later, it can be used for making different grades of superphosphates. The main reaction between sulphuric acid and rock phosphate is as follows:

$$\begin{aligned} Ca_3(PO_4)_2 + 2H_2SO_4 + 5H_2O \longrightarrow\ & Ca(H_2PO_4)_2 \cdot H_2O \\ & + 2CaSO_4 \cdot 2H_2O \end{aligned}$$

A guaranteed percentage of the available phosphoric acid determines the type of superphosphate produced; for instance, '20% superphosphate' or '45 to 50% superphosphate', which are single superphosphate (**SSP**) and triple superphosphate (**TSP**), respectively. The percentages indicate the amount of available phosphorus (as P_2O_5).

Boronated single superphosphate is a modified form of single superphosphate. It contains 0.18% borax and is mostly available in western countries as a fertilizer.

Superphosphates are neutral fertilizers in that they have no appreciable effect on soil pH. Superphosphate (also called ordinary or single superphosphate) contains about 8 to 10% sulphur as calcium sulphate. Superphosphate is also used in the production of mixed fertilizers in which other dry, powdered or finely-granular materials are blended to effect a product that contains nitrogen, phosphorus and potassium. It is also applied directly. Ammoniated superphosphates are prepared by reacting anhydrous or **aqua ammonia** with ordinary or triple superphosphate. Ammoniation of superphosphates offers the advantage of inexpensive nitrogen but decreases the amount of water-soluble phosphorus in the product. The water solubility is greater in superphosphate than in triple superphosphate.

Superphosphoric acid

Superphosphoric acid (**SPA**) is a mixture of orthophosphoric acid and polyphosphoric acid. The phosphorus content (as P_2O_5) can vary from 55% to 72% in the wet process (green acid). The polyphosphoric acid has a general formula, $H_{n+2}P_nO_{3n+1}$.

SPA production involves initial removal of physical water from the weaker acid, followed by the removal of chemically-bound water. This is represented as follows:

$$2H_3PO_4 \longrightarrow H_4P_2O_7 + H_2O \text{ (Pyrophosphoric acid)}$$
$$H_4P_2O_7 + H_3PO_4 \longrightarrow H_5P_3O_{10} + H_2O \text{ (Triphosphoric acid)}$$

Superphosphoric acid of various grades and concentrations can be manufactured from the wet-process phosphoric acid with upto 72% phosphorus (as P_2O_5). Originally, superphosphoric acid was produced from white acid only, but it is now produced from the less expensive green acid. Superphosphoric acid being less corrosive than ortho-phosphoric acid, is easier to transport compared to acids of lower concentration. It is suitable for the production of clear liquid fertilizers. The disadvantages of superphosphoric acid include its high (a) viscosity, causing it to be heated to 60°C or beyond to lower its viscosity to facilitate pumping with centrifugal-type pumps, (b) energy requirement, and (c) corrosiveness to some evaporators.

Superphosphoric acid, in addition to its major use as a fertilizer, is also suitable for the manufacture of animal feed supplement products (such as dicalcium phosphate and ammonium phosphate), ammonium and calcium polyphosphates and liquid fertilizers. (See also Polyphosphate fertilizers.)

Supersaturation

Supersaturation is the condition of a solution in which the solvent contains, at equivalent temperature, more dissolved matter (solute) than is present in a saturated solution of the same component. Such a solution may occur or can be made when a saturated solution cools gradually so that nucleating crystals do not occur. The nucleating crystals are extremely unstable; they precipitate when one or two crystals of the solute are added followed by slight agitation or shaking.

Support price

Support price is the minimum price fixed by the government for procuring a commodity, even when there is a glut of the commodity on the market, so that the producer does not suffer financially from the open market price fall. The safeguard is extended to the farming community to protect its financial interests. Sometimes, heavy import duties are levied to raise the price of an imported product to bring it at par with the indigenous material.

Administered food prices, especially in developing countries, have often kept low (particularly for staple foods such as rice, cassava, maize and wheat) because of the low incomes of the population. Another line of thought is that poverty is compounded by the increasing proportion of low-income generating agricultural population. Most small farmers, who cannot produce efficiently, or rich farmers who do not use fertilizers adequately and appropriately, end up with a product which has a low benefit to cost ratio. Nevertheless, the farming community cannot be allowed to disappear in any country and so, governments adopt different economic management policies, like supportive price mechanism (**guaranteed minimum price**) or subsidy or insurance against losses caused by climatic disasters, to protect the interests of farmers.

The expected increase in fertilizer consumption in developing countries will only materialize if the input/output price relationship is favorable to farmers. The cost of fertilizer production has, for a variety of reasons, been rising in developing countries over the years. If fertilizers are sold to the farmer at market prices determined on a cost-plus basis, then it is unlikely that farmers will use more fertilizers. Available evidence demonstrates that the profitability of fertilizer use has a direct bearing on the fertilizer consumption.

From the analysis of the economics of fertilizer use and particularly of the **value-to-cost ratio**, it seems clear that fertilizers need to be made available to the farmer at prices lower than its ex-factory price. This essentially amounts to subsidizing the farmer to the extent of the unfavorable difference.

Prices and subsidies are interrelated questions and assume special significance in government-controlled economies. Prices are, therefore, only need-based and have no relation to market dynamics. The manufacturers or suppliers in such situations are directed to sell fertilizers at controlled prices and are in turn compensated by the government in accordance with some set formulae. This compensation may seem to be a subsidy to the fertilizer manufacturers, but is, in fact, a subsidy to the farmer.

Suppressants

Suppressants is another word for **transpiration retardants**.

Supreme spray oils

Supreme spray oils are also known as **phytobland oil-water emulsions**.

Surface

In physical chemistry, surface is the area of contact between two different states of matter; for example, finely divided solid particles and air or gas (solid-gas) or liquid and air (liquid-gas) or insoluble particles and liquid (solid-liquid).

Surfaces are the sites of physico-chemical activity between the phases in contact and are responsible for various phenomena like adsorption, catalysis and reactivity. The depth of a surface can be of a molecular order in magnitude.

The total area of the exposed surface of a finely divided solid (powder, fiber or other forms) is called **surface area**. Since the activity is maximum at the surface (that is the boundary between the particle and its environment), the larger the surface area of a given substance, the larger is its reactivity. Thus, reducing the particle size is the most efficient way of increasing the physical and chemical reactions (the smaller the size, the higher the reactivity). For example, the coloring of pigments is increased by maximum size reduction. Calcium carbonate is added to acidic soils after reducing its size for quicker reactivity. Most of the fertilizers are added in powder form for quick action.

However, handling of powders poses an environmental hazard. Carbon black is known for its large surface area. Its surface activity accounts for its outstanding ability to increase the strength and abrasion resistance of rubber. The capacity of activated carbon to absorb gas molecules is due to its large surface area. Surface area is measured most accurately by the nitrogen absorption technique (BET method).

Biochemical phenomena such as osmosis, cell function and metabolic mechanisms in plants and animals are due to forces acting at the interfaces between solids, liquids and gases. Surface chemistry has many industrial applications, some of which are in soaps, detergents, and some reinforcements of rubber and plastics. Surface chemistry is also seen in catalyst behavior, air pollution control, color and optical properties of paints, all type of aerosol sprays and monolayers and thin films.

Surface active agents: See Surfactant adjuvant

Surface area: See Surface

Surface creep

Surface creep refers to the movement of non-airborne, coarse and very coarse soil particles by the force of wind down the soil surface or along the ground because of their large size. They are pushed or rolled short distances across the ground surface.

Surface crusts and seals

Soil surface is permeable to water and air because of the pores that connect the surface and the subsurface. If the surface pores clog, or if their average size is reduced, the rate of water entry will also be reduced. This process is called surface sealing or **crusting**. Seals and crusts are similar, except that seals occur when the soil is wet and crusts develop when the soil dries.

A surface crust may be as thin as 1 mm or as thick as a centimeter. In irrigated agriculture, it requires additional labor to irrigate the land more frequently at a slower rate. This may result in crops receiving water (sometimes in excess) at intervals not suited to plant thus causing crusts to be formed. In cases of severe crusting, water may not reach the root zone, and plants can be water-stressed. On the other hand, water may pond around sensitive trees or vines, resulting in their injury or death. In addition to slowing down water penetration, crusts block seedling emergence, thereby reducing the number of plants per hectare.

Crust formation is a physical and chemical process. It is assisted by the presence of sodium on the exchange complex, as sodium reduces the aggregate stability and causes clays to disperse. Dispersed clays are more mobile and, therefore, block pores more readily.

Surface diffusion

Caking of fertilizers is caused by the formation of contact points among the particles. There are different types of contact points, amongst which surface diffusion is one.

Surface diffusion is the result of water-salt complexes, consisting of pairs of hydrated ions that are transported within the adsorbed phase, to subsequently form contacts with adjacent granules.

The diffusion mechanism of caking in fertilizers is greatly influenced by the degree of porosity in the structure of particles.

Surface drainage

Surface drainage removes excess water from land, and affects only the topsoil. There are appropriate surface drainage systems designed for different properties of soil, which may (a) be slowly permeable, (b) be shallow over the rock or fine clay, (c) have surface depressions, (d) be a recipient of water from the run-off, and (e) be deficient in removing excess irrigation water.

The three main surface drainage systems use open ditches, beds (drainage by beds) and smoothing. Open ditches or open drainage are designed according to the topography of the land and soil characteristics. The depth and width of ditches as well as the spacing are based on the available site-specific data. Open ditches are maintained once a year after crop harvest and require periodic cleaning and weeding.

Drainage by beds, also known as **bedding**, is similar to an open W-shaped drainage with one difference; it has a higher crown and a narrower gap between the drains. Bedding is generally preferred in areas of high rainfall and fairly level fields.

In the third type of system, the land is smoothened to remove minor ridges and depressions, and given a uniform slope without changing the topography. This is called **smoothing** which facilitates surface water flow toward ditches. Soil surface smoothing takes at least two years to construct and has to be repaired annually.

Surface ditches can be constructed easily and quickly at a relatively low cost to remove gravitational water. But sometimes this approach is unsuitable. **Open ditches** occupy land that could otherwise be put to productive use, could be inconvenient for the use of machinery on the field, and could harbor rodents and other pests that endanger crops. Open ditches need proper maintenance to keep at bay, weeds and sediment deposits. (See also Drainage.)

Surface irrigation: See Micro-irrigation

Surface mining: See Fertilizer raw material and feedstock

Surface run-off

Surface run-off is that part of water which runs over the soil surface to reach the nearest stream or water channel without entering the soil. There also exists ground-water run-off or seepage flow from ground water where water enters the soil before reaching the stream.

Surface sealing

A surface seal is the process by which dispersed soil particles, detached from soil aggregates, settle back on the surface of the soil, in such a way as to make the soil pores impermeable. The surface layer that gets formed on the soil is called a crust.

Soil aggregates get dispersed due to heavy rainfall. Sealing and crusting occur in the sub-humid to semi-arid tropics especially western, eastern and southern Africa and parts of Asia, where land is bare and rainfall erratic and heavy. Sealing leads to rain water running off laterally because it cannot penetrate the soil. This leads to erosion and a risk of further denudation of land. Sealing hampers the emergence of seedlings because of the hard surface crust. Such lands cannot be put to use productively even though their sub-surface layers may have a healthy capacity to store water. Sealing and crusting also helps the formation of an oxygen-deficient layer under the crust. Rainfall and sprinkler irrigation often forms a surface seal crust especially when the soil is bare. (See also Crusting.)

Surface tension

Surface tension is the property of the surface of a liquid to resemble an elastic membrane tending to minimize its area. Surface tension is defined as the force perpendicular to the line of unit length drawn on the surface.

Molecules on the surface of a liquid are subjected to the forces of attraction of molecules below the surface. This inward pulling force is balanced only by the resistance of the surface molecules to compress. This phenomenon tends to decrease the surface area. Forming of water beads on a leaf is a common example of surface tension. Water turns into a near-spherical shape since a sphere has the smallest possible surface area to volume ratio.

Polar liquids have high surface tension (water = 73 dynes/cm at 20°C) and non-polar liquids have much lower values (benzene = 29 dynes/cm). Thus, they flow more readily than water. This property is used in the preparation of emulsions and dispersions of fertilizers, pesticides and insecticides for application on plants.

Surface treatment

Surface treatment, also known as **external conditioning** or coating, is the process of applying a thin layer of powders or surfactants to the fertilizer granule surface to reduce its caking tendency. The treatment improves the free-flow characteristics. (See also Coated fertilizers.)

Surface water

Surface water is the water that does not seep through the soil, but finds its way to streams, rivers, drainage channels, etc. It is the main source of water for most agricultural, industrial and domestic purposes.

The flow of many streams and rivers exhibits wide seasonal and annual fluctuations. The peak water demand from major rivers often occurs when they have a minimum flow in the basin. Therefore, reservoirs are constructed to store water during seasons of good flow. These reservoirs incorporate hydroelectric flood control and recreational features for meeting the demand of water. Frequently, the income from electrical power subsidizes the water supply.

The surface water composition varies with the terrain through which water flows. The main pollutants of surface water are compounds of nitrates and phosphates in the soil, and effluents from chemical plants. This can lead to ecology of water bodies getting rich in nutrients and thereby supporting a dense plant population (the decomposition of which kills animal life by depriving it of oxygen).

Surfactant adjuvant

Surfactants, also known as **surface active agents**, are compounds that reduce the surface tension (when in water or water solution) and the interfacial tension between two liquids or between a liquid and a solid. There are three categories of surface active agents - **detergents, wetting agents** and **emulsifiers**.

Surfactant adjuvants are one of the four subtypes of adjuvants. The following are examples of the three surfactant classes: (i) **Anionic**. Sodium stearate $C_{17}H_{35}COO^{-}Na^{+}$. (ii) Cationic. Cetyltrimethyl ammonium bromide $C_{16}H_{33}(CH_3)_3N^{+}Br^{-}$. (iii) Non-ionic. Poly (ethylene oxide) laurylalcohol $C_{12}H_{25}O(CH_2 \cdot CH_2O)_{23}H$. (See also Adjuvant.)

Surfactant, anionic: See Adjuvant

Surfactant, cationic: See Adjuvant

Surfactant, non-ionic: See Adjuvant

Suspension: See Suspension fertilizers

Suspension fertilizers

Suspension refers to a phenomenon in which very small particles (solid, liquid or semi-solid) remain suspended more or less uniformly in a medium.

Suspension fertilizers are two-phase fertilizers in which solid particles, such as plant nutrients, are maintained in suspension in an aqueous phase with the aid of a suspending agent like clay. The solids may be either water-soluble or insoluble, or both. Solid nutrient salts such as potassium chloride, suspended in a concentrated ammonium polyphosphate solution is an example of suspension fertilizer. Fertilizers of this class tend to sediment on standing, so their storage and applicability is more difficult than that of clear liquid fertilizers. Mechanical agitation may be necessary in some cases to facilitate a uniform suspension of undissolved plant nutrients. The sedimentation rate depends on the size, density and shape of the suspended crystals as well as the density of the solution phase, its viscosity and the strength of the gellant present in the solution. Suspension fertilizers may contain the same source of micronutrients as dry fertilizers. Even if they are precipitated they still remain in suspension and can be distributed uniformly in the mix.

Suspension fertilizers have the following advantages: (i) There is no segregation of particles, if well agitated. (ii) Labor is saved since one man can operate a tank. (iii) Secondary nutrients and micronutrients from relatively inexpensive sources can be mixed with the fertilizer. (iv) Herbicides and insecticides can be blended satisfactorily. (v) High-analysis grades can be formulated, since salting out is no problem.

However, suspension fertilizers are not easy to handle. They need agitation and suitable pumps and nozzles when fluids are viscous.

Fat particles in milk and red blood corpuscles in blood are some examples of suspended particles. A liquid-in-gas suspension is represented by fog or by an aerosol spray. If particles are larger than colloidal dimensions they tend to precipitate, which can be prevented by the incorporation of protective colloids. Sometimes, polymerization reactions are carried out in suspension.

Sustainable agriculture

Agriculture is the main source of livelihood for more than half of the world's population and its growth catalyzes broad-based economic growth and development, especially in low-income countries.

Agricultural growth and development must be vigorously pursued to (a) alleviate poverty through employment creation and income generation in rural areas, (b) meet the growing food needs of the increasing population, (c) stimulate overall economic growth, and (d) help conserve natural resources.

Profitability of farming must remain an incentive for the farmer. He must feel encouraged to increase agricultural produce to make farming a sustainable proposition. However, there are many reasons why the farmer considers yield enhancing investments risky, especially in developing countries. He fears that the (a) yield may fall below expectations owing to disease or adverse weather conditions, (b) bumper crops may depress prices in a free economy, and (c) authorities may resort to non-imposition of support prices or restrictive maximum prices.

Food production is a function of crop yield per hectare, number of crops per year, and extent of cultivated area. Sustainable food production implies that available resources are used efficiently and equitably. Resources imply the availability of (a) land, water, nutrients and energy, (b) technology, machinery, irrigation, transport facilities and plant protection measures, and (c) knowledge - its generation, maintenance, transfer and adaptation - in agricultural management practices. The development and sustainable use of these resources depend on the economic policy framework and laws relating to land ownership, farm income, taxation, trade, access to technology and markets.

Sustainable agriculture is a system that can evolve toward greater human utility, greater efficiency of resource, and a better balance with nature. Sustainable agriculture leads to improved profits, better protection of the environment and benefits to the community. It enhances the quality of life of farmers and society as a whole, but may not always entail a rigid set of practices because farms form an integral part of our environment. Farming systems differ from region to region because of differences in climate, agricultural conditions and the level of development.

It is necessary to consider long-term implications of farming practices which may vary from one place to another. Food production can be increased on a sustainable basis only when economic policies are pursued in such a way as to make sustainable management of agriculture possible and attractive. Organic farming is an example. For many years, organic gardeners have been growing plants and animals without chemical fertilizers and pesticides. **Slash and burn agriculture**, a self-sustaining system, is ecologically sound, provided the population does not make fallow periods too short for re-generating the soil. Crop rotation and other crop management practices have resulted in fairly satisfactory control of pests and fairly satisfactory yields in the nineteenth century.

Crop production research in the area of self-sustaining agriculture has also produced promising results.

Experts often find that a solution to one problem sometimes creates another more difficult problem. While pursuing sustainable agriculture, they are concerned, for instance, about food contamination from harmful chemicals. Technology and fertilizer use have brought apparent abundance to millions, yet millions remain as impoverished as ever. Significant movement toward and the acceptance of the restructuring of agriculture to a sustainable mode will require a change in the society's choice indicators. That is, the total cost of production must include the off-site costs, such as environmental damage. Desire for economic profit in the short term will need to be tempered by a greater concern for the quality of life in the long term.

S value

The S value represents exchangeable metallic cations held on the adsorption complex and the total quantity of the alkali metal ions (K^+ and Na^+) as well as the alkaline earth metal ions (Ca^{2+} and Mg^{2+}) to be effectively retained in the soil for a defined period.

Swale

Swale refers to the terracing of hillsides for the purpose of halting run-off water and preventing the erosion. With the use of simple levelling tools, made from bamboo and a plumb line that uses a rock as a weight, it is possible to dig swales while following the contours of hillside slopes. The U.S. government, during the 1930s, put in many large swales in the arid regions of the western states. These landforms may be seen even today, working correctly after so many decades.

Swamp gas

Swamp gas, also known as **marsh gas**, is a mixture of methane and carbon dioxide. Alternatively, **methane** itself is also sometimes called swamp gas or marsh gas.

Swamp podzol

Bluff podzol is alternatively known as swamp podzol. **Podzols** are soil groups with zones of illuviation. They are distinguished from strong E horizons, by accumulations of iron, aluminum and humus in the B horizon, like the spodosols in soil taxonomy.

Sweet rice: See Glutinous rice

Sweet soil

Sweet soil is fertile alkaline soil, as distinct from sour or infertile acidic soil.

Sylvinite

The most abundant potash mineral deposit is **sylvite** (KCl). Sylvite and **halite** (NaCl) form a common potash ore, called sylvinite. In nature, fairly pure sylvinite exists, which contains 10 to 20% potassium but no soluble sulphate or other salts.

Sylvite and halite crystals of sylvinite contain significant amounts of gases under high pressure. The potassium (KCl) and sodium chloride (NaCl) crystals are separated based on the difference in their specific gravity. The specific gravity of halite is 2.13 g/cc and of sylvite 1.9 g/cc. The thermal dissolution of the crystallization process is also used to separate potassium chloride from sodium chloride because potassium chloride is much more soluble in hot water than in cold water compared to sodium chloride.

Sylvite

Sylvite (KCl) is the most abundant potash mineral deposit. It contains about 43% potassium chloride, 57% sodium chloride with upto 0.26% bromide. (See also Sylvinite.)

Symbiosis of plants with bacteria and fungi

When two dissimilar organisms live together closely and interact with each other to mutual benefit, the phenomenon is called symbiosis. A well-known example is **lichens**. Many symbioses are obligatory in that the participants cannot survive without beneficial interactions. For example, lichen is an obligatory symbiotic relationship between algae and fungi. Symbiotic organisms offer their host some benefit in exchange for energy or any other benefit it takes from them. Lichens colonize rocks, tree trunks and exposed soil surfaces; algae and blue-green bacteria photosynthesize and fix nitrogen, while fungus provides water and mineral nutrients. Bacteria and protozoa that live in termites' guts assist in nitrogen and cellulose digestion in return for the benefit of wood chips they have received. Symbiotic organisms have to be viewed in contrast with parasites or pathogens which necessarily produce harmful effects on the host in exchange for a benefit.

The best known symbiotic associations between plants and micro-organisms are of two kinds: (i) Nitrogen-fixing associations with bacteria which supply the plant host with nitrogen from the air. (ii) **Mycorrhizae** which help the plant to get nutrients from the soil.

There are symbiotic associations of plants with bacteria and fungi. In the bacteria-plants symbiosis, two types of associations come into play. Blue-green bacteria associate with plants in the shoot system. The bacteria are photosynthetic and do not take food from the plant which provides them with an enclosed aquatic environment and receives fixed nitrogen in return. Some bacteria form an association with the plant root system. Root exudates supply essential minerals and newly-synthesized substances to the bacteria to fix atmospheric nitrogen for the plants. These bacteria, which have a very short life, decompose when dead, and release ammonium and nitrate ions for the use of the host plant.

Two types of bacteria infect the plant root system. Bacteria from an actinomycetes group, like *Frankia*, form nitrogen-fixing nodules on the roots of different kinds of shrubs and trees. The *rhizobium* bacteria infect the roots of the legume family and form nitrogen-fixing nodules. Cobalt is said to be necessary for these micro-organisms for the fixing elemental nitrogen through the formation of Vitamin B_{12}.

The association between fungi and plants is of two types. One is fungi and algae culminating into the growth of lichens. Algae fix di-nitrogen and fungi provide a protective cover which holds water and supply other nutrients to the algae. The surfaces of rocks and trees are covered by lichen, which is the result of the fungi-algae symbiosis.

The other type of fungi and plant root association is mycorrhizae. The fungi get useful substances secreted by roots and help transport nutrients and water to plant roots. Some fungi cover the roots and penetrate only the outer cell layers of the root walls and are called

ectomycorrhizal fungi. Other fungi penetrate the host root cells and are called **endomycorrhizal fungi** which help in increasing the phosphorus uptake from a low-phosphorus soil. (See also Mycorrhizae; Nitrogen fixation; Nitrogen fixation by legumes.)

Symbiotic bacteria

The bacteria that fix nitrogen in the root nodules of legumes are called symbiotic bacteria; for example, *Rhizobium* sp. There are three groups of nitrogen-fixing bacteria that have a symbiotic relation with plants: (i) Blue-green bacteria colonize in specialized cavities in the shoot system of certain cycads and ferns. (ii) *Frankia* spp. is a group of actinomycetes that infect roots of shrubs and trees of many genera, forming nitrogen fixing root nodules. (iii) *Rhizobium* and *Bradyrhizobium* bacteria that infect roots of plants of the legume family, form nitrogen-fixing root nodules.

Fixation rates of up to 500 to 600 kg nitrogen per ha have been estimated for nitrogen fixing rhizobia, though fixation of 50 kg N/ha is very common. A clearer subdivision of rhizobia is based on the growth rates and correlated properties. It produces two groups, namely, slow growers and fast growers. Within each group there are hundreds of known strains, which perform differently in different host species (See also Nitrogen fixation by legumes.)

Symbiotic nitrogen fixation

Symbiotic nitrogen fixation, mostly seen in legumes, is the fixation of atmospheric nitrogen in soil by symbiotic bacteria, such as rhizobia, by forming root nodules. This is also referred to as **biological nitrogen fixation**. Bacteria form nodules (containing leghemoglobin) on the roots of the legume plant which is the site of nitrogen fixation by bacteria. The enzyme involved in nitrogen fixation is called **nitrogenase** which mediates the reduction of nitrogen to ammonia. (See also Nitrogen fixation by legumes.)

Symplast

Symplast is a translocation pathway of a plant that consists of phloem, plasmodesmata and living matter of the fundamental tissue.

Symplast is a system of interconnected protoplasts in a plant. A cell wall possesses minute pores through which plasmodesmata can pass, plasmodesmata being narrow threads of cytoplasm passing through the cell walls of the adjacent plant cells and allowing communication between them. Water and other soluble material in the cytoplasm of a cell can move through the symplast, bypassing other membranes. A symplast is a more important pathway than the vacuolar pathway.

Symptom

Symptom is a visible or otherwise detectable abnormality arising from a disease. Signs and symptoms differ in medical terminology, the former being visible (objective) indications of a disease and the latter, subjective. The visible structures of a pathogen (pustules, conidiophores, etc) for instance, are the signs of a disease.

Syncarpous

The female reproductive organ of a flower may have a single carpel (termed **monocarpellary**, for example, plum), or several fused carpels (called syncarpous, for example, orange), or many separate carpels (**apocarpous**) as in *Michelia*. (See also Carpel.)

Synclines

A fold or a wave-like form in the layers of a sedimentary rock results from deformations in the earth's crust. The basin-shaped fold in which beds of rocks dip toward each other are known as synclines.

Syndrome

Syndrome refers to the totality of effects produced in an organism, by a disease. The total effect may be seen cumulatively or sequentially, and may include such effects as are not directly detectable to the unaided eye. In the commonly used expression 'disease syndrome', the word disease would thus seem superfluous.

Synecology

Synecology refers to the study of groups and communities of organisms. (See also Ecology.)

Synergist: See Synergistic interaction

Synergistic interaction

Synergism is a phenomenon in which the combined action of two substances (fertilizers, drugs, hormones, etc.) produces a greater effect than the sum total of the individual effect of each substance. A substance that induces this result when added to another substance is called **synergist**.

Synergism is the working together of two or more agencies. When the effect of two or more growth factors on the crop is more than the sum of their individual effects, the interaction is said to be **positive** or synergistic. Typical positive interactions are nitrogen-potassium (N-K) and nitrogen-phosphorus (N-P) interactions.

Synergism (or positive interactions) is in accordance with **Liebig's law of minimum**. In severe deficiencies of two or more nutrients, all fertilizer responses are positive interactions. In general, more benefits are obtained from one input if other factors are improved. The better the plant growth, the more it will respond to fertilization with a limiting nutrient. This general rule is another reason that most productive farms tend to use the fertilizer the most. It also implies that improvements in crop yield improve the efficiency of fertilizer use, that is, the useful return per unit of the fertilizer applied.

Bacterial synergism is the ability of two or more organisms to bring about chemical changes that are not possible by either of them individually. For example, the ammonia oxidation to nitrate via nitrite is possible only by a combination of *Nitrosomonas* and *Nitrobacter*. The synergistic effect of N and K or P is more than what is produced by the individual nutrient. (See also Positive interaction on crop growth.)

Syngas: See Synthetic crude oil

Synonym

Synonym in the biological context is a taxonomic name for a substance which has the same application as another, especially the one which is superseded and no longer valid.

Synthesis gas

Synthesis gas is a mixture of carbon monoxide and hydrogen. It is any one of several mixtures used for synthesizing a wide range of compounds, both organic and inorganic, especially ammonia. Such mixtures result from reacting carbon-rich substances with steam, and/or a combination of steam and oxygen. They chiefly contain carbon monoxide and hydrogen, plus a low percentage of carbon dioxide and nitrogen ($< 2\%$). The organic source of synthesis gas may be natural gas, methane, naphtha, heavy petroleum oils or coke.

Synthesis gas is made by the nickel-catalyzed steam cracking of an organic source (methane or natural gas or coke).

$$CH_4 + H_2O \longrightarrow CO + 3H_2$$
$$C + H_2O \longrightarrow CO + H_2$$

With transition-metal catalysts, synthesis gas yields alcohols, aldehydes, acrylic acid, etc. It is the basis of OXO and **Fischer-Tropsch reaction**. Synthesis gas from which carbon monoxide is removed and adjusted to a ratio of 3 parts of hydrogen to 1 part of nitrogen is used for ammonia synthesis. The reaction takes place at a high temperature and pressure.

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

Synthetic auxins: See Auxins

Synthetic crude oil

Petroleum, a naturally occurring liquid crude oil, sometimes includes natural gas, and is formed from organic debris. After removing salt and water, petroleum is refined by fractional distillation, producing different fractions such as gasoline, kerosene, diesel oil, fuel oil, lubricating oil and asphalt. The chemical composition of crude petroleum is chiefly alkanes, saturated alicyclic compounds and aromatic compounds with some sulphur compounds, oxygen compounds, nitrogen and salt.

Coal is also an important source of chemical raw materials. Coal when treated with oxygen and steam at high temperatures, tends to break carbon-carbon bonds to give carbon-hydrogen and carbon-oxygen bonds. The desired product of this coal gasification process is **syngas**, a mixture of hydrogen and carbon monoxide. These mixtures can be converted to synthetic hydrocarbons similar to that obtained from petroleum. Pyrolysis or distillation of coal also yields coal tar and **hydrocarbon gases** which can be upgraded by hydrogenation to synthetic crude oil.

Synthetic magnesite

Synthetic magnesite is a term loosely used as a synonym for magnesia. It is similar to magnesite, **caustic-calcined magnesite** and **dead-burned magnesite**.

Synthetic manure

Compost produced primarily from plant residues is called **artificial manure** or synthetic manure. (See also Compost.)

Synthetic natural gas

Synthetic natural gas is a fuel of approximately the same composition and heat value as that obtained naturally from oil fields.

Synthetic natural gas is made by two methods: (i) Direct hydrogenation of coal. (ii) Methanation of synthesis gas which is obtained by hydrogenation of coal or steam-reforming of naptha or similar petroleum distillate. The other methods are pyrolysis of solid wastes and extraction from oil shale and manures.

Synthetic soil conditioners

Soil conditioners are substances added to the soil in small quantities to improve its structure. These can be optimized though the substrates which are not ideal for plant growth. The purpose of soil conditioners is to exert biotic, chemical or physical influences on the soil in such a way as to improve its structure, water regime, etc.

A synthetic soil conditioner has a well-defined composition, stable quality and properties to suit the soil requirements. The farmer may, for example, supplement or replace natural substances with synthetic substances, if natural substances are unsuitable from the environmental and ecological standpoint, or are in short supply and warrant conservation.

Synthetic conditioners include foams, **colloidal silicates**, polymer dispersions, polymer emulsions and **tensides**. Foamed **polystyrene** and **urea-formaldehyde resins** are used as soil conditioners. Foamed phenolic and **polyurethane** resins are used as **florists' mounting media** or **plant growth media**. Foams used as soil conditioners are flakes, beads or raspings. They are used for incorporating into soils and garden substrates, or for conditioning the weak-structured peat. When incorporated into a soil, foams loosen and aerate the soil, and improve the draining action. Foams are also used as soil conditioners in crop farming and landscaping and as filter materials for covering drain pipes. For soil aeration and structural stabilization around the roots of urban trees, a closed cell of expandable polystyrene foam beads (1 to 2 mm diameter) is recommended.

An open cell urea-formaldehyde foam is made water-absorbing by modifying the condensate resin and converting it into flakes, measuring 4 to 20 mm in diameter. The water-absorbing capacity is more than 90% by volume under vacuum. The water release is uniform and completed without losses due to evaporation, so that plants can economically utilize the water stored in the foam flakes. The water is held in place by suction forces.

In terms of soil physics, urea formaldehyde foams enhance the pore volume, plant-available water capacity and aeration, and lower the soil density. Plants respond with an improved shoot and root growth, and an increased crop yield of superior quality.

Urea formaldehyde foams are biodegradable by soil bacteria, whereas polystyrene foams are not. For reasons of cost, their applications are mainly in the areas of garden crops (such as pot and container plants), cut flowers (carnations, chrysanthemums), flower bulbs, fruits, vegetables and eucalyptus. They are also used in golf courses and for landscaping where foams are used in newly-seeded lawns and woods, They are used while transplanting large trees.

Colloidal silicates are solid, fine-grained, and thus easily distributable with water to form **silica gels** and **sols**. When they are incorporated into the soil, they fill the voids between soil particles and bind them together with organic and inorganic complexing agents to form water-stable crumbs. Pore distribution takes place in this process. The chemical activity is ascribed to the low molecular weight silica sols. In soils, colloidal silicates hold phosphate in solution; its activation by desorption can irreversibly fix heavy metals, depending on the soil pH.

The action of colloidal silicates as soil conditioners depends on their ability to take up water; their quantities should preferably be 10 to 15 kg/100 m^2. In gardening and landscaping, they have an effective life of 3 to 5 years, their after-effects being seen for 10 to 14 years.

Colloidal silicates include compounds of polysilicic acid, synthetically produced and stabilized with a high content of reversibly soluble silicic acid and a small quantity of added flocculating electrolytes.

Agrosil colloidal silicate consists of (a) partly dehydrated sodium silicate precipitated with acids, (b) electrolytes (phosphate, sulphate), and (c) organic additives to retard aging.

Soil conditioners improve the (a) water sorption capacities and activation of plant nutrients in the soil, (b) soil structure through pore redistribution and crumb formation, and (c) fixing of heavy metals (such as Cd, Cu, Pb and Zn) in the presence of alkaline earth metals. These are all direct effects.

The indirect effects are that soil conditioners (a) improve soil life and release excess water, (b) accelerate phosphate mobility, (c) cause the growth of new shoots and roots, (d) enhance the accumulation of both organic and inorganic substances in the vegetation, (e) reduce the use of water and reduce the wilting of grass, and (f) increase resistance to fungal and bacterial diseases.

Among the chemicals used as soil conditioners are polyvinyl acetate (Curasol), polyvinyl propionate, butadiene-styrene copolymer, cis-butadiene and various acrylic acid polymers in aqueous solutions, known as polymer dispersions or emulsions. The cross-linked particles of the uppermost soil layer and the active agent form the closed film-like coatings. Though these are permeable to precipitation, they diminish evaporation. Their incorporation into soil also promotes crumbs. All these polymer dispersions (as organic substances on the soil surface) are degraded quickly by UV-radiation and microbial action. Thus, their action is limited, their stability depending on ambient conditions.

Polymer dispersions are employed chiefly for seed protection (in landscaping) and for healthy growth of vegetables and flower-bulbs. These are applied at planting time by spraying with fertilizers and soil conditioners or mulches (cellulose, straw) and can also be applied after planting. The quantities used depend on the product, ranging from 10 to 50 g/m^2 diluted with water between 1:1 and 1:60 (which is the product to water ratio). The protective action of the polymer dispersion depends on the quantity used and on environmental conditions.

Polyacrylates (aqua-gels) and polyacrylamides (**soil tex G1**) are used alone, or with starch, to promote water storage in soils. The water holding effect, however, varies with the pH, water hardness and dissolved substances, such as soil nutrients.

Polymer formulations are used, especially in conjunction with sprouting seeds and small plants, for protection against erosion by wind and rains. They are important in furrow irrigation systems because they prevent soil erosion and increase water infiltration into the soil. A concentration of 10 ppm of polymer dispersions in irrigation water is essential to achieve the desired effect. Biodegradability of the polymer is a prerequisite for any soil and plant application.

Systematic error

Two types of errors are known, systematic error and random error. Systematic error or determinate error is one which occurs in the same direction each time; it is either always high or always low. The second type of error is called random error which means that a measurement has an equal probability of being high or low. This type of error occurs while estimating the value of the last digit of a measurement.

Systematic sampling

A sample is a small representative portion, taken from a large quantity of material like water, soil etc., such that its chemical analysis can be taken as that of the entire material. In systematic sampling, individual samples are chosen at fixed intervals of the relevant parameter; for example, picking every tenth animal in a population can give a systematic sample of that population.

Systematic symptoms

Symptoms appearing on sites other than at the site of inoculation, are called systematic symptoms. These are usually seen in leaves produced subsequent to inoculation. Systematic symptoms are usually seen in viral diseases.

Systemic fungicides

Fungicides are substances which kill or inhibit the growth of fungi. There are systemic fungicides and **non-systemic fungicides**, although there can be some in-between categories also. Systemic fungicides enter plant tissues and are transported in the plant sap. They may be transported upward (**acropetal translocation**) or downward, from the leaves to the roots (**basipetal translocation**). These compounds usually inhibit fungal growth after the pathogen penetrates the host tissues and thus have curative properties.

Systems approach

A system refers to a set of connected things or actions, forming a complex while working together as parts of a mechanism or an interacting network. Systems approach refers to the study of a system with all its components and their interrelationships together with consideration of their interplay with work ethics and environments. To predict whether a process is spontaneous or not, the entropy changes that occur both in the system and its surroundings must be considered.

Systems analysis involves the analysis of a complex process or operation in order to improve its efficiency, generally by applying a computer system, and is also called operations research. **Operations research** involves a mathematical analysis for providing a quantitative basis for management decisions.

The systems approach can be applied to problems ranging from very simple to so complex that human minds are unable to comprehend the behavior of the system. An example of a simple problem is to schedule the watering of plants in a garden. A more complex system problem, however, may relate to controlling the timing of thousands of traffic signals. The techniques of systems engineering have been applied to a large range of current problems, from industrial automation to the control of weapons and space vehicles.

Systems ecology

Ecology is the science dealing with the totality of interrelationships of living organisms with the external environment. Mathematical concepts have permeated the basic foundations of ecology and have provided a means of exploring, both qualitatively and quantitatively, the interrelations at several levels. This new branch of ecology is known as systems ecology.

The Fertilizer Encyclopedia
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The FERTILIZER ENCYCLOPEDIA

T

Tagged atom: See Tagging

Tagged compound: See Tagging

Tagging

In common parlance, tagging means putting a label or a tag on an object for identification. But in the world of science, it has a different meaning which is given below:

The process of replacing a stable atom in a compound with a radioactive isotope of the same element (to be traced by the radiation it emits) is known as tagging. This method is useful for following the path of the compound in a biological or mechanical system using stable isotopes and a mass spectrometer or a Geiger Muller scintillation counter.

Radioactive isotopes that used to follow an element through a sequence of changes are known as tags or **labels** or **tagged atoms**. Carbon 14, iodine 131, phosphorus 32, etc. are examples of tagged atoms. Radioactive forms of iodine and sodium are used as **tracers** which have applications in the field of agriculture, industry and medicine.

A compound containing a radioactive or stable isotope is called a **tagged compound** or a labeled **compound**. A radioactive labeled compound behaves chemically and physically in the same way as an otherwise identical stable compound and its presence can be detected by a Geiger counter. This method of radioactive tracing is widely used in chemistry, biology, medicine and engineering. For example, to follow the path of super phosphate in a soil or plant system, the fertilizer is tagged with phosphorus isotope ^{32}P.

Tail gas of nitric acid plant: See Nitric acid production processes

Talc

Talc is a natural hydrous magnesium silicate [$Mg_2Si_4O_{10}(OH)_2$] or $3MgO.4SiO_2.H_2O$. It scores 1 on the Mohs' scale of mineral hardness. It occurs in many forms, from foliated to fibrous masses. Its compact massive varieties may be called stealite, which are distinct from the foliated varieties, commonly referred to as talc. Soapstone is an impure variety of stealite.

T and V system in agriculture

T and V system is short for **training and visit system**. (See Benor system of training.)

Tankage

Tankage is processed animal refuse from slaughterhouses, farms, etc. Refuse is treated with steam under pressure for removing water and some of the grease. The fat is removed by solvent extraction and further pressing. The final product is a dried and ground material made out of bones and meat of dead animals.

Tankage garbage contains 3 to 4% ammonia, 2 to 5% phosphoric acid and 0.50 to 1% potash, depending on the proportion of bones in the source.

Tapped bulk density

Tapped bulk density, also called **tapped pour bulk density**, is the mass per unit volume of a substance tipped into a container and then compacted under clearly specified conditions. It represents the **maximum bulk density** expected. (See also Bulk density of fertilizer; Density.)

Tapped pour bulk density

Tapped pour bulk density is another term for **Tapped bulk density**.

Taproot

Taproot is a central, dominant root that normally grows vertically and from which most or all of the smaller roots spread out laterally. It can also be a root tissue that commonly stores carbohydrates and may form adventitious buds for regeneration (See also Root.)

Taranakite

Taranakite represents a group of products formed by phosphorus fertilizers reacting with soil constituents. For example, ammonium aluminum phosphate with the structural formula $Al_5(NH_4)_4HO(PO_4)_6 \cdot H_2O$, is called ammonium · taranakite; if ammonium is replaced by potassium ion (K^+), it becomes potassium taranakite.

Targeted yield from soil

Targeted yield, from a soil is the best yield under the given circumstances. Targeted yield also called **optimum yield**, depends largely on quality of the soil and the adequacy of nutrients for the crop.

The relationship between the **soil test** results and the crop response reveals the quantity and quality of nutrients that are essential. Targeted yield depends on many factors such as climate, soil, plants, and their interactions. These factors vary from region to region, crop to crop and cultivar to cultivar. Sound knowledge of agronomic, environmental and physiological factors is required to achieve targeted yield, without losing the sustainability of the agricultural system.

To ensure the targeted yield, certain good management practices should be followed. They include (a) proper use of natural resources with minimum wastage, (b) reduction of adverse effect on the environment, while maintaining or improving farm profitability.

The **yield targeting concept** is used to calculate fertilizer requirement, based on the soil test and knowledge of yield achieved.

The yield target and fertilizer dose are calculated as

$$T = \frac{NS}{(M - R)} \;; \qquad F_d = \frac{RNS}{(M - R)}$$

where T is the yield target in kg/ha, N is the ratio between the percent nutrient contribution from soil and that from the fertilizer, R is the nutrient requirement in kg/ha of grain production, M is the ratio between nutrient requirement and contribution from the fertilizer, S is the soil test value in kg/ha and F_d is the fertilizer nutrient dose in kg/ha. This approach can be used for a given level of crop production.

Taxonomy

Taxonomy is the branch of science concerned with classification of things and of organisms - living or extinct.

Taylor color code

Color is perhaps the most obvious and easily determinable soil property. **Soil color** is important because it is an indirect measure of soil characteristics such as water drainage, aeration and organic matter content.

Soil colors are determined by matching the color of the soil sample with color chips in a Munsell soil-color book. This color code book has pages, each with color chips arranged systematically according to the three variables - hue, value and chroma - that combine to give colors.

Hue refers to the dominant wavelength or color of light. Value or color brilliance refers to the quantity of light which increases from dark to light colors. Chroma is the relative purity of the dominant wavelength of light. The three properties are given in the order: hue, value and chroma. For example, in the notation, 10YR 6/4, 10YR is the hue, 6 is the value and 4 is the chroma. The color is light yellowish brown. The color system, as proposed by Taylor, is useful in communicating accurately, the color of a soil. (See also Soil color.)

TCA cycle

TCA cycle stands for **tricarboxylic acid cycle**. A series of enzymatic reactions occurring in living cells of anaerobic organisms result in the conversion of pyruvic acid, formed by anaerobic metabolism of carbohydrates, into carbon dioxide and water. The metabolic intermediates are degraded by a combination of decarboxylation and dehydrogenation.

The TCA cycle is the major terminal pathway of oxidation in animal, bacterial and plant cells. Recent research indicates that TCA cycle may have provided the pathway for formation of amino acids.

TCP

TCP is short for **tricalcium phosphate**.

TDS

TDS, expressed in terms of electrical conductivity, is short for **total dissolved solids**. TDS gives the total salt concentration in water used for the irrigation of plants.

As conductivity increases from 0.1 dS/m to 2.25 dS/m, the salinity is considered to have increased from a low to a high value. (See also Water quality.)

Teart

Teart refers to the excess of molybdenum in plants or soil. This causes **molybdenosis** in ruminants that graze on teart plants.

Technology transfer in agriculture

As with any other industry, technology transfer (TT) in agriculture, involves the transfer of new and advanced technology and related information required for commercial exploitation. A modern agriculturist needs to be familiar with new inventions and practices for imbibing the 'lab to land' culture.

Training, retraining, practical demonstrations and visits by extension workers to sites where new inventions and practices have been adopted help the TT exercise to succeed. (See also Benor system of training.)

Tee reactor

Tee reactor is another name for **pipe reactor**. It consists basically of a 5 to 15 m long corrosion-resistant pipe in a T shape which gives it the name T (tee) reactor.

The pipe reactor is simple to operate. It eliminates the need for pumping slurries and is fairly inexpensive. The main advantage of a tee reactor is that it can produce more concentrated slurry than a pre-neutralizer, thus requiring lesser process water.

In a simple reaction chamber, anhydrous ammonia and phosphoric acid react to produce a mixture of ammonium orthophosphate and polyphosphates.

Tegmar

Tegmar is a dwarf variety of intermediate wheatgrass. This sturdy, long-living grass is commonly planted along the riverside, since it is resistant to grass mites, and holds the soil together.

It is a winter-hardy plant and needs no maintenance, once established. Tegmar has adapted itself to grow in waterways.

Tegmar is also known as **turkish wheat grass**.

Tegmar, along with other varieties of **intermediate wheatgrass**, is becoming a popular choice of grass for erosion control and as a pasture crop. It is also used in **stubble mulching**.

Temperature

It is very important to know the atmospheric temperature for a variety of tasks. In agriculture, farmers can plan their operations better if they know the temperature in advance.

Hotness of a body depends on the rate at which heat is transferred to or from it. The measure of hotness of a body is temperature. There are several temperature scales, like Celsius (Centigrade), Fahrenheit, Kelvin and

Réaumer, all named after the scientists who devised them. The calibration points of these scales correspond to the melting point of ice and to the boiling point of water.

In Celsius scale, the melting point of ice is taken as 0°C and the boiling point of water, as 100°C. In Fahrenheit scale, the melting point of ice is 32°F and the boiling point of water is 212°F. In Réaumer scale, the melting point of ice is 0°R, whereas the boiling point of water is 80°R.

Kelvin scale is used for expressing the thermodynamic temperture, with the absolute zero temperature 0°K = –273.15°C.

Tempkin's equation for adsorption pattern of phosphorus

Tempkin's equation is used to study the adsorption pattern of phosphorus against its equilibrium solution concentration, and is given by:

$$M = B \frac{RT}{E} \ln FC$$

where M is the amount of phosphorus adsorbed per unit soil weight, R is the gas constant, T is the temperature of adsorption, E and F are constants, C is the phosphorus concentration in solution and B is the constant related to the bonding energy.

The availability of non-labile phosphorus to the plant is slow and dependent on the nature of the adsorption complex at the surface of iron and aluminum oxides. The availability also depends on the type of mineral surfaces, soil pH, cations and anions, the extent of phosphorus saturation, organic matter, the reaction time and temperature.

Tempkin's equation helps to understand the relationship between the quantity of phosphorus adsorbed/unit weight of soil and concentration of phosphorus in the soil solution. The adsorption equation, however, does not say much about either the mechanism of adsorption or the possible dominance of oxides of iron and aluminum, silicate clays or calcium carbonate ($CaCO_3$) in the adsorption reactions. Similarly, such equations do not indicate whether phosphorus adsorption involves the replacement of hydroxyl, silica or carbonate.

Temporary hardness of water: See Hardness

Temporary staining

Staining is a technique in which normally transparent cells or thin sections of a biological tissue are immersed in one or more colored dyes to make them more clearly visible through a microscope. Temporary staining is used for an immediate microscopic observation of a material. In this kind of staining, the color soon fades but the tissue may subsequently be damaged.

Temporary wilting

Wilting of plants is mainly due to water loss through evaporation. On a hot day, plants transpire heavily and cannot absorb water speedily to keep pace with transpiration loss, even when there is enough water. In such a situation, plants wilt temporarily and recover after sundown, which is considered as temporary wilting.

Tenacity test of soil

There are several puddle tests to judge the technical properties of soils. These tests need no equipment. While these are qualitative in nature, they are very useful to farmers.

Tenacity test, one of the **puddle tests**, checks the cohesiveness of soil. In this test, soil is rolled into a cylinder about 300 mm long and 25 mm in diameter. The cylinder is held at its upper end vertically for 15 seconds, such that the lower 200 mm section of the cylinder is unsupported. If the clay supports the cylinder on its own weight, it is considered to have passed the test of tenacity.

Tensides

Soil conditioners are chemicals that are added to soil to maintain the physical condition of the soil or to improve the structure of the soil. Tensides belong to the group of **synthetic soil conditioners**.

Tensides are wetting agents having hydrophobic and hydrophilic properties within the same molecule. Water-repellent organic matter adsorbs on the hydrophobic ends of molecules of the wetting agents and the hydrophilic ends link soil particles with water. When sprayed, tensides increase water absorption and water efficiency of soil.

Some important tensides are ammonium lauryl sulphate, ethoxylated alkyl phenols, polyoxyethylene esters of alkylated phenols, polyoxyalkylene glycols and their polymers, polyoxyethylene, polypropoxypropanol glycol butyl esters, alkyl polyglycosides, sulfosuccinates and polypropylene oxides.

Tensile strength

Tensile strength is the rupture strength per unit area of material subjected to a specified dynamic load. It is usually expressed in pounds per square inch (psi) or kilograms/square centimeter. This definition applies to elastomeric materials as well as certain metals. For textile fibers, strength is measured as tenacity, which is the rupture load divided by the linear density of the fiber.

Tensiometer

Tensiometer is used to measure the matrix potential of soil moisture (Fig.T.1). It is used to schedule irrigation. The principal limitations of tensiometers are that they are effective only from 0 to minus 0.85 bars. Tensiometers are used more commonly in sandy soils than in fine textured ones.

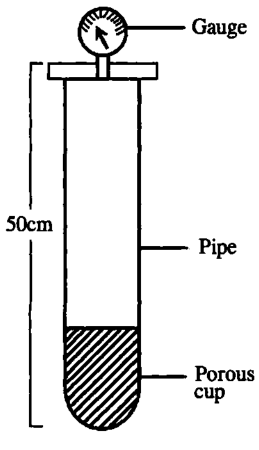


Fig.T.1: A tensiometer.

Terraces

A terrace is one of a series of flat areas on the slope of a hill. It is a level strip of earth usually constructed on or nearly on a contour to make the land suitable for tillage. Terraces in general, prevent erosion, and facilitate cultivation. **Conservation terraces** are innovations to conserve run-off water. Terracing controls soil erosion on a sloping land and intercepts the run-off water before it accumulates at the bottom of the hill.

Depending on how and where they are built, conservation terraces have many different names (Fig.T.2). They do not look like terraces on steep mountainsides in Southeast Asia. Terraces are often combined with grassy waterways to remove excess water.

Fig.T.2: Terracing reduces run-off and controls soil erosion on sloping lands.

A levelled, horizontal strip of earth constructed on the contour of hillsides, known as terrace cultivation, is used for growing crops.

Sometimes banks or walls are built to hold soil in place. These also help to hold water in the field, where paddy is grown. To ensure that water does not accumulate and overflow, causing an avoidable damage, terraces have to be designed and maintained with care.

Tertiary structure

The 3-dimensional shape of coiled or pleated polypeptides is called a tertiary structure. The tertiary structure accounts for the second, repeat distance of 5.1 Å, for α-keratin. Linus Pauling has suggested that each helix can itself be coiled into a super helix, which has one turn for every 35 turns of the alpha helix. Six of these super helixes are woven around the seventh, straight helix to form a seven-strand cable. (See also Protein.)

Terzaghi and Peck method for sticky limit of clay

Terzaghi and Peck designed a method for checking the sticky limit of clay. Suitability of clays can be estimated by **puddle tests for soil**. They do not use empirical data and are more often than not, tests of judgement. One of these tests is the **sticky limit** test, in which clay is mixed with water in such a way that it remains plastic and sticks to a dry spatula blade. It is then allowed to dry up. The moisture content at the point when the tool no longer picks up the clay is the Terzaghi and Peck sticky limit.

Test sample of soil

The test sample of a soil should ideally represent all characteristics of the soil. The test sample is a representative part of the final sample prepared by an appropriate method for a particular test. To avoid a sampling error, the sample should be collected from a sufficiently large field, usually a four hectare field.

To evaluate the variability of soil parameters, intensive soil sampling is essential. This calls for sampling from 20 to 25 locations in the field. Samples from each area are mixed well to form a composite sample before they are sent for laboratory analysis. For small fields, a minimum of 8 places should be sampled, while in very large fields, at least one site within every 2 to 3 hectares should be sampled. For cultivated crops, samples are taken from the depth of the tillage (at 15 to 30 cm). With no-till or minimum till, it is best to take a set of surface samples (at 5 cm depth) and another from a 5 to 20 cm layer. In a low rainfall area, soil is sampled at a depth of 60 to 200 cm to measure the nitrate (NO_3^-) content and the moisture profile.

From randomly selected samples, the distribution and standard deviation can be estimated using statistical methods. It is possible to conclude the representative nature of a particular sample and the significance of its deviation from the sample mean, standard deviation, standard error and standard error of difference.

Test weight as a measure of grain yield

Test weight as a measure of the grain yield is the weight of 1000 grains of test material. It is also called the **thousand-grain weight**.

In bigger-sized grains, fewer seeds are considered adequate. For example, 100 grains of cowpea weigh 140 g whereas 1000 grains of rice weigh 22 g. The weight of a measured volume of grain, known as the test weight, is a traditional quality factor in the grading of grains. On the metric scale, the test weight is expressed as kg/hectoliter (Fig.T.3).

The yield components in cereals are the panicles or ears/unit area, the number of spikelets/panicles or the weight of the ear and the spikelet. In legumes, the number of pods/unit area, grains per pod and the weight of the

Fig.T.3: A fewer number of seeds is considered for test weight in the case of bigger-sized seeds.

grain determine the yield. In tuber crops (potato), the yield development is the product of three distinct factors, namely, the number of stems, the number of tubers/stem and the average tuber weight. In forage plants (alfalfa), the yield components are the plants/unit area, the shoots/plant and the yield/shoot.

In cereals, the relationship between the yield and its components is:

Grain yield = No. of panicles or ears/m^2 or no. of spikelets/panicle or ear × 1000 grain wt (g) × filled spikelet (%) × 10^{-5}

In order to reach a target of rice crop to produce 6 t/ha grain yield, for example, it is necessary to have a combination of the following components: 400 panicles/m^2, 80 spikelets/panicle with 85% filled spikelets, and wt of 1000 grains, 22 g.

$$\text{Grain yield (t/ha)} = 400 \times 80 \times 0.85 \times 22 \times 10^{-5} = 6$$

A low test weight in wheat is associated with a low flour yield. Packing efficiency (grain volume expressed as a percentage of the container volume) is closely related to test weight. The test weight is a product of the kernel density and the absolute volume of the container.

Texaco method for coal gasification for ammonium production: See Ammonia production processes

Texaco process for ammonia production by partial oxidation: See Ammonia production processes

Textural classes of soil

Texture is the physical structure of a solid or semi-solid material that results from the shape, arrangement and proportion of its components. The term is used in the textile industry to characterize fabrics of various types and in the food industry to describe quality characteristics of bakery products, margarines, meats, spun proteins, etc. It is also regarded by geologists as a property of rocks and soils.

Textural class is a defined range of particle size distributions with similar behavior. Textural classes of soil are mainly determined by the particle size. The USDA soil **textural triangle** was designed so that any combination of a particle size could be included within a textural class. In this classification, only mineral particles of less than 2 mm diameter are considered whereas organic matter is not considered at all.

Sand (coarsest particles), *silt* (*medium-sized* particles) and clay (finest particles) are the major textural classes of soil. The textural classes may be modified by the addition of suitable adjectives, when coarse fragments are present in substantial amounts, 'stony silt loam' or 'silt loam stony phase', to name a few.

Determination of a soil textural class is done either in a laboratory or on the field. Laboratory techniques involve (a) passing a soil sample through netted sieves that separate the larger particles, and then (b) separating the silt and clay components by monitoring the rate at which they settle to the bottom of a cylinder, which contains water and a dispersing chemical. The heaviest particles settle first and the smallest last. Measuring the density of the solution at specified time intervals permits an analyst to determine the proportion of solids of a given size. (See also Soil texture.)

Textural triangle

The textural triangle is used as a general guide to determine the soil textural class after the percentages of sand, clay and silt are established after laboratory analyses. Each corner of the textural triangle represents 100% of a size fraction: sand, silt and clay (Fig.T.4).

Each side of the triangle represents a major textural class, beyond which classes in between are represented. Within the triangle, the areas that are labeled are the allowable combinations of the three-size separates – sand, silt and clay. For each textural class, the names are indicated. For example, a sandy loam may have no more

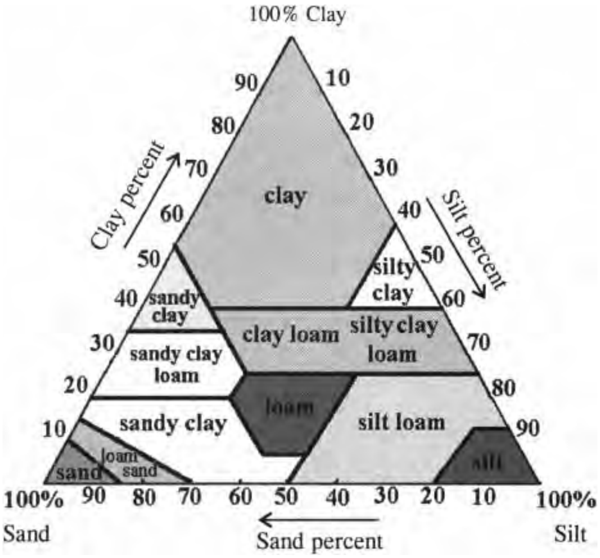


Fig.T.4: Triangle of soil textural classification for particles less than 2 mm size.

than 10 percent, about 65 percent sand and about 25 percent silt. Loam and clay have a specific range of sand, silt and clay. A clay texture must have 40 percent clay and may have as much as 40 percent silt or 45 percent sand. A loam may have 7 to 27 percent clay, 28 to 50 percent silt and 23 to 52 percent sand. In the classification and mapping of a soil, names of the fragments precede the textural name of the soil. For example, if a sandy loam contains over 20% gravel, the textural name becomes 'gravelly sandy loam'; if it contains more than 50% gravel of the soil weight, it is known as 'very gravelly sandy loam'. (See also Soil texture.)

Theoretical field capacity of a machine

Theoretical field capacity of a machine is defined as:

$$\text{Theoretical field capacity} = \frac{S \times W}{8.25}$$

where S is the speed (m/h), and W is the width of the machine in meters. (See also Efficiency; Field capacity of a machine.)

Thermal decomposition

Decomposition is the process by which a substance breaks down into simpler substances with the evolution or absorption of heat. For example, water breaks down into hydrogen and oxygen, calcium carbonate into calcium oxide and carbon dioxide.

$$CaCO_3 \overset{\Delta}{\rightleftharpoons} CaO + CO_2$$

Decomposition can be electrolytic, bacterial or enzymatic, or just a reaction, brought about by heat and light.

The decomposition of a substance by heat in the absence of air is known as thermal decomposition. For example, coal heated between 350 to 1000°C, in the absence of air, undergoes thermal decomposition to give coal tar, coal gas, charcoal and carbon. Coal gas is used for ammonia synthesis.

Pyrolysis or **destructive distillation** also falls under thermal decomposition.

Thermal dissociation

Dissociation is the reversible decomposition of molecules into two or more simpler fragments, atoms, radicals or ions. When heat induces the **dissociation**, it is called thermal dissociation.

$$2HI \xrightarrow{\Delta} H_2 + I_2$$

Thermal pollution

Thermal pollution refers to the release of excessive heat, which pollutes the environment. For example, when warm water from cooling towers of a power plant is let off into rivers and lakes, it is a case of thermal **pollution** in an aquatic environment. Such pollutants mostly emerge from industrial plants.

Thermal profile

Over the years, as land surfaces on earth are exposed to various natural forces (such as extreme temperatures, rains, flooding, etc.), many changes take place on the surfaces. Thermal profile is an aspect of soil which represents the soil temperature fluctuations in various seasons. It is created by plotting the temperatures along the X-axis and the depths along the Y-axis. Depending on the time of the year and by selecting the characteristic temperatures, a thermal profile of the soil is obtained. (See also Soil profile.)

Thermic

Thermic is a soil temperature regime where the average temperature at 50 cm depth is between 15 to 22°C and there is more than a 5°C difference between the mean summer and the mean winter soil temperatures.

Thermic potential is the difference between the absorption power (which is the ability of soil to store heat) and the emissive power. Isothermic potential means the same difference when the summer and winter temperatures differ by less than 5°C.

Thermic potential: See Thermic

Thickening agent

A variety of hydrophilic substances act as thickening agents to increase the viscosity of liquid mixtures and solutions, and their emulsifying properties. Thus, these agents aid in maintaining the stability of the mixtures or solutions.

Four types of thickening agents are known: (a) starches, gums, casein, gelatin and phytocolloids, (b) semi-synthetic cellulose derivatives like carbon methyl cellulose, (c) polyvinyl alcohol and carboxy vinylates, and (d) bentonite, silicates and colloidal silica. The first group is widely used in the food industry especially in ice creams, confectionaries, gravies, etc. The other major consumers, are in the paper, adhesive, textile and detergent industries.

Thickening of slurry

Thickening of slurry is the process of obtaining a concentrated slurry from a diluted suspension of a solid in a liquid. This method is used in several industries. Sedimentation is one of the methods for thickening slurry.

Thidiazuron

Thidiazuron is substituted urea that is used to defoliate cotton plants. Thidiazuron, which has cytokinin activity, is one of the many harvesting aids needed in agriculture.

Thiobacillus

Thiobacillus is the most important autotrophic group of sulphur-oxidizing organisms. The oxidation of elemental sulphur to sulphate (in soil) can be achieved chemically. It is, however, a much slower process than microbial oxidation. The rate of oxidation of biological sulphur depends on (a) soil microbial population, (b) characteristics of the sulphate source, and (c) soil environmental conditions.

Sulphur-oxidation rate varies from soil to soil owing to the presence of a varying number of organisms; the rate increases with inoculation. Thiobacilli are the non-spore forming Gram-negative rods, 1 to 3 μm long and 0.5 μm in diameter. There are 9 species of *Thiobacillus* including *T. ferroxidans, T. thiooxidans, T. novellus, T. thioparus* and *T. denitrificans*, out of which *T. ferroxidans* have been studied in detail. They can oxidize ferrous salts as follows:

$$4\,FeCO_3 + 6H_2O + O_2 \longrightarrow 4\,Fe(OH)_3 + 4CO_2$$

Three classes of bacteria are involved in sulphur oxidation and are active in the rhizosphere. These are (a) **chemolithotrophic sulphur bacteria**, like thiobacilli, which utilize the energy released from the oxidation of inorganic sulphur for the fixation of carbon dioxide in organic matter, (b) **photolithotrophic sulphur bacteria**, like *Chlorobium* or green bacterium and *Chromatium* or **purple bacterium**, which fix photosynthetic carbon, using sulphide and sulphur compounds as "oxidant sinks", and (c) **heterotrophic bacteria** that convert sulphur to thiosulphate.

Thiourea

Thiourea is a sulphur analogue of urea. It is a crystalline and colorless solid which is relatively insoluble in water. Thiourea, capable of breaking the dormancy of seeds, is used to stimulate seed germination. Seeds are soaked for less than 24 hours before planting.

Thixotropy

Thixotropy is the property of a substance becoming less viscous when stress is applied to it. For example, some gels become temporarily fluid when shaken or stirred. This happens when the forces bonding the dispersed particles into a cross-linked structure (gel) are weak. A mechanical agitation liquefies the gel. Majority of the paste-like and jelly-like systems (such as cell protoplasm, gelatine solution, bentonite suspension, etc.) are thixotropic.

Thomas converter

Thomas converter is used to make iron from a high phosphorus iron ore, by oxidation in contact with a base (CaO). The slag mainly contains a lime-phosphate-silicate melt to form calcium silicophosphate. At the end of the blowing process, the slag floats on the molten steel surface. The addition of phosphate rock to the converter in place of lime increases the P_2O_5 content. This is, however, not possible with phosphate containing fluorine. (See also Dephosphorated slag.)

Thomas slag

Thomas slag (another name for **dephosphorated slag** or **basic slag**) is a by-product in the **Bessemer process**. The Bessemer process is used to make steel from phosphate-containing iron ores. It is regarded as a good phosphate fertilizer on acidic soils and is also valued for its liming effect and micronutrient content. The slag is usually applied in a finely ground state, but sometimes also by granulation with potash.

Mixed fertilizers have potassium to phosphorus (P_2O_5 to K_2O) ratios between 1:1 and 1:3. The addition of fused phosphate or dicalcium phosphate is legally permitted to allow the phosphorus content of the slag to be adjusted to maintain a constant phosphorus to potassium (P:K) ratio. (See also Dephosphorated slag.)

Thorn forests

Vegetation common in tropical, subtropical and warm temperate zones comprises a thorn forest. Such forests are dominated by plants that are small and thorny, and shrubs and trees that remain low. Most plants have small leaves which grow rapidly during the wet season. Most trees are deciduous in nature shedding their leaves during the long dry spells, characterized by wide temperature variation between days and nights.

Seasonal rainfall in such semi-arid, warm and dry regions is between 250 and 500 millimeters. Rainfall in tropical semi-arid thorn forests occurs only for 2 months in a year. Such forests are seen in the south-western parts of North America and Africa, and some parts of Australia and South America. A reduced biomass, deciduousness, thorns, spines, succulent stems, etc. are seen as the adaptations of such vegetation. Typical examples are plants of the cactus family, xerophytic palms, etc.

Thousand-grain weight

Thousand-grain weight is synonymous with **test weight as a measure of grain yield**.

Threshold dose of a nutrient

The threshold dose of a nutrient is its minimum concentration above which only measurable changes or effects are observed in a plant. The phenomenon is very similar to the threshold energy of a chemical reaction or the detection limit in a chemical analysis.

Soil samples are analyzed to evaluate the soil productivity status on the basis of which fertilizer application and soil amendments are decided. This information and other factors (namely, the expected crop production, the cropping history and physical characteristics of the soil) determine the required amount of nutrients and soil amendments.

Threshold limit value

Threshold limit value (TLV) refers to a set of standards established at the American Conference of Governmental Industrial Hygienists for concentration of airborne substances in the work room air. These are time-weight averages based on conditions which workers may be repeatedly exposed to, day after day, without adverse effects. The TLV values, which are revised annually, provide the basis for the safety regulations of **OSHA** (Occupational Safety and Health Administration). They are intended to serve more as a guide to control health hazards.

Throughput capacity

The throughput capacity describes the productivity of machines (such as grain augers, balers, forage harvesters and combines) that handle or process a product. (See also Capacity.)

Thylakoids

Thylakoids are flattened sacs arranged in stacks inside the chloroplast. Covered by pigmented membranes, the light reaction of photosynthesis occurs on them.

Tile drainage

Tile drainage is a type of **subsurface drainage system**. It uses sections of clay or concrete tiles or plastic tubes which may be a meter long and about half a meter in diameter. This system, if planned properly, can remain operational for a very long period of time.

The placing of the tiles depends on the soil permeability. The lesser the permeability, the shallower would be the placement and closer would be the tiles to each other. Plastic tubes are cheaper to use and easier to install than tiles. It is necessary to ensure that the openings of the tubes are protected from pests. Drain lines are usually made from perforated plastic pipes or from loosely fitting ceramic pipes, laid and buried in a trench dug to correct the grade (bottom slope). A layer of gravel (the envelope) stops the soil from blocking the holes or entering the pipe.

In organic soils and some clay soils, mole drains are made by pulling a torpedo-shaped steel or iron mole through the ground, creating an unlined tunnel that lasts for many years.

Tile drainage – an environmental perspective

Tile drainage is a type of **subsurface drainage system**. Sections of clay or concrete tiles or plastic tubes, placed under the soil are used to drain away excess water from that land. Tile drainage systems are implemented in regions with soils that are less permeable, while ensuring the availability of water to plants.

Tile drainage has been adopted on many waterlogged lands to convert them into agricultural lands.

Well drained soils facilitate deep root development, and so, crops are believed to be better equipped during moderately dry years.

However, tile drainage has been a subject of controversy as far as the environment is concerned. An increased usage of the tile drainage system across large land masses, characterized by wetlands and grasses, threatens the natural habitat there. For instance, the wetlands of South and North Dakota in the USA are said to be home to a large number of bird species migrating across the country. Environmentalists argue that conversion of such unique regions into arable farms would disturb the delicate balance crucial to the ecosystem. Tall and dense grass holds the soil together and prevents erosion by both wind and water. A wetland complex acts like a filter for silt and pollutants. Such natural factors which help conserve environmental balance can get disturbed by tile drainage.

Tile drainage helps to dry up 'wet spots' on fields. It does not allow water to stagnate but encourages it to flow down the hill till it reaches a drainage ditch, a lake, river or a stream. Tile drainage is said to, however, increase the risk of flooding much more than when a surface drainage system is installed.

Increased areas under tile drainage have witnessed increased levels of nitrates in the surrounding natural sources of water. Such water pollutes drinking water. Nitrate contamination is a serious health hazard and causes blue baby syndrome, apart from other illnesses.

Tillage

Tillage is the mechanical manipulation of land for growing crops. It is done with different mechanical equipment as is seen in Fig.T.5.

Farmers have adopted the practice of tillage since ancient times.

Three commonly accepted reasons for tillage operations are to (a) manage crop residues, (b) kill weeds, and (c) alter soil structure, especially while preparing the soil for seed planting or seedlings. This conventional tillage involves intensive working of the soil to produce a fine **tilth**, which is often piled up in ridges, mounds and raised or sunken beds.

Tilling removes plant debris from the surface of the soil and exposes the tilled soil to erosion. **Primary tillage** involves the breaking and loosening of soil to a depth of

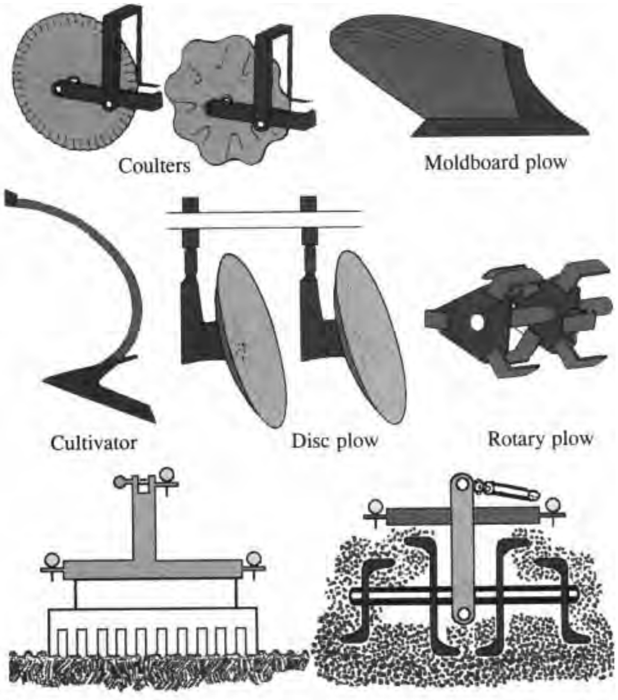


Fig.T.5: Commonly used tillage implements.

15 to 90 cm using moldboard and disc plows. In **secondary tillage**, soil is stirred at relatively shallow depths, using the spike-tooth harrow, the spring tooth harrow and the disc harrow.

Conventional tillage, a combination of primary and secondary tillage, is normally done to prepare seedbeds. Where conventional tillage is done on dry land, the crusting and compaction is less; compaction increases on wet soil. The depth and the extent of tillage depends on whether the objective is to prepare a root bed or a seedbed.

Another type of tillage is the **conservation tillage**, where the organic residues of the crop are retained and the field surface is kept rough. This controls weeding and erosion and requires the barest minimum cultivation to prepare the soil for crops. It is practiced extensively in the annual production of grain crops in the tropics.

Minimum tillage is the minimum soil manipulation necessary for crop production under its existing soil and climatic conditions. Some of the minimum tillage equipment prepare the land for planting, for sowing seeds and for applying fertilizers and herbicides - all in one trip of the field.

No-tillage is a procedure whereby a crop is planted directly into the soil with no preparatory tillage after the harvest of the previous crop. The planting of wheat in the stubble of a previous crop, without any prior tillage, is an example of no-tillage planting.

Continuous cropping and tillage by tractors, heavy machinery, animal hooves and shoes, etc. cause changes in the soil porosity, increasing the compaction. Soil compaction results in (a) a decrease in the soil pore space, (b) a decrease in macropore space, and (c) an increase in micropore space. (See also Conservation tillage; Deep tillage.)

Tilth

Tilth is the physical condition of the topsoil after tillage, reflecting its state of fitness for plant growth. The texture, structure, consistency and pore space of the soil collectively indicate its physical state.

A fine tilth consists of small clods and loose crumbling soil particles. In a coarse tilth, relatively large clods constitute majority of the broken material. The effect of tillage on tilth is closely related to the soil water content at the time of tillage. This is especially true when the tillage of wet clay soils creates large chunks or clods do not break down into a good seedbed when the chunks dry. Hence, issues relating to the kind of tillage and the timing of tillage operations need to be addressed to maximize the beneficial effects of tillage on the soil tilth.

Timber and range site indices

Timber index is a numerical measure of the quality of the land site for tree production. It is calculated according to the heights reached by selected tree species at an arbitrary age.

In general, one hundred years is used as a base for trees growing west of the great plains and fifty years for trees growing east of the great plains or prairie lands of N America. For example, a site index of 150 indicates that the dominant and co-dominant trees growing in a normally stocked stand can be expected to grow to a height of 45 m at the age of one hundred years.

The dominant and co-dominant trees in a group are the most abundant and the second most abundant trees respectively. The number of trees per area is the **stocking rate**. The higher the stocking rate, the greater the competition for nutrients and water. The site index is specific for tree species, climate and stocking rate because soil factors influence productivity.

The site index is related to the soil properties such as its depth to rock, impermeable layer, gravel content, fertility, permeability, etc. The soil position also affects the site index. The most important position characteristics are the aspect and the elevation.

A woodland suitability group is identified by Arabic numbers and a letter symbol. A third symbol, an Arabic numeral, is used to further subdivide the rating. The number represents the productivity (1=best) and the letter represents the major limit. For example, x stands for the presence of stones or rocks, w for the wetness, t for the toxic materials, and d for the depth restriction. An 'id rating' indicates that the land has a high production potential but the rooting depth is limiting. A 4 or 3 rating indicates a low level of productivity (4) due to severe (3) steepness of relief (r).

A rangeland is usually evaluated separately from a cultivated and forest land. The **USDA** system uses the range site as an index of potentially sustained vegetation production. Here, the potential for damage due to soil erosion and vegetation deterioration are considered. The range site is determined for land parcels rather than a single soil. A parcel may include several soil series that can be managed as a single unit, and is based on soil properties (such as texture, water-holding capacity, and solum thickness, etc.) that influence the total forage production. The composition of range vegetation is part of the range site, but vegetation that is poisonous (or not eaten by animals) detracts from the range site.

Time of fertilizer application: See Environmental issues related to fertilizer use

Tincal

Tincal ($Na_2B_4O_7 \cdot 10H_2O$) is one of the sources of borax found in salt lakes and alkali soils. The ore is purified by re-crystallization. (See also Borate.)

Tipburn, lettuce

Tipburn is a disorder in lettuce, caused by calcium deficiency.

Tissue respiration

At the cellular level, **respiration** refers to tissue respiration or **internal respiration**, which operates in two stages: the first is **glycolysis**, and the other is the **Krebs cycle**. The processes of glycolysis and Krebs cycle are common to all plants and animals that respire aerobically.

Tissue tests

Tissue tests are conducted to detect and assess the requirement of nutrients and unelaborated materials during the process of translocation.

There are two types of tissue tests, for which the petioles and the tender stem portions are used. The first type requires fresh tissue in the field and the second type involves tissue analysis in the laboratory.

Plant analysis, which includes both the rapid in-field tissue testing and the total elemental analysis in the laboratory, is based on the assumption that the amount of nutrients available in the plant is directly proportional to that present in the soil. The tests determine the (a) nutrient-supplying property of the soil, (b) nutrient shortage before it shows deficiency symptoms, (c) effect of fertility treatment on nutrient supply in the plant, and (d) nutrient status in the plant and the crop performance relationship.

The concentration of nutrients in the cell sap is a good indication of the status of the plant at the time of testing. These semi-quantitative tests are meant to verify or predict the deficiencies of N, P, K, S and several micronutrients. These tests are easy to perform and interpret, and can be carried out in a few minutes.

The correction of nutrient stress, based on the tissue tests, is not feasible because (a) the deficiency may already have caused crop loss, (b) the crop may not respond to the applied nutrient at that stage, (c) the crop may be too mature to receive nutrients, and (d) the climatic conditions may not be favorable for fertilization.

In general, testing is done on the conductive tissue of the matured leaf; immature leaves at the top of the plant are avoided. The growth stage of the plant tissue is important, as the nutrient status changes during the season. The best stage for tissue testing is at its bloom or from bloom to the early fruiting stage. The time of the day influences the nutrient level in plants; it is usually higher in the morning than afternoon. The nutrients accumulate at night and are utilized during the day. Hence, the tests are carried out either early morning or late afternoon.

The uptake of nutrients needs to be checked five to six times during the growth season. There are two periods of maximum nutrient demand - the vegetative growth period and the reproductive stage.

The comparison of plants in the field helps in the identification of nutrient deficiency. To minimize variation, the average of test results from 10 to 15 plants are taken. The tests are run on a fresh material. These tests are also known as **quick tissue tests** and are conducted for the analysis of N, P and K by paper tests or glass vial tests. The tissue tests are mostly used for diagnosing deficiencies (and toxicity) in perennials, such as fruit trees, forest trees or alfalfa. They are less used in annuals, as the results tend to arrive too late for corrective action.

High value crops may justify periodic plant testing which can indicate important (a) fertility trends during the season in an annual crop, and (b) long term trends in perennials, like orchards and plantations.

Tolerance limit

Tolerance is the ability of a plant to withstand parasites or adverse environmental conditions.

Tolerance limit refers to the amount of toxic residue allowable in edible plant parts and the outer limit of the acceptance of the difference between two test results of the same attribute. It is the limit of a pesticide/chemical in the plant or animal product certified by the legal authorities as safe for human consumption.

In the composition of standard fertilizers, some allowance is made for variations inherent among different production batches. Such allowable limit is the tolerance limit of that fertilizer and is called **investigational allowance**.

Tolerant plants

A plant that can tolerate a highly toxic soil environment is called a tolerant plant. *Holcus lanutus* and *Agrostis capillaris* are examples of tolerant non-accumulators.

All tolerant plants need not be **indicator plants** or **hyperaccumulator plants**. That is, tolerant plants need not absorb these toxins.

Tolerant tree: See Forest

Top dressing: See Ammonium nitrate

Top dressing by aircrafts or helicopters: See Broadcasting

Topographic watershed

Watershed is also known as topographic watershed or **catchment basin** or **drainage basin**. (See also Watershed.)

Topography

Topography is the surface contour of the earth. It is the configuration of a surface area including its relief or relative elevations and the position of natural and man-made features.

The slope angle and the slope length are important parts of topography, determining the amount of water that runs off or enters the soil. Topography describes the physical features of the earth's surface, which influences the soil genesis mainly in terms of erosion, dispersal of precipitation, the accompanying decomposition of the eroded material and soil drainage. New or young soils get formed at places where soil erosion and soil deposition are active.

With its water and temperature relationship, topography is among the factors responsible for soil formation. The same parent material in the same climatic zone produces different kinds of soils depending on its position – whether on hilltops, steep hillsides or hill bottoms. Water behavior is different at each of these locations leading to varied surface features of the soil.

Toposequence

Toposequence is the sequence of related soils that differ primarily because of the topography as a soil formation factor. Soils with identical parent material, existing within a uniform climatic region and affected by parallel soil-forming factors, may still have varied features due to local relief and/or internal drainage attributes. The name for such a group of related, yet different soils is **catena** or toposequence. They differ only in the position on the landscape where they are found. The position influences the microclimate and the amount of water entering the soil.

Topsoe economic process for ammonia production: See Ammonia production processes

Topsoe S-250 converter system: See Ammonia production processes

Topsoe series 200 converter technology: See Ammonia production processes

Topsoil

Topsoil is the upper portion of the soil (20 to 30 cm deep). Samples from this portion are used for soil analysis or testing. Topsoil is known as the soil layer moved in cultivation or fertile soil material, and is used for top dressing gardens. It is also an A or A_1 horizon.

Torque

Torque is a measure of the force applied to a body through a lever arm that causes twisting or rotary movement to the body and is defined as:

$$T_0 = f \times l_a$$

where T_0 is the torque (kg•m), f is the force (kg) and l_a is the lever arm length (m).

Torric

Torric is a soil moisture regime where moisture is deficient, like in an aridic regime. The subsoil or moisture control section is dry in all parts for more than half the growing season, and is not moist in some parts for as long as 90 consecutive days during the growing season in most years. There is very little soil water storage or recharge, which means there is little water retained for plant growth. Many of the native plants have an unusual capacity to endure low water potentials in the soil and within their tissues. Grazing is the dominant land use in torric regime, except in places where irrigation permits crop production. (See also Aridic regime.)

Torric regime: See Aridic regime

Torrid zone

Torrid zone is another name for **equatorial zone**.

Total available phosphorus

The sum of the water-soluble and the citrate-soluble phosphorus estimates the fraction of phosphorus available to plants, and is termed as the total available phosphorus. (See also Phosphorus available form.)

Total dissolved solids

Total salt concentration in water may be expressed as total dissolved solids (**TDS**). It is one of the parameters that determines the water quality.

Water in the form of rain and snow is quite pure, but by the time it reaches the farm fields, it picks up soluble material from soil and rocks, through which (or over which) it has passed. Thus, the TDS of water may increase to a level where it starts becoming unsuitable for irrigation. Whether the water is suitable or not depends on the plant, the amount of leaching permitted during irrigation and the dryness of the soil before the next irrigation. If the soil is allowed to dry, the salts move up to the surface along with the evaporating water. If the soil is wet, the salt content may become too high for the plant. Normally, the top soil salt concentration is 2 to 3 times that of the irrigation water and at depths deeper than 20 to 30 cm, it is 5 to 6 times higher.

In regularly irrigated fields, where salts are not leached out of the soil, provisions must be made to remove the salts through drainage.

The TDS or salinity is expressed in terms of electrical conductivity of water and is expressed in deciSiemens per meter (dS/m). There are four classes of water quality, with the conductivity ranging from 0.01 to 2.25 dS/m. The salinity hazard ranges from low to very high.

Total error in sampling

Error arising in sampling - particularly in the case of heterogeneous materials like soils, fertilizers, etc. is the most important source of uncertainty in the analysis. If we represent the sampling error as S_S and the analytical error as S_A, the total error S_T is given by:

$$S_T = \sqrt{S_s^2 + S_A^2}$$

Or

$$S_T = \sqrt{V_S + V_A}$$

where V_S is the sampling variance and V_A is the analytical variance. (See also Sample.)

Total phosphate of lime

Bone phosphate of lime (**BPL**) in a phosphate ore is tricalcium phosphate $Ca_3(PO_4)_2$. The phosphorus content of the phosphate rock in commercial trading is calculated as the weight percentage of tri-calcium phosphate and expressed as bone phosphate of lime or the total phosphate of lime (TPL). (See also Bone meal.)

Total phosphorus in fertilizers

Phosphorus in fertilizers can be water-soluble, citrate-soluble, citrate-insoluble or in its available form. Phosphorus in all these forms together is the total phosphorus in fertilizers (as P_2O_5).

Total quality control

The concept of total quality control embraces all the technical and managerial aspects of quality and safety of the product at all stages of design, development, specification, manufacturing and usage. (See also Quality control.)

Total recycle process in urea production: See Urea production processes

Total sampling error: See Total error in sampling; Sample

Total soil moisture stress

Water potential is the minimum additional work required to move water from the soil system. Since soil water is held in the soil by forces of adsorption, cohesion and solution, it does not work as pure free water, hence the potential is negative. The term total soil moisture stress is also used to describe the negative water potential.

Plants use large quantities of water, and the water-supplying power of soils is related to the amount of available water in the soil. The **available water** is the difference in the amount of water at field capacity (minus 30 kPa or minus 0.3 bar) and the amount of water at the **permanent wilting point** (minus 1500 kPa or minus 15 bars). The water potential gradient established between the roots of transpiring plants and the soil causes water to move from the soil into the roots. This water potential gradient is called the **soil-plant atmosphere continuum**. Some realistic water potential in the continuum during midday when plants are actively absorbing water are: minus 50,000 kPa in the atmosphere, minus 2500 kPa in the leaf, minus 800 kPa in the root and minus 700 kPa in the soil. There is considerable resistance to the upward movement in the xylem, which can produce considerable water potential gradient between the leaf and the root.

During periods of water stress, the damage to a plant is related to the stage of its development. Available data show that four days of visible wilting during the early vegetative stage caused 5 to 10% reduction in the corn yield compared with a 40 to 50% reduction during the time of silk emergence and pollination. Injury from water stress at the dough stage was 20 to 30%. Water stress can be diagnosed by measuring the relative leaf water content; however, measuring the corresponding leaf potential is faster and easier.

The primary effect of water stress is to slow down expansive growth, which however is not always the most important effect. Flower development or fruit set can be especially sensitive to drought at critical periods. Plants can survive drought with the help of adaptations to conserve water, and also to get more water from the soil. (See also Water potential.)

Total soluble salts

Total soluble salts are commonly characterized by the electrical conductivity of water and expressed as deciSiemens/meter (dS/m).

Four water quality classes have been established with the conductivity ranging from 1 to 2.25 dS/m. The salinity hazard ranges from low to very high.

The suitability of water for irrigation depends, among other factors, on the concentration of total soluble salts. Today, crop production in the world's irrigated land is in effect, reduced roughly by as much as 50%, as a result of salt accumulation in soils from soluble salts in irrigation water. (See also Irrigation water quality criteria.)

Tourmaline

Tourmaline, which is a borosilicate, is the main source of boron found in soil. It is a mixture of silicates and borates from where boron is extracted. It is available as a complex cyclosilicate, $Al_6Y_3Na\ [Si_6\ O_{18}]\ (BO_3)_3\ (OHF)_4$ with Y = Mg, Fe, Mn or Li. The rhombohedral system has the shape of an elongated rod or needle type prism.

Tourmaline is used as a gemstone, and because of its double refraction and piezo-electric properties, it is used in polarizers and in some pressure gauges. The best known variety of tourmaline is **black tourmaline** which is rich in iron and is a common mineral in igneous and metamorphic rocks.

Magnesium-rich tourmaline is called **dravite**. Lithium-rich varieties are called **elbaite**. Ferruginous varieties are called **schorlite** which is insoluble in water and resistant to weathering and hence releases boron slowly.

Town compost

Compost produced from materials of urban origin, like street sweepings, dustbin refuge, etc. is town compost, also called **urban compost**. Its typical composition is nitrogen 1.5 to 2.0%, phosphorus (as P_2O_5) 1% and potassium (as K_2O) around 1.5%.

Toxic elements

Elements like mercury, cadmium, lead, arsenic and those with a high concentration of essential elements affect the growth and yield of plants. Such elements are considered toxic.

Manganese toxicity may occur when the soil pH is about 4.4 or less. High levels of exchangeable aluminum in any acidic sub-soil restrict the growth of roots. Plants and even varieties of the same species exhibit differences in tolerance to high levels of aluminum, iron and manganese in solution and to other factors associated with the soil pH. These can cause physiological disorders, irregularities in lesions, imbalance in other essential nutrients, withering of the plant and finally its death. The symptoms are proportional to the concentration of the toxic element, rather than to its nature. The use of toxic elements comes within the purview of the fertilizer laws in the country.

Visual symptoms of toxicity include (a) chlorosis, yellowing, necrosis and scorching of leaves, (b) the fall of flowers and plant sterility, (c) necrosis of the branches and fruit, and (d) stunting, blighting and decaying of the plant.

Arsenic gets accumulated in soils from sprays used to control insects and weeds, and to defoliate crops before harvesting. Although arsenic, accumulated in soil, injures crops, it does not create any hazard for humans or animals.

Cadmium poisoning occurred in Japan from the dumping of mine wastes into rivers, where fish ingested the cadmium from the wastes. Cadmium also appears in some sewage sludge. Using soils for the disposal of sewage represents a potential danger. Mine soils may have toxic levels of cadmium, but natural agricultural soils do not contain harmful levels of cadmium.

Lead is discharged into the air from automobile exhausts and other sources, and it eventually reaches the soil. In soil, lead is converted into forms that are unavailable to plants. Any lead that is absorbed tends to remain in the plant roots and is not transported to the shoots. Soils must become significantly polluted with lead before significant amounts move up to the top of the plants.

Mercury from pesticides and industry is discharged into the air and water. Under conditions of poor aeration, inorganic mercury is converted into methyl mercury, which is very toxic. While plants do not take up mercury readily from soils, mercury should not be disposed of in the soil because mercury is highly toxic in nature.

Soil is being used increasingly for sewage disposal. The high levels of heavy metals and their potential uptake by plants presents an important limitation in the use of soils for sewage and industrial waste disposal.

Rocks and soils contain radioactive elements. While many radioactive elements with very short half-lives are of little concern, those with a long **half-life** pose serious problems. Radioactive caesium appears to be fixed in vermiculite minerals, much like potassium. This limits the availability of caesium to plants. The contamination of soils is through the atmosphere. Plant leaves are known to absorb radioactive elements that fall on them. Testing of nuclear weapons has resulted in a significant loss of tundra vegetation in Alaska. Increased radioactivity was found in the caribou that grazed in the Tundra. The people who ate caribou were found to have 100 times more radioactivity in their bodies than people in other parts of the USA.

Several approaches have been suggested for the decontamination of the soil. One approach is to mix a large quantity of potassium with the soil and irrigate it with sea water to increase the likelihood of potassium uptake by plants relative to caesium. Another approach is to remove the top 40 cm of topsoil and replace it with uncontaminated soil.

Gaucher classification of toxicities caused by various elements in the soil are (a) saline soils containing chlorides of Na, Mg and Ca as well as sulphates of Na and Mg, (b) alkali soils containing sodium carbonate, either in association with other salts, or without, (c) metals such as Mn, Cu, Zn, Ba, Ni and Al (in the form of soluble alumina), and (d) metalloids such as boron, selenium and fluorine.

Toxicity in soils or plants

The ability of a substance to cause damage to living tissues, impairment of the central nervous system, severe illness or death in extreme cases, when ingested, inhaled or absorbed by the skin, is called toxicity. The science that deals with the harmful effects of chemicals and physical agents on living systems is called **toxicology**.

Toxicity is the result of excessive application of a substance to plants or any living organism. The amount of the substance required to produce these results depends on its recipient and the duration of exposure. **Acute toxicity** refers to short duration exposure whereas **chronic toxicity** is a result of repeated or prolonged exposures.

The hazards of toxic material depend on its physical state and its solubility in water and acids. Some metals are harmless in solid state but quite toxic as powder, dust or fume. Many intensely poisonous substances, such as strychnine, if taken in micro amounts, as in prescription drugs, are beneficial.

Toxicity is evaluated on the basis of test dosages experimented on animals under controlled conditions. Most important of these are **LD_{50}** (lethal dose, 50%) and **LC_{50}** (lethal concentration, 50%) tests. These test doses on animals include exposure to (a) oral ingestion, (b) extended skin contact, and (c) inhalation of the material under test. A substance having an LD_{50} less than 50 mg/kg body weight is considered highly toxic.

Certain elements in soil, present in excess make the soil toxic. The various toxicity types are: (a) sulphidic, acid sulphate and alum rich soils (mangrove soils), latosols, gyttja soils of Finland, (b) peaty soil, and (c) naturally occurring highly acidic soils by secondary processes (sulphates). In these soils, toxicity results from certain chemical elements present in the parent rock or the accumulation of residual pesticide (e.g., arsenic, fluorine) or specified pedological evolution.

Soils containing excess salts lead to the development of saline, sodic and saline-sodic soils. Saline and sodic soils are reclaimed by the application of gypsum or leaching with water. Acidic soils are treated with lime to make it useful for cultivation.

It is to be noted that the response to a toxin and the response to a growth inhibitor or retardant are two distinct phenomena, although both act at the same cellular site.

Toxicity of micronutrients

Zinc sulphate, manganese sulphate, borax, solubor, copper sulphate, ammonium molybdate, chelated zinc, chelated iron, zincated urea and boronated single superphosphate are among the recognized micronutrients.

Soils inheriting toxicity from excess micronutrients do not pose a critical problem for most crops. However, in certain manganoferrous and strongly acidic soils, there is manganese toxicity. Also, toxicities are created by the imbalance of applied nutrients and of applied chemicals. The situation can be addressed by liming and by integrated nutrient management strategies. The selection of proper doses of micronutrients is especially critical for boron, copper and molybdenum.

Toxicology

The science that deals with the harmful effects of chemicals and physical agents on living systems is toxicology. The subject is divided into (a) clinical, (b) elemental, (c) forensic, and (d) occupational toxicology. (See also Toxic elements; Toxicity in soils or plants; Toxicity of micronutrients.)

TPL

TPL is short for **total phosphate of lime** which is a measure of the total amount of tricalcium phosphate.

Trace elements

Micronutrients, also known as trace elements, are eight in number - Cl, Fe, Mn, B, Zn, Cu, Mo and Ni. These are required in small or trace quantities and perform a variety of essential functions in plant metabolism. Most of them are constituents of enzymes.

There are a few additional trace elements which are non-essential but beneficial to plants. To this category belong sodium, iodine, strontium, fluorine, vanadium and bromine. (See also Plant nutrients.)

Tracer methods for MIT

MIT stands for mineralization-immobilization turnover. The conversion of organic nitrogen to ammonium ion (NH_4^+) is known as **mineralization**. The measurement of the actual or gross rates of mineralization and immobilization requires the almost exclusive use of radioactive-nitrogen isotope (^{15}N). In general, this radioactive-nitrogen isotope can be used in two contrasting ways to examine the MIT. These are (a) tracer methods in which radioactive nitrogen (^{15}N) is added as the substrate for the purpose of interest, and (b) **pool dilution method**, in which the radioactive nitrogen (^{15}N) with or without $^{15}NH_4$ is added to the product pool of the transformation of interest. (See also Mineralization, ammonium form.)

Tracers: See Tagging

Tracheides

Xylem is one of the two conductive tissues in plants with tube-like cells that transport water and dissolved mineral nutrients in vascular plants from the roots to the leaves. In less advanced vascular plants such as conifers and ferns, the constituent cells of xylem are called tracheids. (See also Xylem.)

Tractors in agriculture

A tractor is a wheeled and self-propelled vehicle used in various agricultural operations. Examples include hauling and towing vehicles, crawlers, etc. They run almost on an endless, self-laid track and perform important functions (Fig.T.6).

Many types of tractors and power units are used in agricultural operations. They are (a) **general purpose tractors**, (b) row top tractors, (c) orchard tractors, (d) vineyard tractors, and (e) industrial and garden tractors. There are also other types, using different propulsion systems, like rear wheel drive (RWD), four wheel drive articulating steering (4WDAS), four wheel drive (4WD), four wheel steer tracks (T), rear and front wheel assist (RFWA), etc.

Fig.T.6: Tractors are used in various operations on a farm.

What counts is the power delivered at the desired place. Tractors are rated by the horsepower they deliver at the drawbar and at the belt.

Tractor-driven implements are used for tillage and stationary operations. Plows, harrows, seed drills and combined harvesters and thrashers are employed for tillage operations, whereas pumps, stationary thrashers, winnowers and graders are used for stationary operations.

General purpose tractors have rear and front wheels spaced the same distance apart. The horsepower ranges very broadly from about 25 to over 300 hp. Smaller sizes are very popular for horticultural purposes and mowing. Mid-sizes are used extensively for cultivating, spraying, tilling, mowing and for mobile and stationary PTO horsepower (power take-off horsepower). The large sizes are normally used for primary tillage and for providing **PTO horsepower** for larger mobile and stationary machines, such as balers and forage harvesters and blowers.

Apart from some stationary machines which are operated by electric motors, practically all the power for operating the modern farm equipment comes from internal combustion engines, most of which are mounted on the tractor. The complete modern tractor also has a hydraulic power system for controlling implements mounted on or pulled by the tractor.

Trademark

A trademark is a word, symbol or insignia designating one or more proprietary products (whether manufactured or otherwise) which are officially registered with a government trademark agency. The accepted designation is a subscripted capital R enclosed in a circle.

According to the U.S. Trademark association, a trade name is the name under which a company does business. Use of a trademark without proper indication of its proprietary nature places the name in jeopardy. A number of trademarks have been invalidated as a result of this practice.

Training and visit system in agriculture: See Benor system of training

Tram-lining

Tram-lining is a system of application of fertilizers and pesticides on large farms where tram cars are moved on fixed laid lines. This makes the operation easy and fast. (See also Aerial spraying.)

Transfer RNA: See Ribonucleic acid

Transgenic plants

Research in molecular biology shows how genetic information is stored, replicated and translated into specific proteins for cellular development. Transfer of useful genes from one organism to another is possible with the help of genetic engineering.

Transgenic plants are the plants having genetic material artificially introduced from another species. Identification and isolation of a gene that controls a useful trait (e.g., resistance to herbicide) is the first step in developing transgenic plants. For transporting the gene into plant cells, an appropriate vector should be selected which, in this case, normally is a bacterium or a plasmid that carries a desired gene in a modified DNA. Once the gene is transferred into the cells in a culture, the cell keeps dividing. The new plantlets that appear express the new gene in each of their cells. Transgenic plants greatly help healthy plant breeding.

Vector also means an organism, often an insect, that carries a disease or a parasite from one animal or plant to another.

The bacterium *Bacillus thuringiensis* produces a protein having insecticidal properties. The gene controlling the protein has been transferred to cotton, corn and potato to develop modified cultivars. Accordingly, transgenic cotton plant, corn and potato are found to be resistant to cotton bollworm, corn borer and the potato beetle, respectively.

In another breakthrough, a bacterial gene that was resistant to the herbicide glyphosate has been successfully transferred to different plants. As a result, the particular herbicide can now be used without damaging the plants.

Tomato crops suffer greatly from a fungus, *Sclerotinia sclerotiorum*. The fungus uses oxalic acid for the attack. By introducing a gene that degrades oxalic acid in tomato plants, the fungal attack can be controlled.

Frost damage is a major cause of crop loss. A common leaf surface bacterium *Pseudomonas syringae* forms ice nucleating proteins. By using genetic engineering, the bacteria were removed and the new transgenic plants survived the temperatures of as low as minus 5°C.

Transitional horizons

Soil is constituted of many horizontal layers which have unique and distinct profiles. There are **master horizons**, named using the letters **O**, **A**, **E**, **B**, **C** and **R**. The intermediate horizontal layers found between the master horizons are called transitional horizons.

Transitional horizons exist when there is a gradual change from one horizon to the next. Two capital letters are used for transitional horizons: **AB**, **EB**, **BE** and **BC** are examples of transitional horizons from A to B, E to B, B to E and B to C, respectively. (See also Soil horizons.)

Transition element

A transition metal or element is any of the number of elements in which the filling of the outermost shell of 8 electrons within a period is interrupted to bring the penultimate shell from 8 to 18 or 32 electrons. Only these elements can use penultimate shell orbitals in bonding.

Transition elements include elements 21 through 29 (scandium through copper), 39 through 47 (yttrium through silver), 57 through 79 (lanthanum through gold) and all known elements from 89 (actinium) onwards.

Transition elements are all metals. Many are known for variable valency or oxidation states, complex ion formation, as well as for possessing extremely valuable properties in a metallic state.

Most of the ions and compounds of the transition metals are colored and many are paramagnetic. Both color and paramagnetism are related to the presence of unpaired electrons in the d orbitals. Because of their ability to accept electrons in unoccupied d orbitals, transition elements and their compounds exhibit catalytic properties.

Translocation

Translocation in plants is the transport of a dissolved substance, especially through the xylem and phloem, or actively across a cell membrane. The movement of food and other organic materials, produced via photosynthesis, takes place in green plants. This translocation occurs through the conducting tissue, **phloem**, through interconnecting tube-like strands, known as **plasmodesmata**. Nutrients move from cell to cell across the root cortex and into the xylem which carries them by mass flow to the young, growing shoot tissues.

Translocation can happen in any of the following situations: (i) Clays move to deeper layers with water. (ii) Soluble salts move along with groundwater. (iii) The vascular and conducting tissues in plants (xylem, tracheids or vessels) take soluble minerals from the plant roots to the various plant organs. (iv) Phloem tubes (sieve tubes) carry organic compounds (synthesized by leaves) to the growing parts of plants. (v) Burrowing animals move materials within the soil. (vi) Sand dunes are transferred by wind action.

Translocation quotient is the ratio of the chemical content of the shoot to that of the root; it is a measure of the mobility or relative translocation. The most common way to estimate the rate of translocation is to allow the leaves to assimilate the CO_2 containing radioactive carbon (^{14}C) and then measure its quantity transported to the leaves. Leaves may export, in six hours, as much as 70 to 80% of the photosynthate produced within a short time. The rate of photosynthate translocation of up to 210 cm/hour has been measured in corn leaves. The plant growth reducing factors, such as water stress, nutrient deficiencies or toxicities and low or high temperatures also reduce the translocation of photosynthates.

As leaves and roots age, some of their nutrients are set free and re-translocated to young growing leaves, roots, fruits or storage organs. Some nutrient elements (like Ca) do not move or translocate easily. Nitrogen and sulphur are readily remobilized in the form of amino acids when proteins break down in old and stressed tissues. Other nutrients readily remobilized are Mg, K and P. Symptoms of nutrient deficiency first appear in older leaves, if a deficient nutrient is remobilized. But if the deficient nutrient is not remobilized, the symptoms will appear in growing points and young leaves.

Translocation quotient: See Translocation

Transpiration

Transpiration of a plant or leaf is the release of water vapor by the plant or leaf when the vapor pressure in the leaf cells is greater than that in the atmosphere. Transpiration cools the leaves.

Foliar transpiration, which can either be stomatal or cuticular, is a function vital to plant growth as it ensures a continued stream of nutrients from the soil entering the plant. Transpiration is controlled by both atmospheric and plant factors. These factors include the stage of plant growth, leaf area, leaf temperature and the amount of soil moisture. Some transpiration takes place by direct evaporation from the outer walls of the epidermal cells through the cuticle, known as **cuticular transpiration**.

In practice, it is difficult to measure the evaporation of soil water separately from the moisture remaining on the surfaces of the vegetation, after precipitation and transpiration. Hence, evapotranspiration is a general term used for all three processes. Should water be freely available in them, the term **potential evapotranspiration (PE)** is used. It is defined as evaporation from an actively growing extended surface of a short green crop of uniform height completely shading the ground, and never short of water. Primarily, the type of leaves and climatic factors determine evapotranspiration. The determination of potential evapotranspiration is difficult. Various methods of indirect assessment and theoretical formulae are (a) direct measurement using evaporation pans, atmometers, lysimeters or evapo-transpirometers, (b) moisture/water budget methods, and (c) meteorological formulae based on the physics of vapor transfer process, energy budget and their combination.

Lysimeter is a simple instrument for estimating **evapotranspiration**. It consists of an oil drum, 58 cm in diameter, placed into the ground with a pipe leading from the base into a collection chamber. The drum is filled with soil over a layer of gravel to facilitate drainage, and grass is grown on it. The soil is kept at **field capacity** by supplementing rainfall with daily irrigation. Potential evapotranspiration (PE) is determined as the difference between the water gain and run-off. This is known as the **water balance method**.

A buffer area which is vegetatively the same and which receives exactly similar irrigation must surround the experimental surface. The tank must be large enough to allow root development. Physical conditions, such as soil texture and structure, inside and outside the lysimeter must be comparable. The crop density within and outside the lysimeter must also be the same.

Transpiration coefficient

The capacity of a plant to use soil water economically differs considerably from one plant species to another. A measure of this capability is the transpiration coefficient, defined as the quantity of water (kg or liter) required for producing 1 kg of plant dry matter. The transpiration coefficient is also an indicator of the **water use efficiency**. The ratio of transpiration by the crop to the amount of water consumptively used by the crop is the **transpiration factor**.

Transpiration efficiency or **transpiration ratio** is the ratio of the weight of water consumed by crops during the growing season to the weight of dry matter harvested. Depending on the location, temperature, humidity, wind and soil fertility, transpiration ratio varies from 200 to 1000 for different crops. The production of one ton dry matter in rice requires 682 tons of water compared to 280 tons for millet.

The flow of water through the plant xylem, from the roots to the stem and the leaves, and evaporation through the stomata of leaves, is called **transpiration stream** or **current**. Substances retarding or inhibiting transpiration are **transpiration retardants** or **suppressants**. These are of 3 types: (a) a polar substance like cetyl alcohol or oxyethylene decosanol, (b) plastics like polyethylene, and (c) substances that lead to stomatal closure like phenylmercuric acetate and decenyl succinic acid.

Transpiration current: See Transpiration coefficient

Transpiration efficiency: See Transpiration coefficient

Transpiration factor: See Transpiration coefficient

Transpiration ratio

Transpiration ratio is another term for **transpiration efficiency**. (See also Transpiration coefficient; Transpiration.)

Transpiration retardants: See Transpiration coefficient

Transpiration stream: See Transpiration coefficient

Transpiration suppressant

Transpiration suppressant is another term for **transpiration retardant**.

Transplanting

The planting of seedlings from one place to another (prepared seedbed) is known as transplanting. Although transplanting is common in rice cultivation, it is also seen in nurseries where seedlings grown to a certain stage are planted in the field.

Transplanting of rice seedlings into puddled fields is a common practice. Hand transplantation provides a method for uniform spacing and plant population control. Rice transplanted in straight rows allows the use of a rotary weeder for weed control. Hand transplantation also ensures efficient use of solar energy.

Where labor costs for transplanting rice are high, direct seeding is practiced by drilling the seed into the dry soil or broadcasting it onto the flooded soil. After direct drilling, the paddy is flooded. Direct seeding can become desirable if the seeds become susceptible to to attack by rats, snails and birds. Direct seeding, if not done in a prescribed manner, may lend to poor stands.

Transport and storage of phosphoric acid during production: See Phosphoric acid production processes

Trap cropping

Trap cropping refers to a crop in which a parasite penetrates, but does not mature (or is not allowed to mature).

Triacidic digestion mixture

A triacidic digestion mixture consists of a mixture of nitric-, sulphuric-, and perchloric acids in the ratio of 9:4:1. It is used for the digestion of plant samples for analysis. The plant material, after sampling, is dried, ground, and after digestion with the acid mixture, determined for its nutrient content.

Digestion with sulphuric-, nitric-, and phosphoric-acids along with copper sulphate is a recommended practice for all fertilizers as well as for condensed phosphates for the estimation of nitrogen.

Triammonium polyphosphate

The ammonium salt of polyphosphoric acid ($H_{n+2}P_nO_{3n+1}$) is triammonium polyphosphate. For example, polypyrophoric acid (n=2), reacting with ammonia gives polyammonium pyrophosphate which is used as a liquid fertilizer in foliar sprays.

$$H_4P_2O_7 + 3NH_3 \longrightarrow (NH_4)_3HP_2O_7$$

Triazines

Triazine is an organic heterocyclic compound containing a six-member ring formed from three nitrogen and three carbon atoms. With its high nitrogen content and low water-solubility, triazine is used as a slow-release nitrogen fertilizer.

Triazines are trimerized products of urea and ammonia, for example, cyanuric acid or melamine. The nitrogen present in these compounds is released slowly. Triazine derivatives (s-triazine) are used as soil active herbicides.

Some examples of triazines are atrazine, simazine and cyanazine. Triazines are commonly called **Hill reaction inhibitors or** used as **photosynthesis inhibitors** because they block electron transport in the photosystem II (a stage in photosynthesis). Triazines are absorbed by roots and transported upward in the xylem, eventually reaching the green-leaf tissue where they exert their toxic effects.

Normally, selectivity is a consequence of differences in the rooting depth between the crop and the weed, but there are notable examples of differential metabolic rates, as with s-triazines in corn and terbacil in mint. Since these compounds operate primarily on a system unique to plants, toxicity to mammals is considered very low. **Simazine** and **atrazine** are the first s-triazines introduced and used extensively in maize. These are also selectively applied to perennial crops, orchids and in non-crop situations.

Tribufos

Defoliants are substances that induce premature shedding of leaves and facilitate harvesting. Defoliants and **desiccants** are both harvesting aids, and are used as herbicides, as many are toxic in nature. They may be organic or inorganic.

Tribufos is a very effective defoliant for cotton and one of the many harvesting aids in use, for various kinds of crops.

Tricalcium phosphate

Tricalcium phosphate (**TCP**) is the calcium salt of orthophosphoric acid. It is also called calcium orthophosphate, calcium phosphate and tribasic. TCP is available naturally in phosphate rock and bone ash. It is used in the manufacture of phosphoric acid, ceramics, dentifrices, as a stabilizer for plastics and as an anti-caking agent in food.

$$2H_3PO_4+3CaCO_3 \longrightarrow Ca_3(PO_4)_2+3H_2O+3CO_2$$

Tricarboxylic acid cycle

Tricarboxylic acid cycle (**TCA cycle**) is another term for **Krebs cycle** or **citric acid cycle**.

Trichoblasts: See Epidermis

Trickle irrigation

Trickle irrigation is another term for **drip irrigation**. It involves frequent or almost continuous application of a very small amount of water to a given soil area. Plastic hoses, 1 to 2 cm in diameter, with emitters, are placed down the rows or around trees in such a way that only a small amount of potential root zone is wetted. Roots in the localized area absorb water rapidly because of the high water potential or water availability.

A major advantage of drip irrigation is a large saving in the total amount of water used. It has other advantages which include adaptability of the system to very steep land and ability to maintain more uniform soil water potential during the growing season. Potatoes develop an irregular shape and become less desirable if the tubers grow alternately rapidly and slowly because of a large change in the available water during the period of tuber development. (See also Irrigation; Irrigation methods.)

Triglyceride

Triglyceride is a naturally occurring ester of a normal acid (fatty acid) and glycerol. These are the chief constituents of oils and fats having a general formula $CH_2(OOCR_1)$ $CH(OOCR_2)$ $CH_2(OOCR_3)$ where R_1, R_2 and R_3 are of different alkyl chains.

The refining processes often yield commercial products in which the R chain lengths are the same. Saponification with alkali releases glycerol and alkali metal salts of fatty acids (soaps). Triglycerides represent a concentrated source of energy since oxidation provides more energy than an equivalent weight of protein or carbohydrate.

The chemical and physical properties depend on the nature of the fatty acids present. Saturated acids give rise to fats with a higher melting point, as in butter and lard. Unsaturation lowers the melting point of fats. Thus, unsaturated fatty acids are present in large amounts in the oil of plants, for example, oleic acid in olive oil and linoleic and linolenic acids in linseed oil.

Trihydrate magnesium carbonate

Magnesium carbonate trihydrate is used to overcome magnesium deficiency. Various formulae are possible depending on the method of preparation. One such typical formula is $Mg(OH)_2\,3MgCO_3{\cdot}3H_2O$.

Triple superphosphate

Triple superphosphate (**TSP**) is the most concentrated straight phosphate fertilizer available and is manufactured by adding phosphoric acid to rock phosphate, producing mainly water-soluble monocalcium phosphate with no calcium sulphate. The source of triple superphosphate is thus, a low-cost phosphate rock.

TSP contains nearly 2.5 times as much phosphate as single superphosphates (17 to 23% phosphorus or 44 to 52% P_2O_5). Owing to a high concentration of phosphorus, TSP is used widely in the production of high analysis compound fertilizers.

Triple superphosphate, also known as **concentrated superphosphate**, contains 45 to 50% monocalcium or water-soluble phosphate and 17 to 20% lime. Its concentrated form is cheaper to transport, store and apply when compared with the dilute form. In most processes, a large percentage of fluorine remains in the product, probably as fluorosilicate or calcium fluoride.

When triple superphosphate is used as a fertilizer, the yield from short season crops like cereals, potato and some vegetables is markedly higher. This fertilizer lets a weak root system establish itself firmly and supports the crop to stand during the growing period.

The following are the advantages of TSP: (i) It is a highly concentrated straight phosphate fertilizer. (ii) It has a low-cost source. (iii) Its manufacture requires small capital investment and low-skilled manpower. TSP has the following disadvantages: (i) Its total nutrient content is lower than that of ammonium phosphate. (ii) Its acidic character deteriorates storage bags. (iii) It is not suitable for blending with urea as it causes the latter to deteriorate.

Triple superphosphate is manufactured by the **Den process** and involves major operations such as (a) the reaction of phosphate rock with phosphoric acid, (b) the Denning step where the reaction solidifies from the liquid phase, the Denning time being 10 to 30 minutes as compared to 30 to 120 minutes for single superphosphate, (c) storage/curing in piles for 3 to 6 weeks, depending on the raw materials used, and (d) granulation. The reactivity of phosphate rock is more important in triple superphosphate production than in phosphoric acid production. Non-reactive rocks require longer reaction time or fine grinding, or both.

The Den process or direct slurry granulation process may prepare triple superphosphate either in a granular or non-granular form. The granular form of TSP is preferred for direct application or blending and the non-granular form for making compound fertilizers. Some of the advantages of the direct slurry granulation process are that the product is available at a lower cost and in denser and stronger granules. It uses conventional granulation equipment. The disadvantages are that the process uses phosphate rocks which have a short reaction time, resulting in a greater loss of soluble phosphorus (as P_2O_5) due to an incomplete reaction or a higher ratio of phosphoric acid. The chemical reaction involved in the production of triple superphosphate is:

$$Ca_3(PO_4)_2 + 4H_3PO_4 \xrightarrow{H_2O} 3Ca(H_2PO_4)_{2(aq)} + 172.58\ \text{kcal}$$

$$Ca_{10}(PO_4)_6F_2 + 14H_3PO_4 \longrightarrow 10Ca(H_2PO_4)_2 + 2HF$$

The product is disintegrated after discharging from the den and piled for curing. After a specified time, the run-off pile material is sold as a fertilizer. When required, the cured material is granulated, dried and screened, before despatch. Granular triple superphosphate is produced directly rather than from the powder fertilizer.

Triple superphosphate production processes

While there is a decline in the use of triple superphosphate (TSP) owing to an increased use of ammonium phosphates, TSP has the following advantages: (i) TSP is the most highly concentrated straight phosphate fertilizer with 44 to 48% phosphorus as P_2O_5, and is 40 to 45% water-soluble. (ii) Part of the phosphorus is derived from phosphate rock, a relatively low-cost source. Rock phosphate contains derived phosphorus (as P_2O_5) in the range of 25 to 30% depending on the Ca to P_2O_5 ratio in the rock.

The three main disadvantages in the use of TSP are that its: (a) total nutrient content is lower than that of ammonium phosphates, (b) acidic character causes deterioration of its bagging materials, and (c) unsuitability for mixing with urea causes physical deterioration.

The reactivity of phosphate rock is important more in the manufacture of TSP than in phosphoric acid. Hence, rock phosphate needs to be ground finely or a longer reaction time is required to be given, or both. The presence of carbonates causes a porous structure to be formed due to CO_2 evolution.

TSP is prepared either in granular or non-granular form. The granular form is preferred for direct application or for blending while the non-granular form is suitable as an intermediate for the production of compound fertilizers by the granulation process.

The basic chemical reactions involved in TSP manufacture are:

$$Ca_3(PO_4)_2 + 4H_3PO_4 + H_2O \longrightarrow 3Ca(H_2PO_4)_2{\cdot}H_2O$$

$$Ca_{10}F_2(PO_4)_6 + 14H_3PO_4 + 10H_2O \longrightarrow 10Ca(H_2PO_4)_2{\cdot}H_2O + 2HF$$

Large quantities of fluorine remain in the product as fluorosilicates or calcium fluoride. The economically optimum ratio of the acid to phosphate rock is best determined experimentally. As the CaO to P_2O_5 weight ratio increases from 1.35 to 1.70, the percentage of P_2O_5 derived from the rock decreases and that derived from the acid increases.

TSP production technology: The production technology involves 4 steps: (i) Reaction. (ii) Denning. (iii) Storage and curing. (iv) Granulation.

(i) In the reaction step, rock phosphate is ground. 95 to 98% of the ground rock phosphate, passed through a 100 mesh sieve, is mixed with phosphoric acid (1 kg rock phosphate of 34% P_2O_5 is mixed with 2.6 kg acid). The acid is of merchant grade with a P_2O_5 content of 52%. The reaction is carried out in a cone-mixer. A similar process known as **Kuhlman process** uses a mixer that has a high-speed stirrer in a cylindrical vessel.

(ii) In the denning (**den process**) step, the mixture from the reaction vessel goes to a den where it solidifies owing to continued reaction and crystallization of monocalcium phosphate. The denning process for TSP is faster than that for single superphospate (SSP). Denning takes 10 to 30 minutes for TSP compared to 30 minutes to 2 hours for SSP.

(iii) In the storage and curing step, the material removed from denning is stored in piles for curing. This requires 3 to 6 weeks, depending on the quality of raw materials. During curing, the free acid, moisture and unreacted rock contents decrease and the available phosphorus and the water-soluble P_2O_5 increase. Some quantity of fluorine compounds evolves which are scrubbed to prevent atmospheric pollution.

After storage and curing, TSP is ground to a 6-mesh screen (3.3 mm). This material is called **run-off-pile TSP** or **ROP-TSP** and is used for making compound fertilizers by agglomeration granulation. The granulated product is commonly used. The powdery form is not preferred because of its dusty nature and caking quality when moist.

(iv) In the granulation process, the milled and screened TSP is conveyed to a drum granulator where water is sprayed and steam is sparged underneath the bed to wet the material. The wet granules are dried in a rotary drier. The dried granules are screened, and the oversized and the fines are returned to the granulator. The dust and fumes from the drier are scrubbed or removed by the dust filter.

Ex-den granulation: In this process, phosphate rock is further ground and the den retention time is larger (25 to 45 minutes instead of 10 to 30 minutes). The product from the den directly goes to granulation instead of to curing. The granulated product is dried to get a product with a 4 to 6% moisture. Further reactions take place during storage.

The product is much easier to granulate than cured TSP because of the plasticity and heat content. This requires less recycle, water and steam, resulting in the saving of power and manpower.

The direct granulation process has the following advantages: (a) low cost, (b) dense and strong granules, and (c) interchangeability of granulation equipment with that for other ammonium phosphates.

The main disadvantages of the direct granulation process are that the short reaction time makes the unreactive rocks unsuitable, and there is greater loss of soluble P_2O_5 due to incomplete reaction.

In the first slurry granulation process, known as **Jacobs-Dorrco process**, ground phosphate rock and phosphoric acid (38 to 40% P_2O_5) are fed into steam-heated reaction vessels. The overall reaction time is 30 minutes and the reaction temperature is 90°C. The thick slurry is fed into a rotary drum granulator with a high proportion of recycle time. The moist granules are dried and screened and the product size material sent to storage.

In the improvements suggested by Leyshorr and Mangat, an aging conveyer is used to transport granules from the granulator to the dryer. Some moisture gets evaporated during transportation in the conveyor and this makes the granules less sticky in the drying operation. This reduces clogging in the feeding chutes. The oversized and the undersized granules, after screening, are crushed and recycled. The recycle ratio (the ratio of the recycle to the product) is 8:1 and 12:1 for the rotary drum and the blunger granulation respectively. This lower ratio for the rotary drum is caused by moisture evaporation due to a counter-current sweep of the air.

The utility requirements are about 40 kWh for electric power, 20 kg steam and 125,000 kcal of fuel oil per ton of product.

A process, very similar to Jacobs-Dorrco process, is used in Europe. However, spraying the slurry onto a cascading curtain of granules at the feed end of a cocurrent rotary dryer combines granulation and drying.

Tripolyphosphoric acid

Polyphosphoric acids have the general formula $H_{n+2}P_nO_{3n+1}$. Thus, when n=1, phosphoric acid (H_3PO_4) is obtained. When n=2, pyrophosphoric acid ($H_4P_2O_7$) is obtained. Similarly, n=3 gives tripolyphosphoric acid ($H_5P_3O_{10}$). It is made by heating phosphoric acid, or dehydrating it. Commercial polyphosphoric acids are a mixture of orthophosphoric acid, pyrophosphoric acid, triphosphoric acid and higher acids.

Tripolyphosphoric acid is a dehydrating and sequestering agent.

Trisaccharides

Trisaccharides are carbohydrates containing three monosaccharide units. These are low molecular weight products obtained by the condensation of monosaccharide units.

Tritium

Tritium is one of the three isotopes of hydrogen, and is radioactive.

Tropical forests

Tropical forests are those that grow in the wide spectrum between the Tropic of Cancer and the Tropic of Capricorn. This equatorial belt region has a diverse range of topographies, geographical variations, and temperatures (like sea coasts, the equatorial region, mountains, etc.) Hence depending on the terrain, there are many tropical forests.

The widely known tropical forest is the **tropical rain forest**. The other types grown in drier and arid environments are seasonal in nature. There are humid seasonal forests, savannah forests and semi-arid thorn forests. There also exist many sub-categories of forests with their own peculiarities of organic matter vegetation, fauna, etc., such as peat forest, swamp forests and semi-evergreen forests.

Tropical rain forests

Tropical rain forests are among the most prominent of **tropical forests**. There are grades of tropical forests, depending on the moisture content between the Tropic of Cancer and the Tropic of Capricorn.

Tropical rain forests receive very large amounts of rain throughout the year, the average levels being between 150 and 200 cm/year. The temperature is around 28°C. This area does not experience much seasonal change. Tropical rain forests are characterized by broad-leaved evergreen trees and include many flowering plants. They are a source of a large number of minor forest products, such as gum arabic, tannin, honey, wild palms, fruits, nuts, medicinal herbs and mushrooms. These forests create warm and moist conditions, and are found in parts of southern Mexico, the Amazon basins of South America, parts of Africa and Asia. These are also referred to as **equatorial forests**, when they are in the equatorial region.

The tropical rain forest is considered the most heterogeneous of all world plant assemblages, comprising hundreds of different species of trees within just one square kilometer area. In this situation, very little solar radiation (around 1%) reaches the surface of the soil. Therefore, the undergrowth is generally in the form of mosses and ferns. The forest also contains the earth's most diverse groups of **epiphytes** and parasites. The trees present an array of stratified canopies. Species tend to crown at various heights depending on the extent of sunlight incidence.

The tropical rain forest vegetation plays important functions in soil formation and utilization. It serves as a humus and nutrient source for soil inhabitants, a nutrient reservoir, and a protective soil cover. Under conditions of high annual precipitation, soluble nutrients are rapidly lost as a result of the continued leaching of the soil. The natural rain forest vegetation, however, prevents accelerated soil erosion and soil dryness, whereas unprotected surfaces continue to be affected by the high-energy rain drop impact causing significant soil erosion.

Tropical rain forests can be further sub-divided into more types such as peat forests, swamp forests and semi-evergreen forests, depending on the peculiar set of environment present in that area.

Tropical region

The region between the Tropics of Cancer and Capricorn is the tropical region. However, meteorologically, the tropics lie between 28.5° N and 18.5° S on both the sides of the equator or the **equatorial zone**. This region has high rainfall, dense forests and many infertile soils.

The tropical forests present intense biological activity and the largest variety of both animal and plant species. Millions of years of heavy rains, combined with high temperature and intense biological activity have left many soils deficient in nutrients.

Though rainfall in the tropics may attain the level of 150 to over 200 cm/year, water supply is relatively scarce. A high rate of evaporation due to the heat greatly reduces the effectiveness of precipitation, measured as the ratio of precipitation to evaporation. Most tropical areas derive 70 to 90% of their annual water supply from the organized water storage system. It is common for the largest rainstorm of the year to account for 10% or more of the annual rain.

Tropical semi-arid regions

Semi-arid regions are those lands where moisture is limited, although it is higher than in arid regions. In tropical semi-arid regions, the annual precipitation can reach as high as 114 to 127 cm.

True density of soil

True density is one of the measures of **density**. It is defined as the mass of a substance per unit volume, excluding voids between the particles and the pores within the particles. An air pycnometer is used to determine true density.

The pycnometer has two sample chambers of equal size. One is flooded with a measured volume of air, while the other is filled with a weighed amount of the soil test sample and then flooded with a measured volume of air. The difference in air volumes is the true volume of the sample. Based on the sample weight and volume, the true density is calculated, which changes with temperature and pressure.

True density is useful in process control and design of process equipments.

True fruits: See Fruit

Truog's reagent

The Truog's reagent is 0.002N H_2SO_4 used to extract the available phosphorus in the soil.

TSP

TSP is short for **triple superphosphate**, obtained by treating rock phosphate with phosphoric acid. It contains around 46% phosphorus (as P_2O_5).

TSP production technology: See Triple superphosphate production processes

T-table

The T-table is a statistical table, giving critical values of the t-distribution. Critical values are such values that will be exceeded, with a given probability, even if the hypothesis is true.

T (tee) reactor for the manufacture of fluid fertilizers

The T reactor is a kind of pipe reactor. It consists of a 5 to 15 m long corrosion-resistant pipe to which, ammonia, phosphoric acid and sometimes water are simultaneously added at one end through a T-shaped piping, which gives it the name T (tee) reactor. In a simple reaction chamber, anhydrous ammonia and phosphoric acid react to produce a mixture of ammonium, orthophosphate and polyphosphates.

The pipe reactor is relatively simple and inexpensive to operate and dispenses with the need of pumping the slurries. Its main advantage is that it can produce more concentrated slurry than a pre-neutralizer, and thus require much less process water.

T-test

The T-test examines the significance of a sample mean as well as the significance of the difference in two samples, using statistical procedures. The test may also be used to define the confidence intervals for the true value of certain phenomena. Some of the tests are (a) T-test, (b) Chi-square test, and (c) **F-test**.

For all these, the parent population is assumed to be normal. Although these tests are applicable to all sample sizes, they are, in practice, applied to small and moderate sized samples only; for large samples, normal approximations are easier and quicker. Suppose x_1, x_2, x_3.....x_n is a set of 'n' observations recorded to test the significance of the difference between the mean and some assigned true mean value μ. To carry out the test, the population variance (the square of standard deviation, S) is given by

$$S^2 = \frac{1}{N-1} \Sigma (X_i - \bar{X})^2$$

where X_i is the value of samples, $\bar{X}$ is the mean of the population, n is the sample size and S^2 is the variance. Then the Students' t is given by the formula:

$$t = \frac{(\bar{X} - \mu)\ (n-1)}{S}$$

Here, μ is the mean of the population and $\bar{X}$ is the sample mean.

After calculating the absolute value of t, that is $|t|$, it is compared with the table value available in statistics books. For different values of the degrees of freedom the table gives the value of $t_{0.05}$ and $t_{0.01}$, which are defined as:

$$P\,[|t| > t_{0.05}] = 0.05$$
$$P\,[|t| > t_{0.01}] = 0.01$$

If the calculated value of $|t|$ exceeds $t_{0.05}$ from the published tables, the difference between $\bar{X}$ and μ is significant at 5% level, and the value is not acceptable. It exceeds $t_{0.01}$, the difference is said to be at 1% significance level or just highly significant. If $|t| < t_{0.05}$, the data is considered consistent with the hypothesis that μ is the mean of the population.

To test the significant difference between two means $\bar{X}_1$ and $\bar{X}_2$ of sample sizes n_1 and n_2, the Students' t is given by:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad \text{or} \quad S^2 = \frac{\Sigma (X_1 - \bar{X}_1)^2 + \Sigma (X_2 - \bar{X}_2)^2}{(n_1 + n_2) - 2}$$

X_1, X_2, $\bar{X}_1$, $\bar{X}_2$, S, n_1 and n_2 have the same meaning as above. (See also Significant difference in analysis.)

Tundra soil

Tundra soils are present in very cold regions near the Poles. These soils are dark brown with a high organic content. They grow dwarf shrubs and mosses.

Tundra soil is one among the six soil zones in the world. Within each zone, there may be various **soil types**. Most of the soils have **permafrost** which inhibits the downward movement of water and contributes to soil wetness when frozen soil melts during summer. Trees grow poorly in these soils. Few people inhabit the tundra region. The reindeer browse on tundra vegetation that may be readily contaminated with radioactive elements that fall out of the atmosphere.

Tunnel drying: See Drying

Turbidimetry

Turbidimetry is a technique wherein the intensity of transmitted light is measured as a function of concentration of the dispersed phase. It measures the degree of opacity of the suspension. Solutions containing fine particles, not visible to the naked eye, scatter light. This technique is not as sensitive as **nephelometry**.

Turgidity: See Turgor

Turgor

The condition of a plant cell when its vacuole is distended with water, pushing the protoplast against the cell wall, is called turgor. That is, an increased vacuole volume stretches the cell wall due to the water intake. In this condition, the hydrostatic pressure of the protoplast against the cell wall balances the force that causes water to enter the cell by osmosis. The cell, inflated with water, stretches the cell wall, developing a moderate pressure potential called **turgor pressure** or **turgor potential**, which helps to expand the growing cell and stiffen the plant tissue.

When the cell walls in plants get distended owing to an increase in the vacuole volume, they are said to be turgid. **Turgidity** assists in maintaining the rigidity of the plant. Decreased turgidity results in wilting.

Turgor potential: See Turgor

Turgor pressure

Turgor pressure is the synonym of **turgor potential**.

Turkish wheat grass

Turkish wheat grass is another name for **tegmar**.

TVA basic process for MAP and DAP production: See Monoammonium and diammonium phosphate production processes

T value

The T value is short for the soil loss tolerance value and is defined in two ways: First it represents the maximum soil erosion loss that is offset by the theoretical maximum rate of soil development which maintains equilibrium between soil losses and gains. Shallow soils over hard bedrock have small T values. Erosion on soils with clay pans may result in shallower rooting depths and smaller T values than for thick permeable soils, as both kinds of soils have developed from thick and water-permeable unconsolidated parent materials. The emphasis is on the maintenance of a certain thickness of soil overlying any impermeable layer that might exist.

Second, the T value is also the maximum average annual soil loss that will allow continuous cropping and maintain soil productivity without additional management inputs. Fertilizers are used to overcome the decline in soil fertility caused by erosion.

TVA pipe-cross reactor process for DAP granulation: See Monoammonium and diammonium phosphate production processes

1:1 type clays

1:1 type clays are layer silicate clay minerals. They contain one silica sheet and one alumina sheet. Kaolinite is the most important clay mineral in this group.

2:1 type clays

Clays are the active mineral portion of soils, with particles less than 2μm in diameter. Clays are predominantly colloidal and crystalline aluminosilicates. The planes of oxygen atoms with silicon and aluminum ions in between, makes a layer. Aluminosilicates are composed of layers of hydrated aluminum and magnesium silicates, which form a crystal lattice. There are three major types of crystalline clay minerals, namely, **1:1 type**, 2:1 type and 2:1:1 type. When a structure is made up of 2 silica sheets for every 1 aluminum sheet (or 2 tetrahedral and 1 octahedral sheet per layer), the clay is said to be of a 2:1 type. It is also called three-layer type clay. 2:1 type clays either have expanding structures or non-expanding structures. Montmorillonite groups of vermiculite clays have an expanding structure, whereas illite groups of clays which have one layer of Al-octahedra and two layers of silica-tetrahedra, are of the non-expanding type.

The cation exchange capacity, for example, increases to a peak with weathering in soils, dominated by 2:1 clays (moderately weathered). This is followed by a very low cation exchange capacity in soils dominated by oxidic clays (intensively weathered). 2:1 clays are transformed into 1:1 clay by the loss of Si-O tetrahedral sheet. This is a formation mode of kaolinite. Cation replacement in minerals (isomorphic substitution) occurs predominantly in 2:1 minerals while very little substitution is seen in 1:1 minerals. The negative charge associated with 2:1 silicate minerals is due to isomorphic substitution of either the Si^{4+} or Al^{3+} cation with cations of lower charge. This negative charge on the surface is uniformly distributed and is permanent. It is independent of the solution pH. The 2:1 clays generally, have a higher cation exchange capacity compared to 1:1 clay minerals.

2:2 type clays

Clays are made up of planes of oxygen atoms interspersed with silicon and aluminum ions, each of such structures forming a layer. When such a structure is made up of 2 tetrahedral and 2 octahedral sheets per layer (2:2 type clay), it belongs to the **chlorite** group. Although these are often called 2:2 type clays, strictly speaking they are 2:1:1 type clays. This clay mineral consists of an interlayer hydroxide sheet in addition to the 2:1 structure referred above. A layer of chlorite has 2 silicate tetrahedral units, one alumina octahedral unit and one magnesium octahedral sheet. Such clays contain O, Si, Al, K, Mg, Fe and do not swell when wet. (See also Chlorite.)

Tyrosinase

An enzyme containing copper, which occurs in plant and animal tissues is known as tyrosinase. The enzyme is responsible for turning peeled potatoes black when exposed to air.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

U

UAN solution

UAN is short for **urea-ammonium nitrate**. The aqueous solution of UAN (the UAN solution) is a liquid fertilizer based on urea and ammonium nitrate, which is easy to handle and apply. It is sometimes called **URAN**, short for urea ammonium nitrate.

UAP

UAP is short for **urea-ammonium phosphate**.

UAS fertilizer

UAS fertilizer stands for **urea-ammonium sulphate fertilizer**. Urea-sulphate granules with grades ranging from 40-0-0-4S to 30-0-0-13S have been made by oil-prilling ammonium sulphate fines in molten urea. These prills are more resistant to attrition and less hygroscopic than urea prills. Mechanical blending of urea and ammonium sulphate is another way to make UAS.

UAW

UAW is short for **useful available water**. Soil water content not only influences plant growth, but also the soil strength, compatibility, trafficability, gas exchange and consistency (hardness when dry, friability when moist and stickiness when wet). The plant available moisture is estimated by subtracting the percentage of water held at **permanent wilting point** from the percentage held at field capacity.

Udalfs

Udalfs are **alfisols** that have a udic soil moisture regime and mesic or warmer soil temperature regimes. They generally have brownish colors throughout and are not saturated with water for long periods of time. Hence udalfs are useful for most crops. (See also Alfisols.)

Uderts

Uderts are the **vertisols** of humid climatic realms. Their cracks open and close rather irregularly, depending upon the weather. In fact, some years may experience no cracking of uderts at all, although this occurs less than 50% of all years. Deep cracks remain open continuously for about two months or intermittently for periods that add up to less than three months. (See also Vertisols.)

Udic regime

Udic regime is a soil moisture regime, indicating that water supply in the soil is adequate throughout the year. This means that for most of the year, the control section is not dry in any part for 90 cumulative days, and is not dry in any part for 45 consecutive days during the four months following the summer solstice, when the soil temperature at a depth of 50 cm is above 5°C.

Udolls

Udolls are mollisols that have a udic soil moisture regime with a mean annual soil temperature of 8°C or more. They have no calcic or gypsic horizon and are not saturated with water for long periods and so they may be favorable to many crops. (See also Mollisols.)

Udults

Udults are ultisols that have a low-to-moderate quantity of organic carbon, reddish or yellowish argillic horizons, and a udic soil moisture regime. Udults are not saturated with water for periods long enough to limit their use for most crops. (See also Alfisols.)

UG

UG is short for **urea-gypsum**, which is an adduct of urea with gypsum and contains around 37% nitrogen.

Uhde closed scrubber system: See Environmental impact of fertilizer industry

Uhde-Gmbh process for DAP production: See Monoammonium and diammonium phosphate production processes

Uhde medium pressure process for nitric acid: See Nitric acid production processes

Uhde methodology for pollution control: See Environmental impact of fertilizer industry

Uhde neutralization process for ammonium nitrate production: See Ammonium nitrate production processes

Uhde technology: See Ammonia production processes

Ultimate analysis of coal

The ultimate analysis of coal determines the total percentage of elements present in coal. (See also Coal.)

Ultisols

Ultisols, which is closely related to alfisols, is one of the 12 soil orders that comprises 8.5% of the earth's ice-free land area. Ultisols have an argillic or kandic horizon and a low base saturation (less than 35%) in lower subsoil horizons. These soils are developed under forest vegetation in humid climates. Ultisols have a mean annual soil temperature of 8°C or higher.

Ultisols are soils of mid-to-low latitudes that have a horizon in which there are translocated silicate clays but only a small supply of bases.

Ultisols are less productive than soils in many other orders. However, the productivity of these soils can be enhanced and maintained with proper management of organic residues, fallow periods and/or chemical inputs. If fertilizers are not appropriately added, these soils wear out. Suborders of the ultisols are aquults, humults, ustults and xerults.

Ultracentrifuge

Ultracentrifugation refers to a sedimentation process of suspended particles subjected to very high centrifugal forces (in a centrifuge). Since different kinds of particles sediment at different centrifugal rates, the process offers a convenient means of ascertaining the homogeneity of suspension. Molecular weights and sizes of sedimenting particles can also be determined from the rates of sedimentation.

Ultracentrifuge is an apparatus that develops a centrifugal force as high as a few million times that of gravity, and is used primarily in biochemical and molecular biology research to separate substances from a solution (Fig. U. 1).

Fig. U. 1: An ultracentrifuge.

Historically, however, ultracentrifuges were developed for analytical purposes to determine the size of colloidal particles. Its other uses are in research on proteins, molecular weight distribution, macromolecular structure and properties and separation of solutes from solution. (See also Centrifuge.)

Ultra filtration

Filtration is a process of separating solid particles from a fluid, using a filter. Ultra filtration is filtration under pressure.

Ultra low volume sprayer

A **sprayer** is a machine used for spraying a liquid through a nozzle under pressure. An ultra low volume (ULV) sprayer is used for foliar applications on a farm. The spray ejects minute droplets of the size of 60 to 70 microns. Wind can carry these droplets over the entire crop cover. However, since the ULV sprayer is prone to spray drift, it cannot be used to apply strong herbicides or toxic chemicals.

The ultra low volume sprayer is also called the **ULV sprayer** or the ultra low volume applicator.

ULV sprayer: See Ultra low volume sprayer

Umbrepts

Umbrepts are **inceptisols** formed in cold or temperate climates commonly with an umbric epipedon, and possibly with a mollic or an anthropic epipedon 25 mm or more thick under certain conditions. These soils are not dominated by amorphous materials and are not saturated with water for periods long enough to limit their use for most crops.

Umbric

Three special zones or layers have been defined in soil taxonomy for purposes of classification. They are epipedons, diagnostic horizons and the control section. Of the six epipedons recognized in soil taxonomy, umbric is one which, like mollic, is with base saturation less than 50%.

Umbric horizon is a surface horizon (or epipedon), which is acidic and dark colored. In terms of color, consistency, structure, thickness, and organic carbon and phosphorus contents, it is like a mollic horizon, except that it has less than 50% base cation saturation when measured at pH 7. (See also Soil horizons.)

Umbric horizon: See Umbric

Undrained soil

Undrained soil is one that has slow internal drainage because of its clay texture or dense impermeable horizon. Such soils have yellow and red mottles in the wet zone. Mottles are spots where iron is reduced and re-oxidized, indicating a fluctuating water table or temporary wetness.

The **USDA** recognizes seven soil drainage classes. They are: very poorly drained soils, poorly drained soils, imperfectly drained soils, moderately well-drained soils, well-drained soils, somewhat excessively drained soils and excessively drained soils. (See also Soil drainage class.)

Uniformity coefficient of irrigation

The uniformity coefficient (UC) of irrigation is measured as:

$$UC = 1 - \frac{Y}{D}$$

where y is the average volume of irrigation water (in terms of depth of water) infiltrated or caught, and d is the average depth of water infiltrated or caught. This coefficient indicates the degree to which water has been applied and has penetrated uniformly throughout the field. When each value represents an equal area and when deviation from the average depth is zero, the uniformity coefficient is 1.0. UC values of above 0.8 are acceptable.

A useful measurement of the effectiveness of irrigation is the **uniformity of water distribution** or **irrigation efficiency**.

Uniformity of water distribution: See Uniformity coefficient of irrigation

Unit leaf rate

Unit leaf rate is another term for **net assimilation rate**.

Universal reagent

Universal reagent is a mixture of indicators. Each indicator gives a relatively stable color at a specified pH. The reagent enables one to approximately determine the pH of the soil sample solution or of water extract.

Universal soil loss equation

The rate of soil erosion on an agricultural land is affected by the rainfall characteristics, soil erodibility, slope characteristics, vegetative cover and/or management practices. The quantitative data forms the basis for predicting the erosion rate by using the universal soil loss equation developed by Wischmeier and Smith. The universal soil loss equation (**USLE**) given below, is widely used in the USA to predict the extent of erosion from farm fields. The equation, first proposed in 1965 in the USA with six factors, is considered universal because it is sufficient to describe the soil erosion process.

$$A = RKLSCP$$

where A is the long term average soil loss, R is the long term average rainfall run-off erosivity factor, K is the soil erodibility index, L is the slope length factor, S is the slope angle factor, C is the soil cover factor and P is the erosion control practice factor. The equation is designed to predict water erosion rates on agricultural land surfaces, exclusive of erosion resulting from the formation of large gullies. (See also Wischmeier and Smith equation for water erosion prediction.)

Unsaturated flow of water

Unsaturated flow is the flow of water held with water potential lower than minus 1/3 bar. Water will flow toward the region of lower potential. This means that in a uniform soil, water moves from the wetter to the drier areas of the soil mainly because of the downward pull of gravity.

When there is rain or irrigation, water moves into the soil which is called **water infiltration**. When the soil profile is wet and water moves through it, it is called **percolation**. The movement of water by gravity is called **saturated flow**. In an unsaturated soil, the flow is faster if there are large and continuous pores in the soil.

Organic matter helps to keep infiltration high. When water potential is higher than minus 33 kPa, the water flow through the soil is saturated. When water potential is lower than minus 20 to minus 30 kPa, the water flow is called unsaturated. The unsaturated flow goes toward the drier areas and in any direction. Its rate increases as the water potential gradient increases and is faster (several centimeters per hour) when the soil is wetted approximately to its **field capacity**. When the soil is near the permanent wilting percentage, the flow is very slow.

In general, water movement in an unsaturated zone is vertical but it can also have a significant lateral movement. The most important parameters in the unsaturated flow are the unsaturated hydraulic conductivity and, to a lesser extent, the water capacity functions. These two parameters depend on the pore-size distribution. In both the saturated and unsaturated cases, water flows under a hydraulic gradient. In saturated flow the hydraulic head is most important and in unsaturated flow it is the matric potential which is most important. Unsaturated flow is more common than saturated flow.

Unsaturation of chemical compounds

Unsaturation of a chemical compound is one in which not all the available valence bonds of carbon in the alkyl chain are satisfied. In such compounds the extra bonds usually form double or triple bonds (mainly with carbons). Thus unsaturated compounds are more reactive than saturated compounds, as other elements readily add to the unsaturated linkage. An unsaturated compound (ethylene butadiene, benzene) has fewer hydrogen atoms or equivalent groups than the corresponding saturated compound (ethane, butane or cyclohexane).

In structural formulae unsaturation may be represented by parallel lines joining carbon atoms (ethylene $CH_2=CH_2$, butadiene $CH_2=CH\text{-}CH = CH_2$ or by colons or triple dots, $CH_2 : CH_2 \cdot CH : CH$).

Unslaked lime

Calcium oxide is also known as unslaked lime, **burned lime** or **quicklime** and is used for liming purposes, especially when unusually rapid neutralization is required. It has a neutralizing value of 179% as compared to 100% for calcium carbonate. (See also Liming materials.)

UP

UP is short for **urea-phosphate**, a crystalline adduct of urea and orthophosphoric acid. It is a solid fertilizer and the general commercial grade available is 17-44-0. Urea phosphates of lesser purity are used for the production of suspension fertilizers.

Upland moor peat

Upland moor peat, also called **black peat**, is a highly decomposed type of peat, used as raw material for making **peat** fertilizers.

Uptake of nutrients

Water and nutrients are absorbed at sites located on or at the surface of the roots. The absorption of nutrients and water by the roots is dependent on the surface area-density of roots. Mathematically, uptake = availability × surface area and density. The **nutrient uptake** is the nutrient taken up by the plant from the soil or atmosphere in a given period. The absorption of nutrients by plants depends on the stage of crop growth. For example, cereal grain absorbs around 20 kg of nitrogen, 10 kg phosphorus and 25 kg of potassium per ton of grain produced. (See also Nutrient uptake.)

URAN

URAN, short for **urea ammonium nitrate**, is a liquid fertilizer used in foliar and soil application.

Urban compost

Urban compost or **town compost** is the compost made from the wastes of urban areas and industry. (See also Compost.)

Urban waste

Urban waste comprises solid waste materials including garbage, cellulosics, glass, metals, etc, but not sewage (municipal waste). Garbage is used in some countries both directly as a fuel and fermented to yield proteins. The cellulosic portion can be hydrolyzed to glucose, which, in turn, is converted to methane by anaerobic fermentation. A continuous process for this operation utilizing waste newspapers or sawdust also exists.

Urea

Urea, $CO(NH_2)_2$, also referred to as carbamide, is a white, crystalline, organic, water-soluble fertilizer. It contains around 46% nitrogen, the highest N percentage any solid fertilizer can have.

Apart from its major use as a fertilizer, urea is also employed in the manufacture of paints, glues, plastics, paper, textiles, feed and weed control chemicals as well as a source of non-protein nitrogen.

Urea (Fig.U.2) is an acceptable fertilizer for rice and preferable to nitrates for flooded rice because of the reduction of nitrates to N_2O and/or nitrogen (in anaerobic conditions) which is lost to the atmosphere. Also, rice can utilize the ammonium form of nitrogen efficiently. Hydrolysis and nitrification (in aerobic conditions) are rapid in tropical, sub-tropical and warm climates.

Urea can thus be used efficiently but its use requires a better understanding than that required for other inorganic salts. It is applied to flooded soil three times: at the time of planting, tillering and panicle development. Similar to other nitrogenous fertilizers, urea promotes the growth of both weeds and crops. Urea solution after evaporation in vacuum evaporators, can be finally spray-dried into pellets or prills. When protected from moisture (to which it is susceptible), urea is non-caking, free-flowing and suitable for storage and handling.

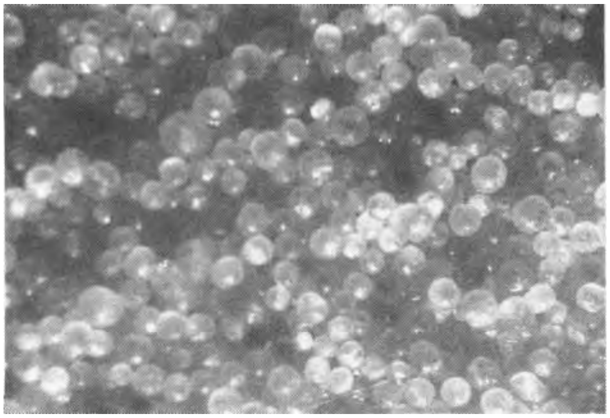


Fig. U.2: Urea granules.

However, the benefits of urea outweigh its disadvantages. Insofar as the weed growth is concerned, effective methods should be devised to minimize it to a manageable level.

Urea is converted rapidly to ammonia by hydrolysis in the soil via the ammonium carbonate formation route, the latter being unstable (decomposing to ammonia and carbon dioxide). Urea is not as quick acting as ammonium nitrate because the nitrifying bacteria require a few days of warm and moist soil conditions to convert ammonia to the nitrate form. The formation of ammonium ion is slightly acidic in its ultimate reaction with the soil.

Urea is decomposed by the enzyme urease and a part of urea is lost as gaseous nitrogen. The time between urea application and the first availability of water to the soil is important, as also the temperature, because the enzyme is less reactive in cold than at high temperature (25 to 30°C). Prevention and retardation of the hydrolytic action of urease is important following the addition of urea to soil. This may help to avoid difficulties associated with ammonia formation and alkalization.

Many substances are urease inhibitors, but very few meet the rather specific requirements of being (a) effective at low concentrations, (b) relatively non-toxic to higher forms of life, (c) inexpensive, and (d) compatible with urea.

Urea can be sprayed on leaves and can also be mixed with insecticides or herbicides for soil application. A urea-ammonium nitrate mixture with herbicide is also used for weed control.

Urea, although an excellent fertilizer, suffers from the following drawbacks: (i) When applied to a bare soil surface, urea hydrolyzes rapidly and loses a significant quantity of ammonia by volatilization. Such losses vary from soil to soil and are greater for urea in a pellet form rather than in a solution form. Burning residues on the field is suggested as a practical means to control the ammonia loss because the burning reduces the concentration of the enzyme urease in plants. (ii) Rapid hydrolysis of urea in soils can cause injury to the seedlings by ammonia, if large quantities of the fertilizer are placed too close to the seeds. (iii) The fertilizer grade urea may contain toxic biuret which is formed during urea manufacture by an excessive temperature rise. A large concentration of biuret in urea (> 2%) causes injury to plants.

Feed-grade urea is sometimes referred to by the number 262 which is the product of its nitrogen content (42%) multiplied by 6.25, the latter being the factor used by chemists to convert nitrogen to its protein equivalent.

Urea is sometimes phytotoxic when placed close to seeds or seedlings. The phytotoxicity is caused by high local concentrations of ammonia during the hydrolysis stage or by accumulation of nitrite during the nitrification step. Another possible cause is the presence of biuret impurity in urea.

The whole series of **urea-formaldehyde compounds**, ranging from soluble to completely water-insoluble, are produced by reacting urea with formaldehyde in different ratios. The fertilizer grade contains a minimum of 35% nitrogen, largely water-insoluble but in a gradually available form. The suitability of these compounds as fertilizers also depends on the quantity and quality of cold-water-insoluble nitrogen. The solubility reflects the rate at which the nitrogen becomes available. Formaldehyde-treated urea seems to be more waterproof and less subject to dissolution by light showers or heavy dew.

In addition to the marked improvements in the size, strength and density of granular urea, urea has a number of good characteristics compared to ammonium nitrate. These include its (a) lesser tendency to stick and cake than ammonium nitrate, (b) insensitivity to fire and explosion, and (c) resistance to corrosion during handling and applying.

A popular urea-formaldehyde product in the USA contains 38% nitrogen (of which 28% is water-insoluble) and has an activity index of 50. Urea-formaldehyde products are used to fertilize sod and certain speciality crops. As a result of the slow nitrification pattern, urea-formaldehyde prevents excessive leaching of nitrates. The use of urea-formaldehyde is not popular because it is costlier than the other nitrogenous fertilizers.

The condensation product of urea and acetaldehyde is commercially known as **urea-z**. It is a slow-release nitrogen fertilizer containing around 31% nitrogen. **Urea crotonaldehyde**, a derivative of urea (also known as **crotonylidene diurea**), is also a slow-release nitrogen fertilizer.

Urea-sulphur is a relatively new compound containing 40% nitrogen and 10% sulphur. The prilled material has excellent physical properties. Its urea part dissolves after being applied to the soil, leaving elemental sulphur that is converted into sulphate by the oxidizing bacteria.

Adding urea slurry to diammonium phosphate slurry (before or during granulation) makes urea-phosphate which has a higher nitrogen-to-phosphorus ratio than the ammonium phosphate does; the product contains 29% nitrogen and 12.7% phosphorus (29.0% P_2O_5).

A new liquid fertilizer material [$CO(NH_2)_2 \cdot H_3PO_4$] is made by the reaction of urea, phosphoric acid and water. Depending on the ratio of the reactants, the nitrogen content varies from 10% to 28% and the phosphorus content from 9 to 18%. (See also Urea production processes.)

Urea-ammonium nitrate solution

A urea-ammonium nitrate (**UAN** or **URAN**) solution is prepared by dissolving solid urea in aqueous ammonium nitrate solution. A 75 to 80% **urea solution** at 120°C is mixed with ammonium nitrate (80 to 85%) solution at 40°C. Water is then added to make up the desired concentration and the solution is cooled to obtain the desired ammonium nitrate to urea ratio.

URAN or UAN represents the most popular, non-pressure nitrogen solution. The principal non-pressure solutions have 28, 30 and 32% nitrogen. Each URAN solution has a specific **salting-out temperature** which is the temperature below which salts precipitate from the solution. The salt-out temperatures are minus 18°C, minus 10°C and minus 2°C for 28, 30 and 32 percent nitrogen grades, respectively.

URAN or UAN solutions are added directly to grasses or cereals. These are used mostly directly or by broadcasting or band application. The solutions can also be sprayed or mixed with irrigation water. The nitrogen solutions are often added directly to grasses and small grains. This is popular in several countries because it is (a) safe and easy to use, (b) easy to inject into irrigation systems, (c) safe to handle and store, (d) uniform in surface application, (e) easily transported in pipe lines, barges and railcars, (f) cheaper to produce than most solid fertilizers, and (g) an excellent source for making NPK fluid mixtures.

Urea-ammonium phosphate

Various combinations of urea and ammonium phosphate produce urea-ammonium phosphate (**UAP**) fertilizers, which can be of different concentrations.

Ammonium phosphate is supplied either as a slurry (produced by ammoniation of phosphoric acid) or in a solid form as mono-ammonium phosphate (**MAP**) or diammonium phosphate (**DAP**), while urea is supplied as a solid (crushed prills or crystals) or as a melt or as a concentrated solution. Several types of granulators are used. The standard grades produced are: 28-28-0, 22-22-11 and 18-18-18. Urea is incorporated into ammonium phosphate by the slurry granulation process. These are produced at fertilizer factories. The UAP produced in Coromandel Fertilizers Ltd. in India, for instance, has a plant nutrient specification of 28-28-0.

In the melt granulation process, ammonium polyphosphate melt and molten urea are coagulated in a pugmill to give 28-28-0 as well as 35-17-0 grades. UAP is prilled into a dense mass, with an average diameter of 1.5 mm. (See also Polyphosphate fertilizers.)

Urea-ammonium polyphosphate

Urea-ammonium polyphosphate is a mixture of urea and ammonium polyphosphate in an aqueous solution. It is used as a fertilizer. The addition of 99.5% urea solution to ammonium polyphosphate (APP) gives granular urea-APP with a product analysis of 28-28-0.

Urea-ammonium sulphate fertilizer

Urea-ammonium sulphate (UAS) is a liquid fertilizer, produced by mixing 21.2% ammonium sulphate with 37.6% urea and water to get a total nitrogen content of 22%. The salting-out temperature is 40°C. Adding ammonium thiosulphate can lower the salting-out temperature. Granular-urea sulphate with grades ranging from 40-0-0-4S to 30-0-0-13S has been made by oil prilling preparations of ammonium sulphate fines in molten urea. This liquid **UAS fertilizer** can also be made by reacting sulphuric acid with urea:

$$CO(NH_2)_2 + H_2SO_4 \longrightarrow (NH_2)_2CO \cdot H_2SO_4$$

These solutions (pH 1.0) are highly acidic and corrosive. Hence the reaction vessel must be made of special molybdenum steel or should have a polythene lining. Urea-ammonium sulphate granules are more resistant to attrition and less hygroscopic than urea prills and can be further improved by the addition of gypsum which forms a complex with urea.

Tennessee Valley Authority (TVA) has also manufactured a 29-0-0-5S urea-ammonium sulphate suspension fertilizer based on urea (70% aq. solution), sulphuric acid (93%), anhydrous ammonia and water. Clay (~ 2%) is used to give the final product.

Urea-APP

Urea-APP is short for **urea-ammonium polyphosphate** which is made by the melt granulation process, analyzing to 28-28-0 and 36-17-0.

Urea briquettes

A compressed material cut into blocks or bricks is called a briquette. Briquettes are generally used in soil application areas, like in the case of peat, coal dust, etc.

Urea briquettes are also known as **urea supergranules**.

Urea-crotonaldehyde

Urea-crotonaldehyde, also known as **crotonylidene diurea**, is a derivative of urea. It is a slow-release nitrogen fertilizer. Powdered urea-crotonaldehyde containing 30% nitrogen can be used directly as a fertilizer. Floranid, a commercial product with a 28% nitrogen content, having crotonaldehyde-urea (90%) and nitrate nitrogen (10%), is available. The microbial transformation of chemically-bound nitrogen in this fertilizer is temperature dependent.

Urea finishing process: See Urea production processes

Ureaform

Combining urea with varying amounts of formaldehyde makes ureaform, with about 38% nitrogen. In a sand-sized pellet form, ureaform looks yellowish white in color, and absorbs water without losing its physical condition. In this fertilizer, nitrogen is available to plants very slowly. It is not easily soluble and does not leach out of the root zones of plants. Ureaform is mostly used for lawns, golf greens or turfs, and not so much for field crops.

In the manufacture of urea-formaldehyde, a slow-release fertilizer, the oligomer condensation is not always in the desired proportions. Urea-formaldehyde products are separated into three fractions: (a) CWS or cold water (25°C) soluble, (b) **HWS** or hot water (100°C) soluble, and (c) **HWI** or hot water insoluble. These products are used in warmer climates.

The nitrogen release from ureaform varies with the urea content. This is expressed by the **activity index (AI)** and is calculated on the basis of the water-soluble fraction of the fertilizer under various conditions.

$$\text{Activity index} = \frac{\%\ \text{CWIN} - \%\ \text{HWIN}}{\%\ \text{CWIN}} \times 100$$

where CWIN is the percent nitrogen insoluble in cold water (25°C) and HWIN is the percent nitrogen insoluble in hot water (98 to 100°C).

Urea-formaldehyde compounds

A whole series of urea-formaldehyde compounds can be made by reacting urea with formaldehyde in different ratios. These compounds, instead of being definite compounds, consist of methylene urea polymers varying in the chain length, with larger molecules, and a degree of cross-linking. These compounds range from being soluble to being completely water-insoluble. The fertilizer grade contains a minimum of 35% nitrogen which is largely insoluble but in a gradually available form. The suitability of these compounds as fertilizers also depends on the quantity and quality of cold-water insoluble nitrogen, which reflects the rate at which the nitrogen will become available.

The use of urea-formaldehyde is not popular because it is costlier than other nitrogenous fertilizers.

Urea-formaldehyde foam as soil conditioner: See Synthetic soil conditioners

Urea-formaldehyde foams

Urea-formaldehyde foams (also known as **ureaform**) are condensates of urea with formaldehyde in a well-defined molar ratio. These are solid with rigid walls and little flexibility. Ureaform foams are produced with densities varying from 2 to 50 kg/m^3. Foams with densities of around 22 kg/m^3 are used as soil conditioners for mixing with soils and substrates. The cell walls are partly open and biodegradable. These white, odourless, solids contain 38% nitrogen and belong to a class of slow-release nitrogen fertilizers.

Ureaform, instead of being a definite compound, consists of methylene urea polymers varying in chain length, with larger molecules, and a degree of cross-linking. A whole series of compounds, ranging from being quite soluble to completely insoluble, is possible, depending on the mole ratio of urea formaldehyde and on the pH, time and temperature of reaction. The activity index of the ureaform depends on cold-water-insoluble and hot-water-soluble nitrogen.

Various grades of urea-formaldehyde foams, used as soil conditioners, are made water absorbent by modifying the condensate resin. Under vacuum, the water-retention capacity of the foam is more than 90% of its volume. At atmospheric pressure, the initial water uptake is slow but rewetting is very fast. Water release is uniform and reaches completion without losses by evaporation, so that the plants can use the water. Urea-formaldehyde foams optimize the air and water regimes in soils and substrates, lower the soil density, enhance the pore volume and increase the plant available water capacity. Plants respond to these foams with an improved shoot and root growth and a higher crop yield. Besides providing nitrogen, ureaforms can be used in the formulation of compound fertilizers containing other nutrients, such as phosphorus and potassium.

Urea-formaldehyde resins: See Coated fertilizers

Urea granulation: See Urea production processes

Urea-gypsum fertilizer

The addition of gypsum to a melt of urea gives an adduct which, upon granulation, gives an urea-gypsum (UG) fertilizer. It contains 36.8% nitrogen and supplies, apart from nitrogen, sulphur and calcium to plants.

Urea-phosphate

Urea-phosphate (UP) is made by neutralizing orthophosphoric acid (H_3PO_4) with urea $CO(NH_2)_3$. The resulting compound, $CO(NH_2)_2 \cdot H_3PO_4$ called carbamide phosphoric acid is a white, crystalline and dry powder. It is used as a fertilizer containing 17.7% nitrogen and 19.6% phosphorus, and also as an intermediate in the production of solid and liquid fertilizers. The typical grade available is 17-43-0.

$$CO(NH_2)_2 + H_3PO_4 \longrightarrow CO(NH_2)_2 \cdot H_3PO_4$$

Urea prilling: See Urea production processes

Urea production processes

Urea, $CO(NH_2)_2$, also called **carbamide**, is the most important nitrogenous fertilizer. It is a slow-release fertilizer, which undergoes two transformations in the soil before it is available to the crop. The first is hydrolysis, giving out ammonia; the second is the ammonia oxidizing to a nitrite form and then to a nitrate form. These reactions are rapid in warm climates and slow in cool soils, like those in Europe.

Comparatively a low cost of production and a high nutrient content make urea the world's leading, solid nitrogen fertilizer. More than 50 million tons of urea is now produced in the world annually. One third of this is from the Indian subcontinent.

Urea, as a cheap source of protein, is also used as a cattle feed. It is also a raw material for melamine plastics and for various glues like urea formaldehyde or urea-melamine-formaldehyde.

The various process-variables in the production of urea are the (a) temperature, (b) pressure, (c) mole ratio of ammonia to carbon dioxide (NH_3:CO_2), and (d) presence of water and oxygen.

The rate of conversion of ammonium carbonate to urea with no excess ammonia increases with temperature. It is maximum of about 50% at 170 to 190°C. The rate of reaction increases with temperature, and is slow below 150°C. Corrosion, which occurs and increases with temperature, is acceptable when the temperature is between 180 to 200°C.

At a constant temperature, the conversion increases with pressure only upto a critical point. The critical pressure is a function of temperature and composition. At the preferred temperature of 180 to 200°C, the pressures of around 140 to 250 atmospheres are used.

Excess ammonia above the stoichiometric mole ratio favors the rate of reaction. The percentage of carbon dioxide converted to urea is increased while that of ammonia is decreased. Because of easy recycling of ammonia compared to carbon dioxide, most processes use 50% or more of ammonia.

The presence of water decreases the conversion and the presence of a small amount of oxygen decreases the corrosion. Typical operating conditions are: 180 to 210°C, 140 to 250 atmospheres, NH_3:CO_2 mole ratio of 3:1 to 4:1 and retention time of 20 to 30 minutes.

Urea is manufactured by the reaction of anhydrous ammonia with carbon dioxide under very high pressure, in the presence of a catalyst, firstly to give carbamate and then urea. The reactions involved are

$$2NH_3 + CO_2 \longrightarrow NH_2COONH_4$$
$$NH_2COONH_4 \longrightarrow NH_2CONH_2 + H_2O$$

The reaction mixture is highly corrosive. The reaction cannot be completed in one pass, and the product decomposes at a relatively low temperature. Because of these problems, the development of efficient production methods for urea lagged considerably behind those for the other nitrogen fertilizers, such as ammonium nitrate and sulphate. Since the effluent from the urea reactor is an aqueous solution, containing urea and unconverted ammonium carbamate, the solution must be heated to remove the carbamate. The decomposition leads to a hot, gaseous mixture of ammonia, carbon dioxide and water vapor. Recycling this corrosive gas is probably the most difficult problem encountered in the development of urea synthesis.

Urea processes describe how unreacted materials are separated from the urea synthesis solution and recovered. These are considered below:

(i) **Total recycle process**: In the total recycle processes, the unconverted ammonia-carbon dioxide mixture is recycled through the urea reactor without any nitrogen. This is the most flexible of the urea processes, and also most expensive. The disadvantages are that the process reliability is low due to mutual dependence of any two production plants, inflexible proportions of the co-products and difficulties in synchronizing the operations of the two plants.

Effluents from urea plant contain urea, water of reaction, unconverted carbamate, and excess ammonia.

These need to be separated to form the urea solution and to recycle CO_2 and NH_3. The carbamate is decomposed to separate from urea and gives carbon dioxide (CO_2) and ammonia (NH_3) according to the following equation:

$$NH_2CO_2NH_4 \rightleftharpoons CO_2 + 2NH_3$$

Ammonia and carbon dioxide are removed as gases along with the water vapor. These CO_2 and NH_3 recombine and hence, the condensed and compressed gaseous mixture produces a carbamate solution.

Based on the recycle principle, the total-recycle processes are classified into five types: (a) hot-gas mixture recycle, (b) separated-gas recycle, (c) slurry recycle, (d) carbamate solution recycle, and (e) stripping. All the first four types use carbamate decomposition similar to the once-through or partial recycle processes. The stripping process is, however, completely different and will be treated separately.

(a) The hot-gas recycle process compresses the mixture of carbon dioxide, ammonia and water in five stages by reciprocating compressors to a pressure of 120 to 130 atmospheres and at a temperature of 260 to 270°C. It is cooled to 160°C to condense the gases. While these operating conditions did not lead to success, with centrifugal compressors operating at high temperatures of 400 to 540°C, the process was successfully demonstrated in large capacity plants.

(b) The separated gas-recycle method was developed to overcome difficulties of the hot-gas mixture recycle. Ammonia and carbon dioxide are compressed without the carbamate formation. Carbon dioxide from the decomposers is absorbed in monoethanolamine, and ammonia is recycled. The absorbed carbon dioxide is released by heating and recycled. Inventa (Switzerland) and CPI Allied (US) have developed processes of this type. The advantage is that the conversion is not reduced by recycling the water through the reactor, and that recycling of corrosive solution to the reactor is avoided. The disadvantage is that the costs of the make up monoethanolamine and heat recovery are high.

(c) In the slurry recycle process, light paraffin oil is added to a CO_2-NH_3-H_2O mixture. Carbamate forms a suspension with 35 to 40% oil which is pumped to a urea synthesis reactor with fresh carbon dioxide and ammonia. After decomposing the carbamate, the oil is separated from the urea solution by decantation for recycling. Pechiney (France) has developed a process based on this principle.

(d) Carbamate-solution-recycle system is the most popular total-recycle process. Different proprietary processes - such as Stamicarbon, Mitsui Toatsu, Montedison, and Snamprogetti - differ mainly in engineering details, heat recovery methods, and means of energy conversion. A typical total-recycle urea process of Mitsui Toatsu is given in Fig.U.3.

All solution-recycle processes involve absorbing carbon dioxide and ammonia in water and recycling it as an aqueous carbamate solution to the synthesis step. A minimum amount of water is to be maintained because any further water addition lowers the percentage conversion and increases the energy requirement for evaporating the excess water.

All solution-recycle processes use similar reactor conditions which include the maintenance of (a) the temperature at about 185°C and pressure of about 200 atmosphere, and (b) the ammonia to carbon dioxide ratio of about 4:1 in the synthesis loop. These conditions let conversion of 65 to 67% of carbon dioxide to urea conversion to be achieved for each pass. The overall conversion is more than 99% urea.

Several parameters are involved in the design of the carbamate-solution recycle system, and they are so interrelated and independent that it is difficult to analyze them separately.

(ii) **Stripping process based plants**: Stamicarbon of the Netherlands, Snamprogetti of Italy and Toyo Engineering Corporation of Japan have developed carbon dioxide stripping process technologies and built plants which are in operation. All of them have running plants, each producing more than 1700 tons of urea per day. The three processes closely approach stoichiometric values in raw material consumptions and have reduced steam consumption close to economic levels.

Stamicarbon's current technology is based on a pool reactor which reduces the number of high pressure vessels and thus the machinery cost. The flow diagram of **Stamicarbon process** is given Fig.U.4. Snamprogetti and Toyo designs aimed at achieving high ammonia to

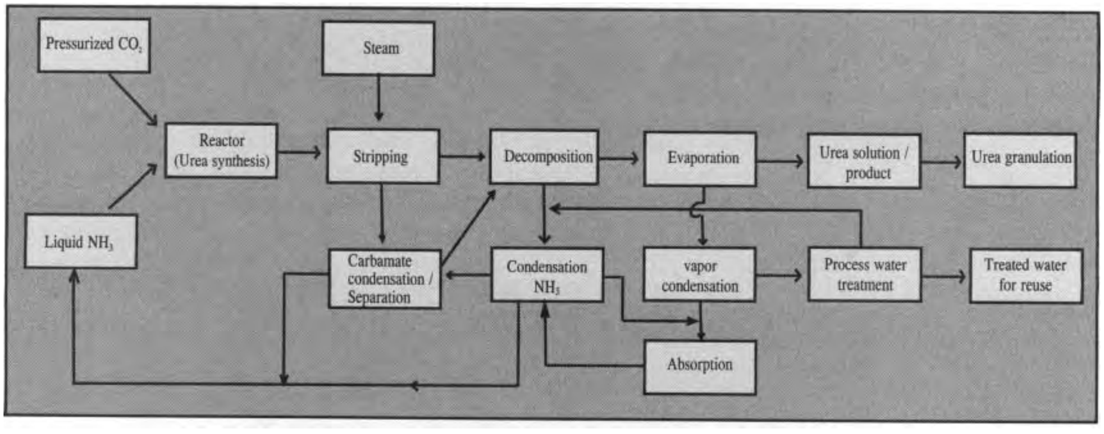


Fig.U.3: Flow diagram of the total recycle process of urea production.

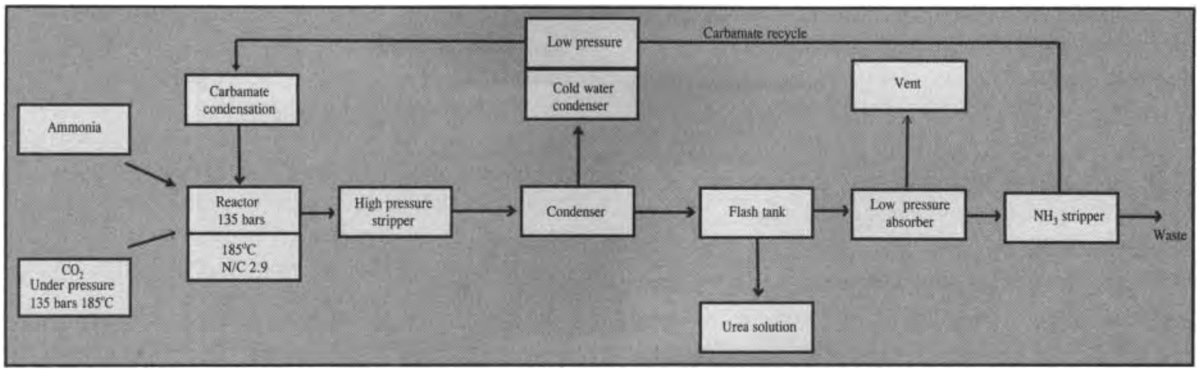


Fig. U.4: Flow diagram of Stamicarbon process of urea production.

carbon dioxide ratios have two decomposition stages, while Stamicarbon has an onstage nitrogen to carbon ratio control instrument. All processes still use oxygen for passivity in the synthesis loop. Snamprogetti uses a bimetallic zirconium/25-22-2 (Ni,Cr,Mo) stripper, in view of the very low corrosion property of zirconium, while Toyo uses duplex alloy (ferrite-austenite) and Stamicarbon uses a patented proprietary material called saferx for making the stripper.

Ammonia emissions are now reduced from 8 kg/ton to 0.7 kg/ton of the final product. All the three technologies operate at a pressure of 140 to 175 atmospheres and in a temperature range of 183 to 190°C. The ammonia/carbon dioxide mole ratio varies from 2.95 to 4.0 and the water to carbon dioxide molar ratio varies from 0.39 to 0.6 in all technologies.

(iii) **Urea finishing processes**: Urea solution is evaporated in stages to produce a melt which can then be prilled, granulated, flaked and crystallized. At present only prilling and granulation can be considered important. Recently, granular urea has gained importance since it has a higher strength and can be formed in larger sizes and it is more compatible with other fertilizers. The granulation route of finishing urea causes less pollution.

Comparative urea characteristics from prilling and granulation processes are given in Table-U.1.

Table-U.1: Urea characteristics from prilling and granulation processes.

Property	Prilling	Granulation
Moisture, %	0.30	0.20
Impurity, (biuret)%	0.90	0.70
Average size, mm	1.70	2.50
Crushing strength, kg	0.60	3.00

(a) **Granulation**: Many granulation processes have been developed. They include Tennessee Valley Authority (TVA)'s pan granulation and falling curtain granulation processes, Norsk Hydro's high temperature pan granulation process, TEC's fluidized bed granulation process, Hydro Agri Licensing and Engineering's fluidized bed granulation process and C&I girdler's spherodizer spray drum process.

Toyo Engineering Corporation has developed a spouted fluid bed process for granulation purposes. At present fluid bed technology is the only one that can offer single-train units matching current urea plant sizes. All processes give urea containing a minimum of 46.2% nitrogen and 0.7 to 0.8% biuret. The general moisture content is around 0.2% though Stamicarbon gives a product with 0.05% moisture.

(b) **Prilling**: Prilled urea is made by techniques involving a spinning bucket, shower heads or acoustic vibrations. The most common is the spinning method. Stamicarbon uses its own bucket technique, while Snamprogetti and Toyo use tuttle bucket. In prilling, urea is melted and concentrated to 99.8% by vacuum evaporation, then quickly transferred to the bucket to minimize biuret formation. The liquid drops are forced through cylindrical concrete towers with an induced or natural draft of an airflow. The prills solidify and are removed from the bottom of the tower. For getting a low biuret content in urea, the latter is recrystallized and the crystals are melted just before prilling.

To improve the crushing strength of urea prills, Stamicarbon utilizes a seeding system where fine urea dust is blown into the tower at a point which is two thirds distance from the bottom. Many prill producers add formaldehyde upstream of prilling either in evaporators or to the melt. This reduces the dust and the caking tendency. The other materials added are clays and mineral oils.

(c) Pollution sources and control: In a urea plant, major sources of pollution are the following: (a) evaporating the water formed as a by-product in urea synthesis (liquid pollution), (b) cooling anhydrous urea melts while forming solid urea-prilling and granulation (gaseous pollution), and (c) purging inert gases accompanied by the raw materials, ammonia and carbon dioxide (gaseous pollution).

In the manufacture of urea, one mole of water is formed for every mole of urea produced. The water formed during urea production as well as the water recovered while concentrating the **urea solution** are both contaminated with urea, ammonia and carbon dioxide. They have to be purified to a level of less than 15 kg/ton of urea. Another source of liquid pollution is through the leakage of the process fluid into the gland cooling water through stuffing boxes of the reciprocating ammonia feed pump and carbamate feed pump. This can be avoided by the use of centrifugal pumps in place of the reciprocating ones.

During prilling or granulation, the air coming out contains 100 to 150 mg of urea dust per Nm^3 air. The internationally accepted value is 20 to 50 mg urea per Nm^3 air. A packed bed type of dust recovery system is adopted for use with the granulator or prilling.

Urease

Urease, an enzyme, converts urea into ammonium carbonate [$(NH_4)_2CO_3$] that releases ammonia. Thus, the enzyme activates the hydrolysis of urea. When the release occurs on or near the soil surface, ammonia is lost to the air; if it occurs near the seeds, they fail to germinate, or it proves to be toxic to the roots of young saplings. Crops can get affected by a high concentration of ammonia. Soybean, jack beans and a number of fungi are sources of urease. Its isoelectric point is pH 5.5.

Urease enzyme catalyzes the hydrolysis of urea which occurs readily in the soils. Large numbers of bacteria, fungi and actinomycetes in soils possess urease. A small group of bacteria, known as urea bacteria, have an exceptional ability to decompose urea. Activity increases in proportion with the size of the soil microbial population and the organic matter content. The presence of relatively fresh plant residues often results in abundant supplies of urease. The greatest activity of urease is reported to occur in the rhizosphere, where microbial activity is high and where it can be excreted from the plant roots.

Although warm temperature (up to 37°C) favors urease activity, the hydrolysis of urea occurs at significant rates at temperatures down to 2°C. The effects of soil moisture levels on urease activity are generally small in comparison to the influence of the pH and temperature. Free ammonia inhibits the enzymatic action of urease.

Urease inhibitor

Upon application to the soil, the amide nitrogen in urea is hydrolyzed by the enzyme urease to ammonia or ammonium ion. This transformation creates two major problems: (i) It results in high volatilization losses of ammonia. (ii) It can severely damage the germination of young seedlings.

Urease inhibitors prevent or depress this transformation of the amide nitrogen to ammonia by inhibiting the hydrolytic action of urease. The use of urease inhibitors reduces the loss of ammonia and seedling damage. A large number of urease inhibitors have been tested for their effectiveness.

There are three types of urease inhibitors. The first one blocks the sulphydryl groups at the active sites on the enzyme; for example, metal ions like Ag^+, Hg^{2+}, Cu^{2+}, etc. Quinones and heterocyclic sulphur compounds act as inhibitors for urease. The second type of inhibitors is structural analogues of urea like thiourea, methyl urea and substituted urea. Compounds reacting with nickel in urease molecule fall under the third type of inhibitors. Hydroxamic acid is the most thoroughly studied inhibitor. N(N-butyl) thiophosphoric triamide (NBPT), phenylphosphorodiamidate (PPD) and cyclotriphosphazatriene derivatives have also been used to inhibit the hydrolysis of urease in soils. Their application has increased the rice grain yield on salty clay soils, but not on clay soils. Similar results were found for no-till corn. However, due to their phytotoxity, the urease inhibitors have to be used carefully.

Urea solution

Urea is an important fertilizer and is widely favored for its high nitrogen content and low cost. An aqueous urea solution is used as a foliar spray for citrus and crops like pineapple. A biuret level of up to 2% can be tolerated in most urea applications. Unlike anhydrous ammonia, urea solution containing ammonium nitrate (**urea-ammonium nitrate solution** or **UAN solution**) is popular in several countries because it is (a) safe to use, (b) easy to inject into irrigation systems, (c) safe to handle and store, and (d) uniformly applicable on surfaces. The UAN solutions are usually available in the market in three concentrations, namely, 32%, 30% and 28% nitrogen. The nitrogen solutions are often added directly to grasses and cereals.

Urea stakes

Urea stakes is another name for **urea supergranules**.

Urea sticks

Urea sticks is synonymous with **urea supergranules**.

Urea-sulphur

Urea-sulphur is a relatively new compound containing 40% nitrogen and 10% sulphur. The prilled material has excellent physical properties. Upon application to the soil, urea dissolves, leaving elemental sulphur that is converted into sulphate by oxidizing bacteria.

Sulphur-coated urea is a controlled-release nitrogen fertilizer. The sulphur coating is done by spraying molten sulphur on a falling curtain of urea particles, in a rotating drum. In a second drum, a molten sealant (a mixture of polythene and brightstock oil) is applied to seal the microscopic pores and cracks in the sulphur coating. The nitrogen concentration is between 36 and 38%. The release rate of urea can be adjusted by adjusting the coating thickness.

Sulphur-coated urea has the greatest potential for use in situations where multiple applications of soluble nitrogen sources are needed during the growing season, particularly on sandy soils under high rainfall or irrigation.

Urea supergranules

Considering that the particle size affects the agronomic response, urea is produced in the form of granules (9.5 to 13.5 mm) to reduce the surface area to volume ratio.

These supergranules (also called **urea briquettes**, **urea tablets**, **urea sticks** or **urea stakes**) release nitrogen slowly to make the fertilizer available for a prolonged period.

Urea supergranules were developed using the mud ball technique followed in China, for increasing the efficiency of fertilizer nitrogen. Urea supergranules are made in different shapes and sizes. They are used in flooded rice soils for increasing the crop yield, decreasing the gaseous loss and ensuring a sustained nitrogen availability.

The fertilizer nitrogen application rate can be adjusted according to the plant demand and the soil nitrogen supply. Some of the promising strategies adopted for improving the nitrogen use efficiency by crops, like rice, relate to the application timings, placement, etc. The use of large urea granules increases the efficiency of urea in rice production compared to the usual practices of broadcasting small granules in flood water. The incorporation of supergranules of urea into puddled soil increases the production efficiency from 35 to 45%, and the nitrogen release efficiency from 75 to 85%. Deep placement of urea supergranules by hand or machine is an agronomically efficient, economically beneficial and environmentally safe practice in traditional, transplanted-rice producing areas. Because of the high level of leaching, urea supergranules are also effective in light sandy soils. For best results, urea supergranules should be placed 4 to 5 cm below the soil surface.

Urea tablets

Urea tablets is the same as **urea supergranules**.

Urea-Z

Urea-Z is a trade name for slow-release urea, prepared by the acid catalyzed reaction of urea with acetaldehyde that contains around 35% nitrogen. The mother liquor, on neutralization yields a white powder of **crotonylidene diurea** (CDU). The primary ingredients are ethylene diurea and 2-ethylene-3-urea, unreacted ethylol urea and urea in small quantities.

Urea-Z is almost insoluble in cold water but soluble in hot water (49 g/l) and has a calculated **activity index** of 90 to 99. Unlike isobutylidene diurea, the nitrogen release from CDU depends on the hydrolysis of the parent compound and microbial activity in the soil. The particle size also influences the nitrogen release.

Uromol

Uromol is a cattle feed supplement made by boiling 1 part of urea with 3 parts of molasses, for 60 minutes. The mixture can either be used as such or may be mixed with bran oil cakes or other supplements. The Punjab Agricultural University in Ludhiana, India has successfully demonstrated the utility of molasses as cattle feed.

Usar: See Alkali soil

USDA

USDA is short for United States Department of Agriculture. This department maintains regional laboratories for agriculture, food research and development in Philadelphia, Peoria, New Orleans and Albany. Its central office is in Washington, D.C. (See Soil drainage class.)

Useful available water

The difference between the water-retention capacity of a soil and its permanent wilting point (expressed in mm water/cm soil), which is liable to be extracted by the roots, is the useful available water (**UAW**). It is given by the formula:

$$UAW = d \times bd\,(RC - PWP)$$

where d is the rooting depth in cm, bd is the bulk density of soil in g/cc, RC is the retention capacity (field capacity), and PWP is the **permanent wilting point**.

Useful available water increases as the soil texture becomes finer, while the moisture content of sandy clay loam remains constant, decreasing slightly in the very clayey region. (See also Available water.)

USLE

USLE is short for **universal soil loss equation**. It is designed to predict water erosion rates on agricultural land surfaces, exclusive of erosion resulting from the formation of large gullies. The USLE equation, developed by Wischmeier and Smith is:

$$A = RKLSCP$$

where A is the computed soil loss per unit area, measured in tons per hectare, R is the rainfall factor, K is the soil erodibility factor, L is the slope length factor, S is the slope gradient factor, C is the cropping management factor and P is the erosion-control practice factor.

Ustalfs

Alfisols that have an ustic soil moisture regime and mesic or warmer soil temperature regime are known as ustalfs. They are brownish or reddish throughout. Since ustalfs are not saturated with water for long periods, they may be considered useful for agriculture.

Ustands

Ustands is a suborder of the soil order **andisols**. The suborder has a moisture regime which is dry in winter.

Usterts

Usterts are **vertisols** of temperate or tropical regions with wide, deep cracks that usually remain open throughout the year. Usterts have either a mean annual soil temperature of 22°C or more, or a mean summer soil temperature and a mean winter soil temperature (at a depth of 50 cm) which differ by less than 5°C, or have cracks that open and close more than once during the year.

Ustic soil moisture regime

Ustic soil moisture regime falls between **aridic** and **udic regimes**. In this regime, the soil remains moist during summers. When the average temperature is above 22°C, the soil control section is dry in some parts for more than 90 days in a year. In some parts it remains moist for more than 180 cumulative days and in others it is continuously moist for 90 consecutive days. In regions where the average annual temperature is below 22°C, the soil is dry in some parts of the control section, for 90 cumulative days.

Ustolls

Ustolls are **mollisols** that have an **ustic soil moisture regime** and a mesic or warmer soil temperature regime. Ustolls may have calcic, petrocalcic or gypsic horizons, and are not saturated with water for too long a period to limit their use for most crops. (See also Mollisols.)

Ustox

Ustox are oxisols that have an **ustic moisture regime**. They have either hyperthermic or isohyperthermic soil temperature regimes or have less than 20 kilogram of organic matter in the surface of a cubic meter.

Ustults

Ustults are **ultisols**, which have low or moderate amounts of organic carbon, are brownish or reddish throughout, and have a **ustic soil moisture regime**.

US Weather Bureau Class A pan

The US Weather Bureau Class A pan, measuring 122 cm in diameter and filled with water to a depth of 19 cm has been adopted by the World Meteorological Organization as the standard instrument for measurement of evapotranspiration.

Measuring or estimating **potential evapotranspiration** in a field is useful in many ways. Water loss is measured using many methods, among which are direct measurements using **evaporation pans**, **atmometers**, **lysimeters** or evapotranspirometers.

Utilization quotient

The efficiency of **nutrient utilization** is the ratio of biomass to the total amount of nutrient in the biomass, and is termed the utilization quotient, **coefficient of utilization** or the efficiency ratio.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

V

Vacuum distillation

Vacuum distillation is a distillation process carried out at a pressure lower than the atmospheric pressure and higher than the pressure for molecular distillation. Since lowering the pressure lowers the boiling point, vacuum distillation is useful for distilling high boiling and heat sensitive materials such as petroleum, fatty acids, vitamins, etc.

Vacuum filtration

Vacuum filtration is the filtration process wherein a vacuum pump is used to suck the gas or liquid to enhance the rate of filtration.

It is generally used to purify bacterial and viral cultures.

Vacuum silage

Grass or any green fodder compacted and stored in airtight conditions, typically in a silo, to feed animals in winter, is called silage. When silage is connected through a valve to a vacuum pump to remove the air, it is called vacuum silage.

Vadose

Vadose or **gravity water** is the water present in soil above the water table, which drains away under gravity. It is a type of water, classified on the basis of the process of water movement.

Valence

Valence is a whole number which represents the combining power of one element with another. By balancing these integral valence numbers in a given compound, the relative proportions of the elements present can be accounted for.

If hydrogen and chlorine both have a valence of 1, oxygen 2 and nitrogen 3, the valence balancing principle gives the formulas HCl, H_2O, NH_3, Cl_2O, NCl_3 and N_2O_3, which indicate the relative numbers of atoms of these elements in compounds and which they form with each other.

In inorganic compounds, it is necessary to assign either a positive or negative value of each valence number, so that valence balancing will give a zero sum by algebraic addition.

Negative numbers are called polar valence numbers (–1 and –2). The valence of chlorine may be –1, +1, +3, +5 and +7, depending on the type of compounds in which it occurs. In organic chemistry, non-polar valence numbers are used.

Chlorine (Cl^-) - valence -1
Perchlorate (ClO_4^-) - valence +7
Chlorate (ClO_3^-) - valence +5

Certain elements display two or more than two valences in chemical combination. For example, iron is bivalent and trivalent, manganese is bivalent, trivalent, tetravalent and heptavalent.

Value color

Value color refers to the relative lightness or intensity of color and is approximately a function of the square root of the total amount of light. Value is one of the three variables of color, the other two being hue and chroma.

Value : cost ratio

Value: cost ratio (**VCR**) is the ratio of the increased crop output (as a result of the fertilizer use) to the cost of the fertilizer. It is one of the main indicators of profitability used in the economic evaluation of fertilizers.

The VCR changes with the rate of application, and measures economic returns of the fertilizer against the expenditure.

The efficiency of fertilizer application is determined by the crop response and the price ratio of the crop output to the fertilizer input. Food and Agricultural Organization (FAO) defines this ratio using three parameters, namely (a) **marginal rate of return (MRR)**, (b) value:cost ratio (VCR), and (c) fertilizer crop price ratio.

$$\text{VCR} = \frac{(\text{Value of the yield increase x } \gamma) - (\text{Cost of fertilizer})}{\text{Cost of fertilizer applied}}$$

where γ is the scaling coefficient of the yield increase from fertilization to adjust for any differences in the yield when the pilot application is compared to the actual.

Thus, VCR is the ratio of the value of the extra crop produced by fertilizer application to the fertilizer cost. If this ratio is more than one, the process is considered profitable, and if less than one, it is uneconomical. Naturally, the higher the VCR for a fertilizer, the more attractive is the use. In practice, a fertilizer with a VCR higher than 2 is considered economically acceptable.

VCR helps to establish government policy measures necessary to motivate farmers to use fertilizers. Obviously, the VCR value can be regulated either by establishing local prices for crops (by levying custom duties on imported products if they are cheaper than the locally made product), or by fertilizer subsidies.

The profitability of a fertilizer use can also be determined by using an indicator called the value: cost ratio, the quotient obtained by dividing the expected value of yield increase by the cost of fertilizer applied. Profitability indicators may be computed as given below:

$$\begin{aligned} \text{Net Return} &= (C \times P_1) - (F \times P_2) \\ \text{Value-Cost ratio} &= (C \times P_1) \div (F \times P_2) \end{aligned}$$

where C is the number of units of additional yield attributed to the fertilizer application, P_1 is the unit price of the crop, F is the number of units of the fertilizer applied, P_2 is the unit price of fertilizer, $(C \times P_1)$ is the total cost of additional crop yield attributed to fertilizers applied and $(F \times P_2)$ is the cost of fertilizers applied.

Results from fertilizer trials and demonstrations usually do not permit the calculation of a response curve with different nutrients, because of the design used. Nevertheless, if the range of treatments is large enough, the net return and value-cost ratio can be determined.

However, the net return has also to be considered, because at low application rates of fertilizers, the VCR may be 2 or more, because of the small cost of the treatment, but the net return would also be small and unattractive to the farmer. In addition, other factors such as the likelihood of the expected yield, of the assured market for the crop, and of the assured availability of fertilizers to the farmer have also to be considered.

Farmers, especially in developing countries, normally use less fertilizers than the recommended fertilizer rate. The reasons are many: apprehension about the anticipated yield increase, uncertainty about the crop prices, cost and availability of fertilizers, and credit availability, land tenure considerations, farmer's ability to bear the risk, etc.

The marginal rate of return for the farmer is the profit made by him over the break-even yields for given production costs.

VAM

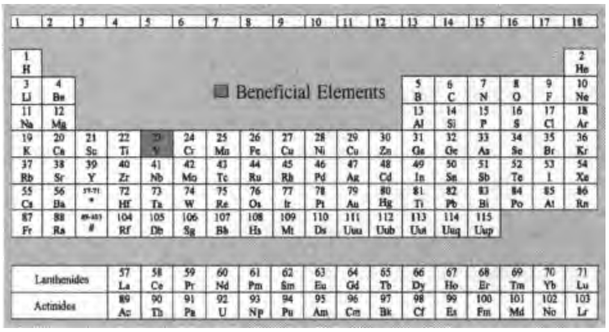
VAM is short for **vesicular arbuscular mycorrhizae**. It is a potential biofertilizer.

Mycorrhizal fungi are often associated with roots of the plant grown under conditions of low soil fertility. These organisms increase the ability of plants to absorb nutrients, such as phosphorus, potassium, copper and zinc. Their hyphae serve as extensions of plant roots, thereby making a large soil volume accessible for nutrient uptake.

Under field conditions, addition of the fertilizer nitrogen, phosphorus, etc. may reduce the presence and activity of mycorrhizae.

Vanadium

Vanadium (V) is a silvery-white, metallic, transition element of Group 5 of the Periodic Table (Fig.V.1) and exhibits a range of valencies from +2 to +5. The ores containing vanadium include vanadite and carnotite.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71 *	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103 #	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Uuu	112 Uub	113 Uut	114 Uuq	115 Uup			

▨ Beneficial Elements

Lanthenides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Fig.V.1: Position of vanadium in the Periodic Table. Vanadium is a beneficial element for plants.

The pure metal, formed by the reduction of vanadium oxide with calcium, is generally used as an alloying element for steel and iron. Several vanadium compounds are used as oxidation catalysts. They are also used as coloring agents in the ceramic industry.

Vanadium comes under the category of beneficial elements which are non-essential but beneficial to plant growth. It is a very useful nutrient for the green alga *Scenedesmus*, but the exact amount of vanadium needed for the growth of higher plants is yet to be established.

Vanadium may replace molybdenum to some extent in nitrogen fixation by micro-organisms such as *Azotobacter* and *Rhizobium*. An increase in growth due to vanadium is seen in asparagus, rice, lettuce, barley and corn. It has also been speculated that vanadium may function in biological oxidation-reduction reactions.

Vanadium stimulates growth and nitrogenase activity in *Anabaena variabilis* in the absence of molybdenum. Low concentrations of vanadium are beneficial for the optimal growth of micro-organisms and higher plants.

Generally, the concentration of vanadium in plants is about 1 ppm.

Van der Waals' equation

Van der Waals' forces are the weak attraction forces between molecules. They are somewhat weaker than hydrogen bonding and far weaker than interatomic valences.

Van der Waals' equation is a mathematical expression for describing the behavior of real gases. The ideal gas equation, derived from the kinetic theory of gases and based on the assumption that there is no inter-particle interaction, and gas particles have zero volume, explains the behavior of ideal gases. This is, however, true only at very low pressures and high temperatures in the case of real ordinary gases.

The ideal gas equation is:

$$PV = nRT$$

where P is the pressure, V is the volume, R is the universal gas constant, T is the temperature in Kelvin and n is the number of moles of gas. To account for the volume of gas particles, van der Waals introduced a correction for V as (V - nb), where b is an empirical constant, and V and n have the same significance as described earlier.

To account for the attractions that occur among particles in a real gas, van der Waals introduced a correction factor for the observed pressure. As the attractions make the pressure smaller than it would be in the absence of any interaction, the observed pressure (P_{obs}) is given as:

$$P_{obs} = P' - a\left(\frac{n}{V}\right)^2$$

where P' is the ideal gas pressure and a is the proportionality constant that can be determined by observing the actual behavior of a real given gas.

The size of the correction factor will depend on the concentration of gas molecules defined in terms of moles of gas particles per litre (n/V). For large numbers of particles, the number of interacting pairs of particles depends on the square of the number of particles and thus on the square of concentration, or $(n/V)^2$.

Inserting the corrections for both the volume of the particles and the attractions of the particles gives the equation:

$$P_{obs} = \frac{nRT}{(V - nb)} - a\left(\frac{n}{V}\right)^2$$

where V is the volume of the container, nb is the volume correction and $a(n/V)^2$ is the pressure correction. This equation can be rearranged to give the van der Waals' equation:

$$[P_{obs} + a\left(\frac{n}{V}\right)^2] \cdot (V - nb) = nRT$$

The fact that real gas tends to behave more ideally at high temperatures can also be explained in terms of van der Waals' model. At high temperatures, the particles move so rapidly that the effects of inter-particle interactions are not very important. Moreover, at low pressures, the volume of gas is small compared to the container and hence the volume correction is not relevant.

Van der Waals' forces: See Van der Waals' equation

Vant Hoff's law

Vant Hoff's law, also known as **Q_{10}** of a process, gives a value that represents the number of times the rate of a process increases for a rise of 10°C in the temperature. (See also Q_{10}.)

Variable costs in agriculture

The sum total of costs in a complete agricultural operation has two components – the variable cost and the fixed cost.

Variable costs are the expenses incurred during farming activities; for example, the purchase of seeds, fertilizers, plant protection chemicals, use of agricultural machinery, hired labor, etc. If the farmer stops farming, he does not incur variable costs. The largest components in variable costs are raw materials, chemicals and catalysts, delivery costs, losses in storage, repairs, maintenance, as well as inefficiencies of the process. Similarly, utilities like electricity, steam, process fuel, process water, refrigeration and effluent treatment also fall under variable costs.

In calculating the production cost, a double consideration of the utilities should be avoided. Thus, electricity cost for producing steam should not be included again if it is included in the list of 'process costs'.

The total annual cost of operation is the sum of the annual ownership costs and the total hourly operating costs. The total annual cost and the total hourly operating costs are expressed in units of currency per year, and per hour, respectively.

Variance

Variance is the square of standard deviation (S) and is a measure of variability.

Thus, Variance = S^2.

$$S = \sqrt{\frac{(X - \bar{x})^2}{N-1}}$$

where x is the individual value, $\bar{x}$ is the mean and n is the frequency.

Two or more mean averages, obtained in an analytical laboratory, are analyzed by a statistical method known as the **analysis of variance** (**AOV**). AOV allows the assessment of variation arising from random error and individual error, and is also called the **mean square error**.

Variance mostly removes the lacunae which are present in the measures of dispersion given before it. The main demerit of variance is that its unit is square of the unit of measurement of variate values. For clarity, say the variable X is measured in centimeters, the unit of variance is cm^2. Generally, this value is large and makes it difficult to decide about the magnitude of variation. The variance gives more weightage to extreme values as compared to those which are nearer to mean value, because the difference is squared in variance.

Variance ratio test

Variance ratio test is also called **F-test**. (See also Significant difference in analysis; Analysis of variance.)

Varisite

Phosphate in soil solution is in a dynamic state and reacts continuously with Ca, Fe and Al; the reaction rate depends on the soil pH and the activity of the reacting cations.

In acid soil, fertilizer $H_2PO_4^-$ reacts with aluminum (Al^{+3}) and iron (Fe^{+3}) in solution to form ferric phosphate ($FePO_4$) and aluminum phosphate ($AlPO_4$). The reaction product of aluminum in soil with phosphorus is aluminum phosphate dihydrate ($AlPO_4 \cdot 2H_2O$), which is known as varisite. As pH increases, iron and aluminum reactions and the activity of the reacting cations decrease, resulting in lower phosphorus adsorption or precipitation and a higher phosphorus concentration in the solution. Large amounts of phosphate are required to achieve good productivity in acidic soils containing aluminum and iron oxides or sesquioxides.

Vascular cambium

Vascular cambium is a type of **lateral meristem** responsible for the secondary growth of the plant. Wood, also called secondary **xylem**, is the result of the activity of vascular cambium.

Vaultation

Vaultation is a synonym of **saltation**.

VCR

VCR is short for **value: cost ratio**.

Vector: See Scalar

Vegetable crop

A vegetable is any part of a plant used wholly or partly for food. Stems, leaves, flowers, seeds, fruits or roots that form part of a plant may be consumed in either a raw or processed form. Most vegetables are seasonals or annuals and are rich in proteins, minerals and fatty substances. Carbohydrates are major constituents of vegetative parts. Green parts of the plant and root vegetables are rich in vitamin C and carotene.

Vegetable crops are grown for their fruits (tomato), seeds and pods (beans, peas, etc.), roots (radish), tubers (potato), leaves (spinach), bulbs (onions) and flowers (cauliflower) (Fig.V.2).

Fig. V.2: Vegetable crops, hybrid snake gourd (1), brinjal (2), cauliflower (3) and okra (4).

Nitrogen is an integral part of chlorophyll and more importantly, of proteins (structural and functional). Nitrogen in the form of nitrate (NO_3^-) is a normal and natural constituent of vegetables but varies in content among different species, varieties, parts of the plant, the state of maturity at harvest, and the amount of sunlight received during maturation. Red beet, spinach, lettuce and carrot contain more than 1 g nitrate (NO_3^-) per kg, while beans, peas, potatoes and cereals have low nitrate content.

Nitrogen deficiency in soil affects the flavour and shelf life of vegetables grown in that soil. The deficiency also makes them susceptible to such diseases as rusts, mildews, grey moulds, etc. Excess nitrogen leads to undesirable consequences, such as a reduction in the useful amino acid content (methionine), increased toxic nitrite content, decreased percentage of dry matter and biological value of proteins.

Non-vegetarians people get 70 mg nitrate (NO_3^-) from vegetables, whereas vegetarians obtain about thrice that quantity. The nitrate content is enhanced when there is less sulphur or excess nitrogen.

Seed vegetables (such as peas and beans) and fruit vegetables (like tomato and brinjal) require relatively longer cultivation periods than the other types of vegetables. They are also more vulnerable to soil nutrient imbalances. On the other hand, leafy vegetables, despite their low nutritive value, have the following advantages. (i) They can be dried. (ii) Their harvesting period is flexible. (iii) They can be obtained after a short period of growth. (iv) Their total harvest per unit of land can be very high. For instance, spinach can yield a very high amount of protein per unit area. A reasonable nitrogen fertilization of spinach is 80 to 100 kg/ha.

Potassium fertilization improves the sugar content, taste and shelf life of vegetables. Phosphorus fertilization enhances the yield, but has a negligible effect on its quality.

Compared to ordinary arable cropping, vegetable production is more intensive, with a quicker succession of crops. Vegetables provide high nutrient input, provided potassium and other elements are supplied in sufficient quantity which ensures their quality (firmness, taste, etc).

Micronutrient deficiency causes reduction in quality in a vegetable crop. For example, deficiency of (a) boron causes carrots to split open and broccoli to develop brown, hollow stems, (b) molybdenum leads to faulty leaf development in cabbage and cauliflower, and (c) calcium affects celery, lettuce and sugar beet. Beans, cabbage and lettuce are more sensitive to the toxic effects from high levels of **soil manganese** than tomatoes or beet root. (See also Horticulture.)

Vermicompost

Vermicompost is the **compost** produced by earthworms through the digestion and discharge of refuse and other organic wastes. Earthworms (unlike cutworms, maggots and wireworms) eat dead organic matter. The ingested organic matter and fine-textured soil excreted as small granular aggregates provide abundant and readily available plant nutrients. Live earthworms aerate the soil and increase the potassium and phosphorus content in the soil. Earthworms multiply easily in a moist, warm and well-aerated soil with a pH between 5.0 and 8.4, containing organic matter with a low salt and high calcium concentration.

In vermicomposting, the worms used are *Lumbricus rubellus* and similar species. Earthworms are commercially raised (**vermiculture**) and multiplied in shallow wooden boxes provided with drainage holes. Compost pits measuring approximately 3 × 4 × 1 m, are filled with organic residues, such as straw, animal manure, green wastes and leaves. Earthworms from a wooden box are emptied on compost pits, where they help to decompose the organic residues. When compost is ready for use, the upper layers of the digested organic matter (the vermicompost) is collected for use or sale (Fig.V.3), and the earthworms are removed to another pit or to wooden boxes, for the process to continue.

Earthworms can break organic wastes into peat-like materials rich in nutrients, with good water-holding capacity and porosity. The maximum waste turnover

Fig. V.3: (Top) Vermicompost being collected by a worker for packing and further processing. (Below) A bag of commercially available vermicompost.

takes 2 to 4 weeks under controlled conditions of water and temperature. A ready-to-use vermicompost is commercially marketed in different sized bags.

Vermiculite

Vermiculite is a clay mineral. It is similar to tri-octahedral smectites, with a structure that is balanced by interlayer ions of mostly magnesium and sometimes calcium. In other words, vermiculite is a hydrated silicate, which results from the alteration of mica, especially an aluminosilicate of magnesium. The formula of vermiculite is:

$$(Mg, Fe, Al)_3\,(Al,Si)_4O_{10}\,(OH)_2\cdot 4H_2O$$

Vermiculite is a tri-octahedral phyllite (2:1) with a basal spacing of 10Å varying between 1Å and 10Å, according to the nature of the interlayer cations.

The following are the principal differences between vermiculites and **smectites**. (i) Vermiculites have a large grain size. (ii) Vermiculites have a higher cation exchange capacity and, when treated with glycol, achieve basal spacing of about 14Å while smectites take double layers, with a basal spacing swelling to 17Å. (iii) Smectites dehydrate more rapidly while vermiculites rehydrate more rapidly.

In soils, vermiculites are mostly clays of transformation, formed from the degradation of micas or illites. They have a high **cation exchange capacity (CEC)** of 100 to 150 meq/100 g, which endows them a high affinity for weakly hydrated ions such as K^+, NH_4^+ and Ca^{2+}. Consequently, vermiculite-rich soils exhibit high potassium-fixation capacity.

Vermiculite does not swell as much as montmorillonite. Vermiculite is a 2:1 clay mineral, similar in structure to hydrous magnesium. On rapid heating, vermiculite assumes a worm-like shape, alluding to a peculiar exfoliation phenomenon. When heated, it can also expand to a lightweight, highly absorbent, fireproof material about 16 times its original volume. In natural state, the mineral has no useful application, but it provides a low-density material with excellent thermal and acoustic insulation properties when exfoliated.

Vermiculites in flakes are useful as a medium for growing tissue-culture plants and for insulation.

Vermiculture

The method of improving soil productivity by employing earthworms is known as vermiculture. **Earthworms** help to convert a barren, rocky and infertile land into a green and fertile land. They aerate and stir the soil and improve water infiltration and root penetration (Fig. V.4).

Sandy, salty, arid, acidic, cold and hot barren soils do not support vermiculture. Animals like mice, mites and

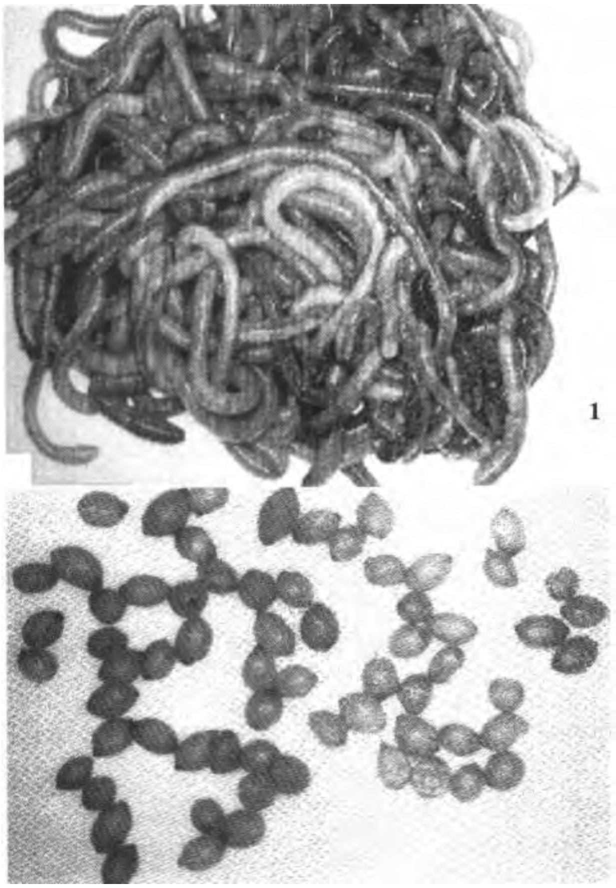


Fig. V.4: Adults and cocoons of the earthworms 'Lampito mauritii' are used as vermiculture.

millipedes as well as strong insecticides and heavy machinery harm earthworms. Vermiculture is advocated in organic farming. (See also Vermicompost.)

Vertical mulching

Vertical mulching is mulching of a subsoil wherein a vertical band of mulching material is poured into a vertical slit in the soil. (See also Mulch.)

Vertical subsurface drainage

Vertical subsurface drainage involves digging vertical inlets into higher level terraces which are devoid of grass. Water moves into the subsurface channels to a lower terrace, thus preventing run-off water and conserving soil.

Vertisols

Vertisols, being one among the 12 world soil orders, consist of swelling clays and occupy about 2.4% of the earth's ice-free land surface. About half of all vertisols are found in tropical environments and the rest in temperate environments. **Limestone**, marl, and basic rocks like basalt are the parent materials for these soils. Hence, vertisols are neutral to alkaline in reaction. They exhibit cation exchange capacity between 20 and 45 moles/kg.

Vertisols are clay soils which exhibit sizeable volume change due to a shrink-swell process. These soils occur in semi-arid climates with clear wet and dry cycles. Vertisols are difficult for cultivation due to their high swelling and sticky nature.

When the swelling pressure exceeds the shear strength due to the wetting of the dry soil, vertisols become active and subjected to structural failure. This is usually expressed as slickensides, occurring as diagonal, polished and grooved slip surfaces, wedge-shaped structural units and microtopography in the form of **gilgai**. Commonly, these soils have self-swallowing and self-mulching surface features, wherein strongly aggregated surface materials fill the vertical structural cracks. Most movements in these soils are believed to occur diagonally along the inclined slickenside fault planes.

Vertisols are fertile owing to the high cation exchange capacity and considerable humus content. Their wetted clay, however, has poor aeration and so the root system in vertisols is shallow. Major limitations for using these highly productive soils for agriculture are the high-energy requirements for tillage and the narrow range of favorable soil moisture for workability. The use of vertisols in construction activities is constrained by their high shrink-swell characteristic.

The suborders belonging to the vertisols are aquerts, cryerts, torrerts, **uderts**, **usterts** and xererts.

Very poorly drained soil

Very poorly drained soil is one of the seven drainage classes recognized by USDA. These soils have a water table at, or near, the surface most of the year. They often have accumulated organic matter on the surface and may have histic epipedons. These soils are so wet that artificial drainage becomes necessary to carry on meaningful cultivation.

Vesicular arbuscular mycorrhizae

Vesicular arbuscular mycorrhizae (VAM), also called **endomycorrhizae** or arbuscular mycorrhizae (AM), are a type of fungi which penetrate the roots of some plants. These fungi, which are particularly helpful in phosphate absorption, are most commonly found on plants, although they are the least visually obvious mycorrhizae. VAM are found in places like deserts, grasslands, tropical forests, etc. containing low phosphorus and organic matter.

Phycomycete fungi develop endomycorrhizae. The fungal spores germinate in the rhizosphere, perhaps stimulated by removal of inhibitory ions and plant exudates. The hyphae penetrate the surface of young roots, establishing a mycelium among the cortical cells. Some hyphae also enter the cortical cells, forming arbuscules, branched, tree-shaped mycelial structures that appear to fill the plant cell. The arbuscule may provide a large active surface for the transfer of sugars to the fungus and nutrient ions to the plants. The extensive numbers of hyphae outside the soil effectively absorb phosphate and zinc and move them rapidly through the mycelium to the plant. The non-septate form of the phycomycete hyphae might facilitate this movement. Formation of VAM is suppressed if the plant receives a high level of phosphate. (See also Mycorrhizae.)

Vetrocoke process for ammonia production

Vetrocoke process uses potassium carbonate solution containing arsenic trioxide to absorb CO_2 from the **syngas**. After shift conversion of carbon monoxide to carbon dioxide, the carbon dioxide content in the syngas is about 18 mol percent. From this mixture, carbon dioxide is removed under pressure by various absorbents, followed by desorption, by decreasing the pressure and increasing the temperature.

The Vetrocoke process requires less heat for desorption. However, the use of arsenic presents disposal and pollution problems which have been overcome by using glycine and a secondary amine in place of arsenic oxide as the activator. (See also Ammonia production processes.)

Village extension worker

A village extension worker is a person who has undergone training to help farmers to practice efficient agricultural methods. These methods are concerned with better use of fertilization and irrigation, and maximizing benefits from the land.

The extension worker can encourage farmers to share information and begin cooperation under conditions of equality and mutual trust, and use mass communication methods. The latter have become effective in extension teaching which includes the use of radio, television, newspapers, extension bulletins, leaflets, circulars, posters, cinema vans and public address systems.

Agricultural extension services should operate with the objective of (a) helping people to help themselves, (b) planning and implementing farmer-centric programs and innovations where people perform within their capacity, (c) teaching through demonstration, (d) developing mutual trust and respect, through programs, using local leadership as a legitimate authority for entry into village work, and (e) providing feedback to research organizations.

A village level worker is a grass-root level worker who helps the farmer in implementing better methods of agricultural practices to maximize the benefits.

Viral RNA: See Ribonucleic acid

Virgin land

Virgin land is that which has never been cultivated and is left in an untouched natural state or undisturbed form. It is a land covered essentially with indigenous growth.

Virus

Virus is a sub-microscopic, parasitic micro-organism comprising a protein or a protein-lipid sheath containing nucleic acid. Viruses are inert outside living cells, but within appropriate cells they can replicate and give rise to the manifestations of the associated viral disease in the host organism. Various viruses infect animals, plants and bacteria; the viruses infecting bacteria are called **bacteriophages**. Few drugs act specifically against viruses, although immunity can be induced in susceptible cells against particular viruses. Various pathogenic organisms formerly regarded as large viruses are now distinguished as *bedsonia*.

Viruses can be resolved only with electron microscope. Since viruses pass through filters that retain bacteria, they are often called filterable viruses. Tobacco mosaic was the first virus to be crystallized and isolated. It contains some 2000 proteins in a sequence of 158 amino acids. Bushy stunt virus, found in tomato plants has a molecular weight of 7.6 million.

Viruses differ from organisms, in that they are only half alive. They lack metabolism, are unable to utilize oxygen to synthesize macromolecules, to grow or to die. They account for many diseases in plants including, mosaic, ringspots, bunchy top, etc.

Viscosity

Viscosity is the quality or degree of being glutinous, sticky or not free flowing. This occurs due to internal friction causing resistance to flow. Viscosity is a measure of the magnitude of such resistance, and is measured by the force per unit area when two parallel layers at unit distance away move with unit speed relative to each other.

For a Newtonian fluid, the force, F, needed to maintain a velocity gradient, dv/dx, between adjacent planes of a fluid of area A, is given by:

$$F = \eta A \,(dv/dx)$$

where η is a constant, known as the coefficient of viscosity (measured in Pascal sec or in Poise). Non-Newtonian fluids, such as clays, do not follow this law.

The sedimentation of particles in solutions depends on the viscosity of the solvent. Stoke's law expresses the rate of fall of solid particles in the liquid medium and thus we have

$$V = \frac{2}{9} \times \frac{r^2 g\,(p-d)}{\eta}$$

where V is the rate of fall in cm/sec, r is the particle radius, g is the acceleration due to gravity, p is the particle density, d is the density of the liquid, and η is the coefficient of viscosity of the medium.

Water is the primary viscosity standard. Hydrocarbon liquids, such as hexane, are less viscous. Viscosity decreases with an increase in temperature. It is a useful parameter in evaluating storage and handling characteristics of fluid fertilizers, and helps in the quality control of liquid or slurry feeds to the granulation process. Liquid fertilizers or fertilizer solutions should have a low viscosity for uniform foliar spray applications.

Viscosity in centipoises divided by the liquid density at the same temperature gives kinematic viscosity in centistokes. To determine kinematic viscosity, the time is measured for an exact quantity of liquid to flow by gravity through a standard capillary.

Viscosities of some solution fertilizers and suspension fertilizers are given in Table-V.1.

Vishvavallabha: See Biocontrol of pests - some tested methods

Visual observation of plants

Visual observation of plants is a **diagnostic technique** used for the detection of nutrient deficiencies or toxicities in a soil. Plants exhibit visual symptoms due to deficiency or toxicity of a particular nutrient, lack of water, excessive amounts of salts and heavy metals. For example, if plants lack water, they curl or wilt or if they lack nitrogen, the leaves turn yellow, especially the older ones. If they take up excessive amounts of essential nutrients, they exhibit various symptoms like necrosis of the young leaves.

However, when deficiency symptoms in plants appear, the deficiency is already far advanced. When severe diagnostic symptoms appear, the yield may have already reached a stage of being drastically reduced for any corrective action. It may be easy to diagnose the deficiency of one element, but very complicated when two or more nutrients are deficient in a plant. It is for this

Table-V.1: Viscosity of some solution and suspension fertilizers.

Solution fertilizers*			Suspension fertilizers**		
Fertilizer Grade	Viscosity MPa.s at 24°C	Density g/ml at 24°C	Fertilizer Grade	Viscosity MPa.s	Density g/ml at 24°C
8-24-0	30	1.26	12-40-0^{a}	700	1.44
10-34-0^{a}	50	1.37	13-38-0	800	1.44
11-37-0^{a}	80	1.40	9-32-0^{a}	200	1.40
7-21-7^{a}	50	1.33	10-30-0	250	1.37
7-7-7^{c}	4	1.24	31-0-0^{b}	150	1.32
5-10-10^{c}	40	1.25	18-0-18	160	1.37
32-0-0^{b}	50	1.33	13-13-13	600	1.40
28-0-0^{b}	23	1.27	4-12-24	400	1.41
			0-0-31^{d}	360	1.30

** Based on thermal phosphoric acid; ** Based on wet-process orthophosphoric and polyphosphoric acids; a-containing polyphosphate; b-urea-ammonium nitrate solution; c-supplementary nitrogen from urea-ammonium nitrate solution; and d-potash suspension. (Source: "Fertilizer Manual", 1998. UNIDO, IFDC and Kluwer Academic Publishers, The Netherlands. With permission).*

reason that waiting for a nutrient deficiency to surface is not a good management procedure. And hence, this method of diagnosis is not always advisable.

It is not uncommon for a micronutrient deficiency symptom to resemble a disease or insect damage. For example, leafhopper-damage on alfalfa leaves can be mistaken for boron deficiency. Interveinal chlorosis caused by tungro virus in rice may be mistaken for zinc deficiency.

Vital stain

Vital stains are such stains which, at low concentrations, are non-toxic to living tissues, and can be used to stain living materials.

Vital stains can be used for permanent **staining**. For example, methylene blue (0.125% methylene blue in 0.75% sodium chloride solution) is used for staining the nuclei in cells.

Vitamins

Vitamins are a class of organic substances required in small amounts by living organisms to maintain normal health.

Some well-identified vitamins are (a) vitamin A (retinol), (b) vitamin B complex which are water-soluble vitamins [for example, vitamin B_1 (thiamin), B_2 (riboflavin), B_6 (pyridoxine) and B_{12} (cyanocobalamin)], (c) vitamin C (ascorbic acid), (d) vitamin D, (found in the liver and in fish oils), which is important for the absorption of calcium and for the prevention of diseases like rickets in children and osteomalacia in adults, (e) vitamin E (tocopherol), (f) vitamin H (biotin), (g) vitamin K, found mainly in green leaves, and essential in treating blood-clotting, (h) vitamin M (folic acid), and (i) vitamin P. Bioflavanoides are regarded as a vitamin in the USA.

Most B and C vitamins occur in plants, animals and micro-organisms. The vitamin D group includes vitamin D_2 (calciferol) and D_3 (cholecalciferol). The vitamin K group includes K_1, (phylloquinone) and K_2 (menaquinone).

Animals cannot synthesize many vitamins and these must, therefore, be supplied in their food through plants and microbes. Vitamin A, D, E and K are fat-soluble and are stored in fat bodies. Vitamins B and C are water-soluble and cannot be stored, and have to be regularly supplied through the diet.

All animals contain gut bacteria capable of producing sufficient amount of B vitamins. The livestock are able to produce adequate supplies of vitamin D in their coats and skin, irradiated during the summer months.

Foods may contain vitamin precursors (called **provitamins**), and they change chemically in the body to form actual vitamins. Many vitamins are destroyed by light and heat, (e.g.,, during cooking). When **brown rice** is milled, it is deprived of about 80% of thiamin, 56% of riboflavin, 65% of niacin, 60% of pantothenic acid and 55% pyridoxine.

Many people depend on rice for a major part of energy intake (almost 80%). But highly polished rice is deficient in B complex, which is subsequently made up by the addition of thiamin, niacin and iron.

Vitamins and minerals reduce the incidence of diseases like beriberi, pellagra, scurvy, etc. Milled rice can be enriched by coating it with enriching ingredients. Par boiling can be considered as a form of enrichment as some vitamins and minerals are retained in the process.

Deficiencies of some vitamins can cause ill health. To overcome these deficiencies in animals, livestock feed must contain synthetic vitamin supplements, added in balanced amounts according to the needs of the animals.

Vitamins function as coenzymes. Active parts of the enzyme systems catalyze many anabolic and catabolic reactions of living organisms, necessary for producing energy, synthesizing tissue components, hormones and chemical regulators, and detoxification and degradation of waste products. Owing to their role in metabolism, vitamins are generally concentrated in metabolically most active tissues of animals and plants; for example, in the liver or kidneys, and in seed germ.

Vitrands

Vitrand is a suborder of **andisols** which are black or dark brown soils with weakly developed horizons.

Vitriolated bone

In Europe, **bone superphosphate** or **dissolved bone** is called vitriolated bone.

Void ratio: See Voids

Voids

Voids are pores forming open spaces in soil and also in organic matter particles. Air, water and organisms occupy these pores or voids. Generally, voids occupy 45 to 50% of the soil volume.

Void ratio (e) is used to express the relationship between the soil's solid and pore phases.

$$e = \frac{(V_A + V_w)}{V_S} = \frac{V_p}{(V_T - V_p)}$$

where V is the volume, A is air, w is water, S is solid, T is the total volume and p is the pore.

Volatilization of nitrogen

Nutrients are lost through four main mechanisms - soil erosion, removal by crops, volatilization of gases and leaching. The nitrogen and sulphur losses occur when (a) the plant material is burned, (b) ammonia escapes from the soil, fertilizer or plants, and (c) microbes reduce nitrates and sulphates to the gaseous forms. Volatilization of ammonia reduces nitrification and the resultant soil acidity. Ammonia volatilizes from alkaline or neutral solutions. Some losses are unavoidable but the avoidable losses occur when fertilizers containing ammonium are mixed with lime or applied to soils that are too dry or alkaline, or when the ammonia fertilizer is injected at a very shallow depth.

Microbial volatilization of nitrogen and sulphur gives nitrogen and nitrous oxide from the nitrate, and hydrogen sulphide from the sulphate. Denitrification losses of nitrogen, nitric oxide or nitrous oxide leave a basic residue due to the formation of hydroxyl ions, equivalent to the amount of the nitrate reduced.

In principle, denitrification can be eliminated by preventing the combination of the wet and warm conditions in the presence of nitrates and decomposable organic matter; paradoxically though, this combination is desirable in agricultural practice.

Fire, whatever may be the cause, conserves most plant nutrients as carbonates, oxides and phosphates in the ash. But much of the nitrogen and sulphur escape as gaseous oxides, eventually to fall somewhere else as components of acid rain. This can be eliminated if burning can be replaced by microbial decay.

Volcanic clay

Volcanic clay is another name for **bentonite** which is a soft, plastic, porous and light-colored rock consisting largely of colloidal silica. It is composed essentially of clay minerals, especially of the montmorillonite group which swells extensively when wet.

In young soils such as andepts (**inceptisols**), the texture has little meaning because of the presence of large quantities of X-ray amorphous colloids. Phosphorus retention in these soils is closely related to the content of X-ray amorphous colloids and their surface area. Volcanic ash is an important parent material of such soils and its weathering imparts a high phosphorus sorption capacity to soils.

Volumetric analysis

Volumetric analysis involves titration, a technique in which one solution is used to analyze another. The solution used to carry out the analysis is called titrant and is delivered from a device called a burette which measures the volume accurately. The point in the titration at which enough titrant has been added to react exactly with the substance being determined, is called the **end point**, **equivalent point** or **stoichiometric point**. This point is often marked by the change of color of the chemical added, called an indicator.

Titration needs the following requirements to be met: (i) The concentration of the titrant must be known. Such titrant is called a **standard solution**. (ii) The exact reaction between the titrant and the substance being analyzed must be known. (iii) The stoichiometric point (equivalent point) must be known. An indicator that changes color at, or very near the stoichiometric point, is often used. (iv) The indicator should change color at the end point. The indicator very commonly used for acid-base titrations, is phenolphthalein, which is colorless in acid and turns pink at the end point when an acid is titrated with a base. (v) The volume of the titrant required to reach the stoichiometric point must be known as accurately as possible.

Volumetric techniques for analysis are generally more convenient and faster than gravimetric procedures, and are widely used for the analysis of acids and bases.

Volunteer wheat

Cereal grain, especially wheat, that continues to grow after the harvest is called volunteer wheat.

Sometimes, seeds fall early or get blown over by wind and fall on the ground. Some other times, mature wheat gets shattered by strong wind or hail. Such seeds germinate later and grow on the field, post harvest. Such wheat plants are volunteer wheat. Removing these plants is time-consuming hence often ignored.

Volunteer wheat poses danger to subsequent crops and also becomes home to many viral and fungal diseases like leaf and stem rust diseases, streak mosaic, etc. Mites, flying insects (Hessian fly) and aphids also reside on these plants. Besides the danger from pathogens, another problem with volunteer wheat is that it removes the moisture from the soil.

Volunteer wheat emerging immediately after the harvest causes the most harm. Risk is thus significantly reduced if early volunteer wheat, within a distance of half a kilometer or so from the crop, is immediately removed. Alternatively, this activity should be carried out two weeks before planting a new crop, followed by an appropriate weedicide program.

Von Liebig's law of minimum

The law of minimum stated by Liebig is a simple but logical guide for predicting crop response to fertilization. The law states, "Every field contains a maximum of one or more nutrients and a minimum of one or more nutrients. With this minimum (be it lime, potash, nitrogen, phosphoric acid, magnesia or any other nutrient), the yields stand in direct relation. It is the factor that governs and controls the yield. Should this minimum be lime, the yield will remain the same and be no greater even though the amount of potash, silica, phosphoric acid, etc. is increased a hundred fold. Liebig's law of minimum dominated the thinking of agricultural workers for a long time and it has been of universal importance in soil fertility management. (See also Law of minimum).

Vrikshayurveda : See Biocontrol of pests, some tested methods

V value

V value represents the percent base saturation of the soil and is calculated using any one of the following formulae:

$$V = \frac{S}{T} \times 100, \text{ or } V = \frac{S}{S+H} \times 100, \text{ or } V = \frac{T-H}{T} \times 100$$

where H is the hydrogen ion concentration, T is the cation exchange capacity of the soil and S is the total exchangeable metallic cations (calcium, magnesium, sodium and potassium) held on the adsorption complex.

The Fertilizer Encyclopedia
by Vasant Gowariker, V. N. Krishnamurthy, Sudha Gowariker,
Manik Dhanorkar and Kalyani Paranjape

The FERTILIZER ENCYCLOPEDIA

W

Walkley-Black method

The contents of soil organic matter and humus are usually determined by a wet combustion process. The process consists of digestion of the soil sample in a mixture consisting of sulphuric acid and an excess of potassium dichromate. The unused oxidant is titrated. Two methods, namely, **Anne method** and Walkley-Black method are employed for determination of the organic carbon content of the soil.

In the Anne method, the organic matter is attacked and destroyed when it is boiled slowly with a mixture of sulphuric acid and an excess of potassium dichromate. The latter is determined by Mohr's salt ($FeSO_4$) in the presence of diphenylamine as indicator.

The Walkley-Black method, also called the **cold method for the determination of organic carbon** content in soils, is based on the same principle as the Anne method, but involves no heating. The method consists of weighing 0.1 to 0.5 g of the air-dried soil with the particle size less than 2 mm in diameter and putting it into a 500 ml Erlenmeyer flask. To this, 15 ml of 0.267N potassium dichromate reagent is added. The flask is connected to a reflux condenser and the contents are boiled for 30 minutes and cooled. The condenser is washed and the liquid is titrated with a ferrous sulphate solution using diphenyl anthranilic acid as an indicator till the color changes from violet to bright green. A blank analysis with no soil is also done.

$$\text{Percentage of organic carbon} = [(\text{meq. } K_2Cr_2O_7 - \text{meq. } FeSO_4) \times 0.3] \times 1.15$$

$$\text{Percentage of organic matter} = \text{Percentage of organic carbon} \times 1.724$$

Warm manure

Warm manure combines aerobic and anaerobic decomposition in a manure heap. Fresh inputs in the upper layers decompose aerobically, while those in the lower layers, in the absence of air. This is a time-consuming method, but it retains a greater carbon content than a compost does. Such heaps take upto three months to become ready for use.

Waste control

Waste materials can be classified by the type (as gaseous, liquid, solid, etc.) and by the source (as chemical, municipal, agricultural, urban, etc). There are many methods of treating waste, which are either converted into useful by-products or disposed of safely. Dumping them in streams and rivers has been made illegal and ocean dumping has been prohibited since 1973.

Treatment methods for waste control include incineration (garbage, paper, plastics), precipitation (smoke, solid-in-liquid suspensions), adsorption (gases and vapors), chemical treatment (neutralization, ion-exchange, chlorination), reclamation of sulphate liquors (paper industry), metals and rubber, compaction (urban wastes), bacterial digestion (sewage), and comminution and melting (glass, metals). Some may involve a combination of these methods.

The recent methods include the following: (i) Flash pyrolysis of certain solid wastes is a method which gives synthetic fuel oil and other useful products. (ii) Urban, animal and agricultural wastes can be fermented by anaerobic bacteria to yield proteins, fuel oil etc. The possibilities of converting cannery and food processing wastes into protein-rich foods and feeds are under investigation. (iii) Catalytic oxidation of exhaust emission gases (as seen in devices which have been installed in cars). (iv) Methane can be recovered from manures. (v) Incorporation of special additives to certain plastics (polystyrene bottles) renders them biodegradable. (vi) High pressure hydrogenation of garbage yields a low-sulphur combustible oil. Radioactive wastes are de-activated by adsorption or ion exchange, as well as by solidification and hydraulic fracturing. High-activity wastes are buried in steel-lined concrete tanks. (vii) Catalytic oxidation of waste chlorinated hydrocarbons, with partial recovery of chlorine is another method of waste control.

Waste disposal on soils

Billions of liters of waste water produced daily demand environmentally acceptable water disposal methods.

Three major waste water disposal techniques are (a) treatment and discharge into surface waters, (b) treatment and reuse, and (c) disposal via septic tanks and spray irrigation.

The disposal of sewage effluents from septic systems is of primary importance. Soil disposal of waste is the final step in the on-site purification of household sewage. The soil filters and treats the effluent as it passes over the soil. Soil micro-organisms use organic matter and nutrients in the waste and deactivate disease organisms, purifying the effluent before it reaches the ground or the surface water supplies.

The success and longevity of a septic system primarily depend on the soil in which it is placed. Soil properties also determine the success or failure of sludge and effluent disposal on land. Soils useful for on-site septic systems and off-site waste disposal must combine moderate permeability and sufficient depth along with a suitable slope and enough active surface area for effective waste treatment.

Shear strength is the most important measure of soil strength. It determines, in part, whether the soil will erode by water, fail catastrophically under the pull of gravity or compact under the load. The treatment is successful when the waste is safely disposed off or utilized without contaminating the surface or ground water.

Wasteland

A land not capable of yielding any useful crop, unless properly reclaimed or rehabilitated, is known as wasteland.

Wastes and emissions from ammonia plants: See Environmental impact of ammonia industry

Wastes and emissions from fertilizer production: See Environmental impact of fertilizer industry

Wastes and emissions from nitric acid plants: See Environmental impact of nitric acid industry

Wastes and emissions from sulphuric acid manufacture: See Environmental impact of sulphuric acid industry

Wastes and pollutants from phosphoric acid production: See Environmental impact of phosphoric acid industry

Water

Water (H_2O) is a tasteless and colorless liquid with a boiling point of 100°C and a freezing point of 0°C. Chemically, it is a compound of hydrogen and oxygen.

Water covers 74% of the earth's surface. It is essential to life which itself began in water and is considered the most precious natural resource. Desalination technology has the potential to convert sea water (which accounts for 97% of the total water on the earth) into fresh water.

The structure of liquid water is still controversial; the hydrogen bonding in water which is H···O-H imposes a high degree of ordered structure. The current models, supported by x-ray scattering studies, show short-range ordered regions which are constantly disintegrating and reforming. This ordering of the liquid state is sufficient to make the water density, at about 0°C, higher than that of the relatively open-structured ice. The maximum density occurs at 3.98°C, which explains why ice floats on water and why water below ice contracts. This is of great biological significance for all aquatic organisms.

The gas phase consists of water molecules in which the H-O-H angle is 105°. Due to its angular shape, a water molecule has a permanent dipole moment; is strongly hydrogen bonded and has a high dielectric constant - the properties that make water a powerful solvent for polar as well as ionic compounds. Just as in the case of cupric ion (Cu^{2+}) which is essentially $[Cu(H_2O)_6]^{2+}$, species in solution are strongly hydrated. Crystalline hydrates are also common for inorganic substances. Pure liquid water is very weakly dissociated into H_3O^+ and OH^- ions by self-ionization as:

$$2H_2O \rightleftharpoons H_3O^+ + OH^-$$

Consequently, species that increase the concentration of the positive species, H_3O^+, are acidic and the species increasing the concentration of the negative species, OH^-, are basic. The phenomenon of ion transport in water and the classification of materials as water-loving (**hydrophilic**) and water-hating (**hydrophobic**) substances are well known. Water has a strong absorption in the infrared region of the spectrum and its transparency to visible ultra violet (UV) and near-UV radiation allows solar radiation to reach the earth during daytime but restricts rapid heat loss at night.

Soil water content has an effect on soil formation, erosion and structural stability, but the primary concern is of water availability for plant growth as the latter is proportional to the amount of water present.

Water is the key factor in nutrient uptake by root interception, mass flow and diffusion. In plants, water has the following four functions. Water is (a) the most abundant chemical compound in active protoplasm, (b) essential for photosynthesis and in the conversion of starches to sugars, (c) the solvent through which nutrients move into the plant parts, and (d) the turgidity provider to plants, which enables the plants to have a proper form and position required to capture sunlight. Although most of the water is absorbed from the soil through the roots, some water is also absorbed through the leaf stomata.

Water infiltrates the pores between soil particles and is held with varying degrees of tenacity. Soil water can be measured directly by weight loss on drying, or by using a soil water tensiometer, electric resistance method or by a neutron probe or a time domain reflectance probe. The tenacity or soil tension with which water is held by the soil particles increases as the soil water content decreases. Water tension in soil at any moment controls the soil water movement and its use by plants.

Water flows into and through soil and is held by the soil for use by plants. The physical characteristics of soil such as the number of pores and the sizes of pores greatly influence the amount of water that can flow through it in a time period and the amount that can be held in it, against the pull of gravity. Water vapor is always present in soil.

Plants vary in their water demand and their tolerance to dry periods. It is estimated that the overall efficiency of water in irrigated and dry land farming is 20 to 50%. Crops with low water requirements (for example, barley and sorghum) or short growing season crops (for example, lettuce and beans) can make best use of the limited water resources.

Water application efficiency

Water application efficiency (E_a) is defined as the ratio of the volume of water stored in the soil root zone by irrigation to the volume of water delivered at the farm. Water application efficiency is expressed as

$$E_a = 100 \times \frac{W_s}{W_d}$$

where W_s is the volume or quantity of water stored in the soil root zone by irrigation, and W_d is the volume or quantity of water delivered to the area being irrigated. This efficiency may be calculated for an individual furrow or border, or farm. It overlaps the definition of conveyance efficiency, when applied to areas larger than a field. Water application efficiency helps in understanding the efficiency of irrigation.

Water balance: See Water balance equation

Water balance equation

Water balance of a growing crop is defined as the difference between the requirement and the availability of water at a given time and place. Water balance can be estimated by an equation known as the water balance equation based on which the quantity of water needed for irrigation purposes can be decided. It takes into account various water losses via evapotranspiration, run-off and soil absorption.

The water balance equation is:

$$P = Q + U + E + W$$

where P is the quantity of water added through irrigation or precipitation, Q is the quantity of water lost through run-off, U is the water quantity available from the deep drainage passing beyond the root zone, E is the water quantity lost by evapotranspiration, and W is the change in water storage in the soil.

The soil water balance estimate is a guide to predict the probable length of the growing season, irrigation needs, leaching of soils for salts, fluctuation in water table levels under regional climates, drought hazards and soil water availability in different regions.

With the water balance equation, the processing and integration of data is easy. The disadvantages are that the level of measurement accuracy in sampling and in drying soils during the rainy weather are low. Therefore, the applicability of the equation is restricted to regions of high potential evaporation rates and well defined periods of rainy and dry weather.

Water balance method: See Transpiration

Water budget

A continuing short-term (weekly or monthly) computation of the supply and demand of moisture is known as a water budget. The knowledge of the precipitation-potential and evapotranspiration-soil moisture storage provides the basis for calculating the moisture available within the rhizosphere. Such data are beneficial, for instance, in informing agriculturists when to replenish the soil moisture through irrigation, before soil water depletion could seriously harm crops.

Water conservation: See Conservation

Water content

The water content is the water lost from a soil or a fertilizer sample when it is dried at 105°C to a constant weight. It is expressed either in terms of mass of water per unit mass of soil or as the volume of water per unit apparent volume of the soil or the fertilizer.

$$\text{Moisture content by weight (\%)} = \frac{\text{Loss in weight on drying}}{\text{Weight of oven dry soil}} \times 100$$

The water content in a plant is not static because there is a continuous process of intake from, and loss to, the surrounding environment.

The amount of water in a soil directly affects the growth of crops, microbes and soil organisms. The strength of the soil, which determines the root penetration and the energy requirements for tillage, depends on the water content.

Direct or indirect measurements of soil water are necessary, for which there are many techniques available. Some methods do not require taking a soil sample to a laboratory. These include the electrical resistance method, neutron probe method, tensiometer method and soil psychrometer technique. These methods are used regularly and are quicker to use than the gravimetric method for rapid and frequent estimations of soil water content.

Water conductivity diminishes sharply as the water content decreases, because more pores are empty and unavailable for water flow. The sharp decline in conductivity with decreasing soil water content has two important consequences, namely, that it limits drainage loss, and the loss by evaporation and transpiration. The water that is briefly held in the soil due to a very high water content, is hardly of any use for plant growth. Unless the profile or the substratum has some impeding layers to stop drainage, surplus water drains out of the pedon within a few days.

Water conveyance efficiency

Water conveyance efficiency is defined as the ratio of the quantity of water present in a system to the quantity of water introduced into that particular system.

Water cycle

Water cycle or **hydrologic cycle** refers to the circulation of water of the earth among the land, oceans and the atmosphere. Water evaporates from the seas into the atmosphere where it may form clouds. Much of this water is precipitated as rain, snow, sleet or hail back to the earth's surface. Of this, some is returned to the atmosphere by the transpiration of plants, and some joins rivers and returns to the sea. Some water joins the ground water and eventually reaches a sea, lake or river. Some water evaporates back into the atmosphere from the surface of the land or from rivers, streams, lakes, etc. Over 97% of the earth's water is in the oceans.

Water economy

Water economy depends on many factors, such as the climate, terrain, type of soil available, percolation, infiltration, evapotranspiration, water storage run-off, etc. The economic efficiency is the net return of profits or other benefits per unit of expenditure on water. The obvious way to enhance this efficiency is to get cheap water and valuable crops. High-value fruit and vegetable crops are prominent components of agriculture in regions with expensive water.

Any planning for water economy must take into account various losses. The losses through run-off and seepage can be minimized by improving the irrigation system which shall consider (a) good land grading, (b) uniform water application at the right rate and the right time, and (c) suitable length of the run-off size of bay in flood irrigation, etc.

Although the run-off and seepage may be a straightforward loss to an individual farm, on a regional basis, any pumping from underground strata (aquifers), drains, streams and lakes from one site can become a hazard elsewhere, in terms of water tables and salt accumulation.

Transpiration increases in proportion to plant (crops) growth; direct evaporation, run-off and seepage do not. An improved plant cover shades the soil, thus reducing the evaporation, and the surface run-off.

Improvement of water efficiency can be achieved by doubling the cropping, suitably increasing the planting density or establishing a ground cover quickly. These can be done by practices that increase soil fertility, crops with more vigor or longer growing season and control of pests and diseases.

Water erosion

Soil erosion caused by moving water (such as rivers, canals and streams) is called water erosion. Soil erosion by water is a major problem the world over.

Water erosion may not only remove the nutrients but also reduce the soil's chemical capacity to retain the added nutrients. The erosion reduces the pedon thickness and the volume of soil available for water storage and root exploration for nutrients. Under extreme **gully erosion**, so much soil is removed that farm machinery and animals cannot move from field to field across the gullies.

Raindrops on the soil surface cause most of the soil detachment in water erosion and the flowing water causes most of the transportation (Fig.W.1). The erosion takes several forms, depending on the intensity of water flow. **Sheet erosion** occurs when there is uniform water flow over the soil surface. **Rills** occur as water concentrates in shallow channels and when they deepen, they form **gullies**. The soil lost from one field is often deposited on another, or is carried into a stream, a river or a lake where the sediments become a pollutant. Sediments added to streams are not always pure as they may carry nutrients or pesticides to the water.

Fig. W.1: Soil erosion by run-off water in a cultivated field.

Erosion creates two problems: a loss of fertility and of soil depth at the eroding place and the addition of unwanted sediment at the place where water is received.

The **universal soil loss equation** is widely used to predict the severity of water erosion from farm fields.

$$A = RKLSCP$$

It takes into account the average rainfall-run-off erosivity factor (R), the soil erodibility factor (K), the slope length factor (L), the slope angle factor (S), the soil cover factor (C), and erosion control practice factor (P) to calculate the annual soil loss for a location (A).

The following are three practices used for controlling water erosion: (i) A soil cover is by far the best method for erosion control. It may be living or dead, long or short, plant, mineral, natural or manufactured. As long as it provides protection from raindrop impact and overflow, it will be effective. Some of the covers are mulch (straw, paper, plastic, wood chips and rocks), a canopy of living plants (grass, trees, perennial crops), and construction sites with jute netting, asphalt, latex, plastic sprays, etc. (ii) Spraying a slurry of fiber, straw, seed, fertilizer and chemical on the roadside is **hydro mulching**. The chemical mulch holds the seed in place and protects the slope from erosion until the grass seed germinates and establishes itself. (iii) Mechanical conservation practices such as conservation terraces, strip cropping, contour cropping and **conservation tillage** or minimum tillage or no tillage are commonly used to reduce the slope length and steepness, consequently soil erosion.

Water extract

Water extract is a solution extracted from a soil mixed with water in the ratio of 1:5 or 1:10. It is useful for determining nutrients and other water-soluble minerals in the soil.

Watergas

Watergas is a mixture of gases from coke, air and steam. The steam is decomposed by passing it over a bed of incandescent coke, or by high-temperature reaction with natural gas or similar hydrocarbons. The composition of the gas, which is used in ammonia synthesis and organic synthesis, is approximately as follows: carbon monoxide 40%, hydrogen 50%, carbon dioxide 3% and nitrogen 3%.

Water, hard

Water containing calcium and magnesium carbonates, bicarbonates, sulphate or chlorides beyond a certain level, as a result of long contact with rocky substrates and soils is called **hard water**. The degree of hardness is expressed either as grains per liter or parts per million of calcium carbonate (1 grain of calcium carbonate per gallon, that is 4.546 liters, is equivalent to 17.1 ppm).

Upto 5 grains is considered **soft water**. Over 30 grains is very hard. Hardness may be temporary (carbonates and bicarbonates) or permanent (sulphates, chlorides). Treatment with zeolites is necessary to soften hard water permanently. Temporary hardness can be reduced by boiling. These impurities are responsible for boiler scale and corrosion of metals on long contact. Hard waters require the use of synthetic detergents for satisfactory 'sudsing'.

Hard waters may be softened by precipitation processes which involve the use of hydrated lime, sometimes along with soda ash; cation-exchange processes which involve the use of sodium-cation exchangers (**zeolite**) or hydrogen cation-exchangers or a combinations of these.

The process choice depends on the composition of hard water, the end uses of the softened water, type of hardness to be removed, the degree of removal required and the relative and the processing costs.

Water harvesting

The process of collecting run-off water from land surfaces during rains and storing it in reservoirs in the soil is known as water harvesting (Fig.W.2). Instead of letting the excess water go waste and join the floodwaters, it is stored in shallow ponds, dug out at the lowest level of the farm for use in lean periods.

Fig.W.2: Excess run-off water is stored in shallow ponds for later use.

Several methods are used for water harvesting. Soil surfaces can be treated with chemicals to prevent water from percolating into the soil. Crop fields situated at lower levels can then utilize the consequent increase in the run-off water. Run-offs can be increased greatly if smooth sandy loam and clay soils are treated with 450 kg/ha sodium carbonate.

A water repellent catchment involves soils sprayed with sodium rosinate which, when applied at a rate of 175 kg/ha, increases the run-off and simultaneously stabilizes the soil. However, sodium rosinate gets oxidized easily.

If trees are replaced by short vegetation like grass, the run-off is increased and can be collected for use in farm areas.

A low cost plastic sheet or metallic film can be laid over the ground so that rainwater can be prevented from percolating, and can be stored. Spreading plastic films and then covering them with gravel can be installed in catchments. The gravel protects the plastic from wind and weather. The US Department of Agriculture has developed a unit called a **rain trap**. A rubber sheet spread over the gravel collects rain, which is then stored in large rubber bags. The stored water is then pumped to the desired field.

Evaporation from reservoirs can be reduced by both organic surface coatings and floating solids. Certain long-chain organic alcohol molecules (hexadecanol, octadecanol), which have high evaporation temperatures (so that they do not evaporate readily) are spread out in a thin film on the water.

The cost of coating reservoirs is high, and some films are so airtight that fish in the water suffocate. Floating bits of plastics, other floating granules or bubbled concrete (which floats) reduce evaporation. Certain irrigation techniques are important in water conservation. The greatest water conservation is possible with **drip** and **sprinkler irrigation**.

Water-hating materials

Substances that hate (or have no affinity for) water are called hydrophobic materials. They are either hydrocarbons or have a long hydrocarbon chain in their molecules. Hexadecanol, cetyl alcohol or kerosene are water-hating materials.

Water-holding capacity

Water-holding capacity is a general term, which indicates the ability of the soil to retain water after free drainage has ceased. Water is held in soil by adhesive bonding between oxygen atoms on the soil mineral surfaces and the hydrogen of water. Hydrogen of water also forms cohesive bonds with oxygen atoms of other water molecules. Strong combined adhesion and cohesion forces cause water films of considerable thickness to be held on the surface of soil particles.

As the forces holding water in the soil are surface-attractive forces, the more the surface area of the soil, the greater the amount of the water adsorbed.

Water is also held in small pores by capillary forces. The small pores and particles in the soil hold the maximum amount of water (also called the **field capacity** of that soil).

Clayey soils have small pores and small-sized particles; hence they hold maximum amount of water, which means they have the maximum water-holding capacity. Among the clayey soils, the swelling montmorillonitic clays hold more water than non-swelling kaolinite and sesquioxide clays. But these clays hold water so tightly that it does not necessarily become available to plants. The largest amount of water available to plants is held by the silt loams or other high-silt soils which have larger particles than those of clayey soils, and so have a smaller total surface area. They have small pores to hold large amounts of water, and hence they have a high water potential.

Increasing the organic matter in the soil is an important strategy for increasing the available water-holding capacity. Furthermore, deep plowing increases the water infiltration rate and the availability of water to crops.

The pressure required to force water off the soil and the soil water potential provide useful information in determining the strength with which water is held in the soil. The **maximum water-holding capacity** (MWHC) indicates the average moisture content of a sample of loose soil of one cm height which, like its lower surface, is in equilibrium with the water table.

The water content of the soil is measured in four ways: (a) the gravimetric method, (b) tensiometer, (c) electrical conductivity, and (d) radioactive tracers. The amount of water a soil holds when all pores are filled with water is called the **saturation percentage**.

Water hyacinth, a potential fertilizer

Water hyacinth (*Eichhornia crassipes*), also called 'blue devil', is a **hydrophyte** (water plant) which commonly grows as a weed in stagnant water bodies like lakes, rivers, streams, ponds, waterways, ditches and backwaters.

This hydrophyte, with its origins in the Amazon basin, grows well in tropical and subtropical climates. Its propagation is both by vegetative and sexual means, and is habitual to adapt to the changing environment as well as the water quality. It has the capacity to alter the ecosystem of the water body by raising the water temperature and causing oxygen fluctuation.

The weed's ability to completely wipe out native aquatic plant species makes it a serious pest of concern. On the other hand, it is a good absorber of nitrogen, phosphorus and potassium from water and is a good source of compost material. Crop yields can be increased by applying water hyacinth as a fertilizer.

Researchers have estimated that 180 tons of water hyacinth can cover an area of 0.4 ha and can produce up to 60 tons of dry organic matter in a year. It has also been recorded that water hyacinth, if used for vermicomposting, can decompose faster than general agricultural waste. Water hyacinth is further reported to increase the weight, the number and the rate of multiplication of earthworms used for composting.

Water infiltration

Water infiltration refers to water movement into soils during rains or irrigation. Infiltration is rapid with large and continuous soil pores, but slow in soils with clogged pores, lodged particles or structure breakdown.

One good effect of infiltration is that it is virtually impossible for the upper sections of the soil to be saturated with water. The extent of water penetration is indicative of how well rains or irrigation water has recharged the soil water storage. The extent of water penetration is seen by just pushing a spread or rod into the soil. The infiltration rate is often limited by the rate at which the water is applied. Knowledge of the infiltration rate helps to ensure that water does not collect on the soil through irrigation.

The rate of infiltration slows with time. The amount of water that seeps into the soil (through rains or irrigation) may not be proportional to the duration of rain or watering – a fact that must be taken into account while deciding how long the soil is to be irrigated. Irrigation systems are designed keeping this in mind. During a rainstorm, the infiltration rate cannot keep pace with the downpour, leading to acceleration of the run-off. This explains why one long storm may contribute more than many short storms to the water shed yield, stream flooding and soil erosion. Understanding of the infiltration phenomenon is also important in relation to waste water disposal.

Water-insoluble phosphorus content: See Water-soluble phosphorus content in fertilizers

Waterlogged soil

A water saturated soil with its pore spaces soaked in water is considered a waterlogged soil.

In a waterlogged soil (Fig.W.3), plant roots are unable to get oxygen for respiration. Almost all plants of economic importance, except rice, grow best when soil pores are no more than 75% full of water.

Fig. W.3: Waterlogged portion of a plowed field.

Artificial drainage aims at increasing aeration to the growing plant roots by removing at least 25% of the water by volume in saturated soils.

Waterlogging can affect yields adversely by bringing about changes in the (a) soil strength, (b) soil pH, (c) oxygen availability, (d) water and thermal regimes, (e) accumulation of carbon dioxide, bicarbonate, carbonate and sulphides (S^{2-}), (f) oxidation-reduction status of soil, (g) nature of microbes (aerobic, facultative-anaerobic and anaerobic), and (h) nutrient availability by altering the uptake, solubility, translocation and interactions.

Soil becomes unfit to support plant growth if the redox potential is less than minus 200 mV, allowing the aerobic microbes directly or indirectly to reduce the nitrate, manganese dioxide, sulphate and iron oxide. Surface and subsurface drainage is necessary not only to leach the excess salts but also to free the soil from waterlogging.

Symptoms of waterlogging on plants are (a) drooping leaves, (b) decreased stem growth rate, (c) leaf abscission, (d) leaf chlorosis, (e) yellowing of leaves, (f) secondary root formation, (g) decreased root growth, (h) death of smaller roots, (i) absence of fruits, and (j) reduced yields.

Many soils flood occasionally and briefly. However, regular long-term flooding is characteristic of marshes, bogs and alluvial basins, lily ponds, taro fields and other water gardens and the world's single most important crop, wetland rice.

Water-loving materials

Substances that have a liking for water are called hydrophilic substances. Colloids that exhibit affinity for solvents (water) are lyophilic (hydrophilic).

Water management

Water management refers to a set of operations designed to optimally tap the major part of water resources and to put it to the best use with minimum damage to the environment. These operations involve civil work, construction of reservoirs, anti-erosion measures, adjustment of stream courses, etc.

Anti-erosion measures (protection and reclamation of soils) control the transport of topsoil or erosion caused by downstream rivers (called **fluvial erosion**). This is an important water resource management practice in rain-fed dryland farming and soil conservation.

Soils store water temporarily for plant use. The useful storage capacity depends on the soil's depth, texture, structure, organic matter content and the plant root system. The amount stored depends on rainfall, irrigation, run-off, transpiration, evaporation and deep percolation below the root zone. Water losses and crop growth increase with increasing soil wetness. The management of soil water seeks to optimize the use of the available soil water and to minimize the non-productive losses. In addition, irrigation management seeks to optimize the use of imported water as a supplement to rains. The effectiveness and efficiency of soil water management depends greatly on climate, seasonal weather, and plant properties.

The most influential soil properties are those that affect water storage, infiltration and drainage. In dry land agriculture, effective water storage capacity may be the most important single soil property. Storage capacity in turn depends on the depth, texture, organic matter and freedom from constraints on root growth. In irrigated agriculture, or in areas where there are frequent and dependable rains, storage capacity is less important. Variable infiltration rates or extremely slow or fast infiltration rates interfere with irrigation, especially when water is applied by flood or furrow methods. Infiltration rates depend mainly on the soil structure and structural stability in the topsoil. Subsoil impermeability due to clay accumulation or cemented horizons adds to the cost of drainage and salt control measures, sometimes to the point of making irrigation agriculture unsustainable.

Vegetation usually extracts soil water preferentially from the top of the pedon, establishing a drying profile. Growth becomes limited at some stage of drying, depending on the soil water release properties, root distribution, stage of crop development and the effect of the weather on water demand.

The entry of liquid water into soil, which is called **infiltration**, is driven mainly by the attraction of water to soil particle surfaces and pores (matric potential). Infiltration proceeds by the advance of a wetting front, as the wetted zone extends into the dry soil. The rate of infiltration, which depends on the hydraulic properties of the soil, always slows as wetting proceeds, unless the rate of water application is fast. As alkaline soils have a low infiltration rate, it results in rainwater accumulation on the surface, causing waterlogging. Such waterlogging can be avoided by surface drainage during the rainy season. A low natural recharge of the ground water, even during the rainy season, is due to the poor hydraulic conductivity of alkaline soils. To boost groundwater recharge, vertical bores with appropriate filters may be provided.

Irrigation management in alkaline soils is problematic owing to clogging of the dispersed soil particles and low stability of the soil aggregates which control the permeability of water and air.

Irrigation methods, such as sprinkler and drip irrigation, usually try to recharge the root zone adequately and uniformly, without allowing excessive evaporation, run-off and deep percolation.

Surface drainage minimizes undesirable water accumulation over the soil surface; subsurface drainage lowers the water table to improve aeration and salt leaching. Methods of subsurface drainage include the installation of trenches and tile drains (the buried perforated pipes) that help to collect water and deliver it to a sump or sink. Pumping from the sump may be necessary. As water escapes freely from saturated soils, drains (like springs, wells) must be below the water table in order to operate. Drains draw down the water table. A uniform draw down is not practical to achieve. Compromises are imposed by considerations of costs and the permeability of the soil.

There are different methods for assessing the **water use efficiency** which is the ratio of the benefit gained to the water used. The benefit can mean the growth, yield or the value of the product; the water used can be by way of transpiration, evapotranspiration or total water supply. Economic efficiency would be maximal if all the water were used productively for the growth of a high-value produce (crop).

Water mining

The process of extracting water from underground reservoirs is called water mining. Demand for fresh water may result in more ground water extraction than what is replenished (Fig.W.4).

Fig.W.4: Water being mined for drinking.

Water of crystallization

Water of crystallization is an equivalent term for **water of hydration**.

Water of hydration

Water present in a crystalline compound, in a definite proportion, is the water of hydration or **water of crystallization**. Many crystalline salts form hydrates containing one, two, three or more moles of water per mole of the compound. This water may simply occupy lattice positions in the crystal, or it may form bonds with the anions and the cations present. For instance, in the pentahydrate of copper sulphate [$CuSO_4 \cdot 5H_2O$], each copper ion is coordinated to 4 water molecules through the lone pairs of electrons on the oxygen to form a complex $[(Cu(H_2O)_4]^{2+}$. Each sulphate ion has one water molecule held by hydrogen bonding. These two types of bonding are different as the pentahydrate converts to a monohydrate at 100°C and becomes anhydrous above 250°C.

Hydrated salts like $FeSO_4$ or $CuSO_4$ are used as nutrients to plants.

Water pollution

Contamination of fresh or salt water with materials that are toxic, noxious or otherwise harmful to fish, man, animals etc. is known as water pollution.

The discharge of waste water into water bodies, like rivers and streams, has always been a thoughtless and inexpensive means of disposal. This has been made illegal since 1973 and environmental protection agencies have prohibited dumping of wastes into the ocean.

Pollution results from run-offs containing toxic insecticidal residues. Oil spills at sea are also a chronic problem.

Most organic wastes degrade readily in water. Bacteria convert organic waste into inorganic components (nitrogen, phosphorus and carbon) which nourish microscopic algae and thus enter the aquatic food chain. This process consumes the oxygen present in the water, but the water renews its oxygen supply by absorption from the air and by photosynthesis. When the volume of organic waste is too great, however, the water's oxygen supply is exhausted and the water body eutrophies or dies. It then turns slimy and stinks.

Certain wastes in water are not degradable. These include inorganic and synthetic organic chemicals (for example, the pesticide DDT and industrial chemical PCB) and metals (mercury and lead). Toxic non-degradable wastes may immediately poison aquatic life or may enter the aquatic food chain with ultimately serious consequences. Water can do little with non-degradable wastes except dilute them and carry them away from the point of discharge. In ridding itself of the non-degradable waste, a flowing stream scores maximum success, a tidal stream less so, a lake least of all. The ocean is the ultimate sink of non-degradable wastes.

The rise of temperature of a water body by the heat discharged from the cooling system or effluent wastes of industrial installations give rise to thermal pollution. Such a temperature rise may sufficiently upset the ecological balance of the waterway to pose a threat to native life-forms. Cooling the waste water before admitting it into the waterway is one way to overcome this problem.

Water potential

Water potential, also called **soil water potential**, is defined as the chemical potential of water in the soil (or biological system) minus the chemical potential of pure water at the same temperature and pressure.

The chemical potential is the change in Gibbs free energy with respect to change in the amount of the components, with temperature, pressure and the amount of the unchanged components.

Water potential is measured in kilo Pascal - that of pure water being zero. Aqueous solutions of increasing concentration have increasingly negative values. Water tends to move from areas of high (less negative) water potential to areas of low (more negative) water potential. Osmosis in plants is now described in terms of water potential.

Water potential is the minimum additional work required to move water from the soil system. Since the soil water is held in the soil by forces of adsorption, cohesion and solution, it does not work as pure free water, hence the potential is negative. The term **total soil moisture stress** has also been used to describe the negative water potential.

The soil water potential (Y) may be expressed in terms of the water vapor pressure (P) at a certain temperature and pressure with which it is in equilibrium, at a constant absolute temperature (T):

$$Y = RT \ln (P/P_O)$$

where R is the specific gas constant for water vapor and P_O is the vapor pressure of pure free water at the same temperature and pressure.

The equipment for measuring water potential is based on the principle of lowering the aqueous vapor pressure over a solution or soil sample. The thermocouple psychrometers measure the thermal electromotive force from the cooling of the junction in an enclosed space.

The movement of water through the soil depends on four factors: gravity, solute, pressure and matrix; their collective effect is said to be the water potential of that soil. Water moves downward with gravity. In saturated soils, water moves from high to low pressure areas. Solutes make water move from a dilute to a more concentrated solution. In plants, water movement is dominated by solute (osmotic) potentials caused by salts and organic solutes in cell water. These differences in solute concentrations can be maintained because cell membranes restrict solute movement, but allow water to pass through. Water moves from wetter places to drier surfaces or from larger pores to smaller pores because of the soil matrix. In unsaturated soils, the matrix is the force, causing water to move.

Water purification

Water purification refers to the process by which water is treated in such a way as to remove or reduce undesirable impurities. The following methods of purification are used: (i) Sedimentation in which coarse suspended matter is allowed to settle by gravity in special tanks or reservoirs. (ii) Coagulation of aggregates by means of aluminum sulphate, ferric sulphate or sodium aluminate (the aggregates form colloidal impurities by coagulation). (iii) Filtration through a bed of fine sand, either by gravity flow or by pressure to remove suspended particles. (iv) Chlorination, which is effective in sterilizing potable water, swimming pools, etc. (v) Adsorption on activated carbon for removal of organic contaminants causing unpleasant taste and odor. (vi) Hardness removal by ion-exchange or zeolite process.

USDA has reported that mercury can be removed from water by treatment with low percentages of black liquor from Kraft paper-making.

Water quality

Water is one of the most important inputs for realizing and sustaining a high agricultural production. Its quality is determined according to the purpose for which it is used. For instance, the main criteria for assessing water quality for irrigation are its salinity, sodicity hazards and specific ion effects; for other uses, the criteria are its taste, color, odor, turbidity, temperature, hardness, **biological oxygen demand (BOD)**, **chemical oxygen demand (COD)**, nutrient contents (nitrogen and phosphorus) and pathogenic organisms.

COD is a measure of the oxygen-consuming capacity of inorganic or organic matter present in water or waste water. Similarly, BOD represents the amount of oxygen required for bacteria to decompose the organic matter in the solution. BOD or COD gives the amount of organic materials or chemicals in water when it is decomposed or oxidized respectively. A high BOD or COD means the presence of organic materials such as algae, plant residues or manures. Water with high BOD causes poor aeration conditions to occur faster than that with a low BOD.

Suspended solids like clay, sands, silts and organic materials cause turbidity or opaqueness. The suspensions may fill the irrigation canals, clog sprinkler and trickle irrigation systems, erode turbine blades and seal soil surface pores. However, these problems can be avoided by using filters or settling tanks. The water temperature is not much of a concern in irrigation except when it is too cold to promote growth.

Pathogenic organisms are generally absent in natural fresh water sources, except when sewage effluents are used for irrigation. Salinity or total salt concentration is among the most degrading factors for the quality of irrigation water. In plants, salts increase the osmotic pressure of water, as a result the plants are forced to exert more energy to absorb the soil water. The total salt concentration in water can be measured in terms of milligram/liter (mg/l) or parts per million (ppm) or percent (%) or milli-equivalent per liter (meq/l). The salt concentration is also expressed as **total dissolved solids (TDS)**.

The salt content is measured by electrical conductivity in Siemens/meter (S/m) or deciSiemens/meter (dS/m) for soil solutions or milliSiemens/meter (mS/m) for water. The total salt concentration of water is linearly correlated with electrical conductivity and can be calculated using the formula

$$\text{Salt concentration (meq/l)} = \frac{\text{Ec}(\mu\text{S/m})}{100}$$

where Ec is the electrical conductivity, μS is microSiemen and m is meter.

Whether water is suitable for a plant or not, depends on the plant, the amount of leaching permitted during irrigation and the degree of dryness permissible for the soil before the next irrigation. If the soil is allowed to dry, the salts move up to the surface along with the evaporating water. If excess leaching occurs and the soil is wet, the salt content in the soil becomes too high for the plant. Normally, the topsoil (down to a depth of 20 to 30 cm) salt concentration is about 2 to 3 times, and at further depths 5 to 10 times of the salt concentration in irrigation water.

In addition to salinity, the high concentration of sodium is also undesirable in water because sodium adsorbs on the cation exchange sites in the soil and causes the soil aggregates to break down and the soil pores to seal, making them impermeable to water flow. The

sodium hazards of irrigation waters are expressed as **sodium adsorption ratio (SAR)** and **residual sodium carbonate**. The SAR of water is calculated by the equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}}$$

where Na^+, Ca^{2+}, Mg^{2+} are concentrations of the ions expressed in meq/l.

From SAR, the **exchangeable sodium ratio (ESR)** and the **exchangeable sodium percentage (ESP)** can be calculated using the equation:

$$\frac{ESP}{100} = \frac{ESR}{1 + ESR} = \frac{(-0.0126 + 0.01475\ SAR)}{1+(-0.0126 + 0.01475\ SAR)}$$

On the basis of SAR, irrigation water is divided into 4 categories of sodium hazards (low, medium, high and very high) as shown in the Table-W.1.

Table-W.1: Sodium hazards (sodicity) of irrigation Waters.

SAR of irrigation water (meq/l)	Sodicity hazards	Sodicity class
Less than 10	Low	S1
10–18	Medium	S2
18–26	High	S3
More than 26	Very high	S4

Source: Richards (1954). Adapted from "Soil Salinity and Water Quality", 1996, R. Chhabra, Oxford & IBH Publishing Co. Pvt. Ltd., India. With permission.

Ground and river waters are characterized by the presence of bicarbonates. Irrigation waters containing high concentrations of bicarbonate, calcium (Ca^{2+}) and magnesium (Mg^{2+}) tend to precipitate, sometimes as carbonates when the soil solution is concentrated. This leads to the depletion of bivalent ions (Ca^{2+} and Mg^{2+}), and a consequent increase in the SAR.

Various formulations have been proposed to account for the effect of bicarbonate (HCO_3^-) on sodicity hazards of irrigation water. One assumption is based on the fact that all calcium and magnesium [$Ca^{2+}$and Mg^{2+}] precipitate as carbonates. F. M. Eaton proposed a concept, called **residual sodium carbonate (RSC)**, for the assessment of high carbonate waters. According to him,

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

where all ionic concentrations are expressed in meq/l.

For all practical purposes, RSC is hazardous if higher than 2.50, marginal between 1.25 and 2.50, and safe, when lower than 1.25 meq/l.

An improvement to the concept, SAR is based on the use of Langelier's **saturation index (SI)**, originally developed for predicting carbonate deposition in boilers. SI is defined as:

$$SI = 8.4 - pHc$$

$$pHc = (pK_2 - pK_{sp}) + pCa^{2+} + p_{(alk)}$$

where pK_2, pK_{sp} are negative logarithms of the dissociation constant of carbonic acid (H_2CO_3) and calcium carbonate ($CaCO_3$) solubility product, pCa^{2+} is the negative logarithm of calcium ion (Ca^{2+}) concentration and p_{alk} is the negative logarithm of alkalinity concentration ($HCO_3^- + CO_3^{2-}$) and pHc is the pH of the carbonate water or applied water.

If pHc is below 8.4, the tendency of lime to precipitate from applied water is indicated. Dissolution of lime also occurs at this pHc. The above equation changes on including both $Ca^{2+} + Mg^{2+}$ to become:

$$pHc = \Delta P_k + p(Ca^{2+} + Mg^{2+}) + p(HCO_3^- + CO_3^{2-})$$

where Δpk refers to the difference $pK_2 - pK_{sp}$.

The adjusted SAR is now defined as:

$$SAR_{adj} = SAR\ [1 + (8.4 - pHc)]$$

In addition to salinity and sodium hazards, crops may be affected by varying concentrations of certain ions in water, which may cause specific toxic symptoms and/or nutritional disorders.

If the calcium concentration is more than 35% of the total cations, the water is fit for irrigation, if more than 60% of the total cations, the water is unfit for irrigation. Water containing a high potassium concentration reduces the harmful effects of sodium and is considered good. Among the anions present, the main concern is for chloride (Cl^-) and sulphate (SO_4^{2-}). Chloride sensitive plants may suffer if the chloride concentration exceeds 5 to 10 meq/l. Woody species like deciduous trees, citrus and avocado are very sensitive to Cl^- toxicity.

Sulphate (SO_4^{2-}) **water**, high in sulphate having a chloride to sulphate ratio of 1:3 or higher, is more harmful than chloride water because a high sulphate concentration is injurious to plant roots and disturbs the internal metabolism of the plant. A continuous use of such waters leads to the precipitation of calcium as calcium sulphate ($CaSO_4$), causing a rise in the pH and ESP of the soil. A continuous application of water with a high nitrate concentration acts as a source of nitrogen. However, it is harmful to some grains, such as wheat, corn, barley and gram. A higher concentration of nitrogen in the fodder as a result of high nitrate in irrigation water can cause nitrate poisoning in animals, although it is not harmful to the growth of fodder per se.

Boron occurs in varying amounts, usually 0.1 to 5.0 mg/l, in the ground water of arid and semi-arid zones. The optimal boron level between deficiency and toxicity is narrow for many crops. Boron cannot be precipitated or easily removed and in this situation the only solution is dilution.

Saline ground waters occurring in arid and semi-arid zones contain magnesium (Mg^{2+}) and calcium (Ca^{2+}) in the proportion of 1:9. If the magnesium (Mg^{2+})

concentration is more than 50% of the bivalent cations, it is harmful.

The factors that must be taken into account for considering the suitability of any particular water for irrigation purposes are (a) the chemical composition of water, (b) crops to be irrigated, (c) the soils to be irrigated, (d) management practices for irrigation and drainage, and (e) climate. The interaction of all these factors can lead to a modification of the otherwise imposed limits on the use of irrigation water for its successful exploitation.

The guidelines for irrigation water quality established by FAO are shown in Table-W.2.

Water repellent catchment

When fatty or oily substances (which are low in oxygen) coat soil particles, the soil becomes water repellent. In nature, such soils are formed under plant cover. During forest fires, the resins and oils from plants are driven into the soil. Thus, the soil particles get coated and resist wetting. Water repellent catchment is an area that involves soils sprayed with sodium rosinate at the rate of 175 kg/ha. This increases the run-off and aids rainwater harvesting. It also stabilizes the soil. However, sodium rosinate gets oxidized easily.

Water requirement of plant

Plants vary in their demand for water and their tolerance to dry periods. Most crop plants, however, need a continuous water supply. Any shortage of water reduces their growth pattern. For example, if the period of dryness or the rate of transpiration increases, the crop yield suffers. That is why it is necessary to know the amount of water needed for each crop. There are some crops, like barley and sorghum, which do not require much water, and therefore, can survive in water-scarce regions. Short growing season crops, like lettuce and beans, can make best use of the limited water resources.

Water requirement is defined as the ratio of the weight of water absorbed by the plant during the growing season to the weight of dry matter produced by the plant. The daily water requirement varies from about 2 mm to about 1.5 cm.

Nitrogen, if adequate, decreases the requirement of water used per kilogram of the dry matter in grasses.

Water reservoirs

Water reservoirs are often man-made lakes or dams which may be built on rivers and streams or by dredging river into a flat stretch of land (Fig.W.5), or water towers or tanks atop buildings. They are areas constructed to store water for future use. When more water is required than is available, its storage becomes critical. Ponds and lakes are examples of natural reservoirs.

Fig. W.5: Dams are man-made water reservoirs.

Table-W.2: General guidelines for irrigation water quality.

Irrigation water quality index	Degree of problem		
	None	Increasing	Severe
Permeability (infiltration rate) dS/m			
Ec_{iw}, dS/m	More than 0.5	0.5 to 0.2	Less than 0.2
Salinity, dS/m	Less than 0.75	0.75 to 3	More than 3
SAR_{adj}			
Montmorillonite	Less than 6	6 to 9	More than 10
Illite-vermiculite	Less than 8	8 to 16	More than 15
Kaolinite-sesquioxide	Less than 16	16 to 24	More than 25
Specific ion toxicity (affects sensitive crops)			
Boron, meq/l	Less than 0.75	0.75 to 2	More than 2
Chloride meq/l	Less than 4	4 to 10	More than 10
Sodium (adj SAR)	Less than 3	3 to 9	More than 9
Miscellaneous			
HCO_3^- meq/l (sprinkler)	Less than 1.5	1.5 to 8.5	More than 8.5
NO_3^- or NH_4^- nitrogen (meq/l)	Less than 5	5 to 30	More than 30
Cl, meq/I	Less than 1	1 to 2	More than 2
pH	Normal range	6.5 to 8.4	----

Source: Richards, 1954. Adapted from "Soil Salinity and Water Quality", 1996, R. Chhabra, Oxford & IBH Publishing Co. Pvt. Ltd., India. With permission.

Reservoirs supply water for drinking, washing and irrigating fields. Water is drawn from the reservoirs through pipes and in some cases, it is pumped hundreds of kilometers away.

Watershed

Watershed is a region or a ridge of land that separates waters flowing to different rivers, basins or seas. It is the dividing line between the catchment areas. A watershed is also called **topographic watershed, catchment basin** or **drainage basin**. Viewed from a given point along a river course, watershed is an area within a contour from which precipitation flows toward that point in the river. When soils are very permeable or are subject to strong flows, with dissolved rocks in the limestone region (called **Karstic flow**), the hydrological watershed may be significantly different from the topographic watershed. **Hydrological watershed** is concerned with the properties of the earth's water particularly in relation to land.

Watershed area is the total area of the watershed above the discharge measuring point. Watershed planning involves the formulation of a complete strategy for the treatment and use of land and water resources of a watershed.

When watershed lands are used with some predetermined objectives, the implementation of such efforts is referred to as **watershed management**. The objectives here can be to control erosion, stream flow or sedimentation, to improve the vegetative cover and other related resources.

In order to protect watershed, or to prevent floods, measures are taken for soil conservation and land treatment (including structural measures) to improve the infiltration of water and to reduce floods and erosion.

Optimum utilization of the catchment precipitation, which leads to stabilization of agriculture on the watershed and better returns from the given soil, is what comes under the broad area of **watershed-based farming**.

Watershed lag is the time interval between the center of the mass of effective rainfall and the peak of the hydrograph. **Watershed leakage** refers to precipitation falling on one basin, finding its way underground through fissures and water bearing strata, to the sea or a nearby or remote drainage basin.

Watershed area: See Watershed

Watershed-based farming: See Watershed

Watershed lag: See Watershed

Watershed leakage: See Watershed

Watershed management: See Watershed

Water, soft: See Water, hard

Water-soluble phosphorus in fertilizers

Phosphorus in fertilizers can be water-soluble, citrate-soluble or citrate-insoluble. Most countries define water-soluble phosphates as the ones that go into solution at room temperatures when an aqueous suspension is made with 1 g of soil sample in 50 ml of water (in the USA, 1 g soil in 250 ml water). The slurry is then filtered and the amount of phosphorus contained in the filtrate is determined. The amount of phosphorus in the sample is expressed as a percentage by weight that is water-soluble. A sum of water-soluble and the citrate-soluble phosphorus is considered as the fraction available to plants, and is termed **available phosphorus**.

The solubility of phosphorus varies in different phosphate carriers. The water-soluble phosphorus denotes the phosphorus content in the fertilizer.

Generally, water is used for extracting phosphorus (as phosphate) from the fertilizer or soil sample, for a prescribed period of time. The amount of phosphorus in the filtrate which is expressed as a percentage-by-weight of the sample, represents the water-soluble fraction of the sample. The residue after the water extraction is called **water-insoluble phosphorus content** and is extracted with 1N ammonium citrate to get citrate-soluble phosphorus. Along with water-soluble phosphorus content, the extraction gives the **total available phosphorus** content.

Water supply

Water supply is the available water resources and the means by which sufficient water of a suitable quality is supplied for agricultural, industrial and domestic purposes. Water precipitated over land is available either as 'surface water' in the form of rivers and lakes and supplemented by reservoirs, or as ground water, held underground, typically in an aquifer. Ground water is generally pumped to the surface. It may also rise as a spring or artesian well. Water may also be extracted from sewage, purified and recycled.

Water table

Water table refers to the upper surface of ground water below which the soil, fissures and pores in the rock strata are saturated with water. This surface is uneven and its position varies, among other things, according to the amount of infiltrated rainfall. When the hydrostatic pressure of ground water is equal to the atmospheric pressure, the water table is known as **natural water table** below which water moves freely under the influence of gravity.

A high water table may limit the volume of the soil with good aeration and thus restrict the rooting volume. A fluctuating water table may result in the roots being killed, and a rise of water intake. When the water table recedes, the plant is left with insufficient root surfaces. The roots can reach the capillary fringe, and the plants can use moisture from the water table if it is near the surface.

The position of the water table is shown by the level at which water stands in the adjoining wells. However, on slopes, water is well drained and water table is far below the soil surface. Poorly drained soils tend to occur in low parts of the landscape where water table exists close to the soil surface leading to various degrees of anoxia and reduction.

Water use efficiency

The amount of water required to produce a unit of dry weight material of plants is a measure of the water use efficiency (**WUE**). It is a ratio of the yield to the water used, irrespective of the water source and is expressed as the crop yield in metric tons per hectare-cm of water. The water use efficiency increases with the promotion of plant growth and better photosynthesis which, in turn, leads to an increased crop yield.

The efficiency of water use is said to increase, if the amount of water used per unit of production decreases. Substantial increase in grain yield and water use efficiency can occur in both dry and normal rainfall years. For example, in one experiment, the water-use efficiency increased from 50 t/cm of water to 89 t/cm of water with the highest application rate of nitrogen and phosphorus. Under high-fertility and irrigated conditions, the water use efficiency in corn was 116 t/cm of water, compared to 119 t/cm with medium fertility.

The efficiency of water use is calculated by (a) dividing the steady state carbon dioxide exchange rate by the transpiration rate, (b) dividing the dry matter accumulation by water lost through transpiration, and most commonly (c) dividing the dry matter accumulation by water lost through evapotranspiration. Higher water use efficiency has been reported for maize-soybean and maize-mung bean intercrops. Water use efficiency can be increased through root zone modification by increasing the water storage and root development in the profile or by alleviating such problem conditions as poor drainage or high salinity.

Tillage leaves large amounts of surface residues and a rough surface helps to save the water by about 20%. The reasons for this are that tillage (a) increases water infiltration, vigorous plant growth, heavy crop residues and extensive root growth, (b) decreases evaporation from the surface, and (c) increases the reservoir of water in the soil.

Water use efficiency is becoming more and more important as higher yields push water supplies to the limit. There are two ways to improve water use efficiency: (i) Reduce evaporation from leaves. Potassium, added to salty irrigation water reduces the transpiration ratios. (ii) Increase the ratio of output of dry matter per unit of water used. This appears to be the most feasible approach at present. Proper fertilization is one of the most practical methods of increasing crop output or yield per unit of water used.

Waterways

To solve the problem of inadequate water distribution, water is often transported to great distances in canals or waterways (Fig.W.6). Waterways, natural or man-made, are used for transporting water and reducing erosion. (See also Grass waterway.)

Fig.W.6: Waterways like canals carry water to distant places for various purposes.

Weak electrolytes

Weak electrolytes are substances that produce relatively few ions when dissolved in water. The most common weak electrolytes are weak acids and weak bases. Acetic acid is an example of a weak acid as it dissociates only 1% in water. Weak electrolytes dissociate only to a small extent in an aqueous solution. The most common weak base is ammonia as it produces only 1% hydroxyl when dissolved in an aqueous solution as indicated below:

$$NH_{3(aq)} + H_2O \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

(See also Electrolyte).

Weathering

Weathering is a process in which substances disintegrate or decompose by exposure to the forces of nature (like rainwater, frost, wind, temperature changes, plants and animals), and eventually produce soil particles.

The formation of soils from rocks through the action of frost and extreme temperature changes is an example of weathering. Freezing and thawing, uneven heating, abrasion, and shrinking and swelling break large particles into small ones. Burrowing of animals and the growing of plant roots into thin cracks of rocks can force cracks to open until the rocks break. Growing salt crystals may have the same effect.

Human actions that cause weathering include construction, tillage, lumbering, fire use, fumes, solid and liquid effluents from chemical industries, and the manipulation of geological water systems. These have increased exponentially in recent centuries.

The physical and chemical weathering of rocks lead to the formation of soils. Under natural conditions in the tropics, **physical weathering** is essentially a mechanical disintegration of rock materials brought about by (a) sudden and wide variations in temperature, (b) an abrasive action of particles present in the wind, (c) rain, particularly hail, falling with force on the rock, and (d) the roots of trees penetrating into cracks and joints. However, mechanical disintegration of rocks by plants is far less.

Chemical weathering or decomposition changes the chemical structure of the rock. It is a process that changes minerals from their original composition, through the addition of hydrogen to the structure (hydrolysis), addition of water (hydration), gain or loss of electrons (oxidation or reduction), dissolution, and carbonation. Each of these fundamental processes occurs wherever water is in contact with mineral particles.

The major chemical weathering agents are carbonic acid (which is a combination of water with atmospheric carbon dioxide, capable of dissolving soluble rocks and minerals), oxygen (combining with rock materials) and water (combining chemically with rock materials). Chemical weathering is aided by physical weathering since rocks, heavily fractured and/or fragmented by physical processes, are vulnerable to chemical processes.

Plants and animals cause **organic weathering**, possibly in combination with chemical and mechanical processes. For example, burrowing animals and plant roots may physically break up rocks. Lichens, growing on bare rock surfaces, may cause decomposition through the removal of nutrients. After precipitation, the relatively soluble products of chemical weathering give rise to products and rocks (such as **limestone**, **gypsum**, rock salt, silica, phosphate and potassium compounds) which are useful as fertilizers.

The three most important factors affecting weathering are climate, the physical and chemical characteristics of rocks. Weathered particles of rocks are the parent materials for soil synthesis. They may remain sedentary or be transported by natural forces and get deposited in new locations.

Another factor affecting the weathering process is that all minerals do not decay at the same rate. Some are more resistant than others. Thus, under specified climatic conditions and with specified types of parent material, the resultant soil should contain some of the original minerals in a greater quantity than others. Olivine weathers rapidly while quartz is relatively stable and highly resistant to weathering.

With the knowledge of the weathering sequence, it is possible to project the relative amount and type of mineral that will accumulate in the soil with time. In a parent material containing equal quantities of bases, the order of weathering is Ca > Mg > Na > K. Under the same climatic conditions, the oxides of silicon, iron, and aluminum - residual products of decomposition - are resistant and will most likely accumulate in the soil.

Weathering index

Weathering index (**WI**) provides information about the weather and of changes within the soil caused by time, water, wind, temperature, vegetation and animal life. WI is given by the ratio of stable soil minerals (like quartz) to unstable soil minerals (like feldspars). The larger the ratio, the more weathered is the soil.

Weatherly high pressure process for nitric acid manufacture: See Nitric acid production processes

Weedicides

Weeds are plants that are useless or destructive and grow where they are not desired. A weed grows abundantly and takes nutrition, water and space meant for plants which are under cultivation. Besides, they may also be harmful; for example, poison ivy and oak can produce a skin rash, goldenrod and ragweed can cause hay fever, and thistles have prickly leaves that can hurt the skin.

Chemicals, used for a selective control of weeds, are called weedicides. Several copper salts, iron sulphate, sulphuric acid and other chemicals were used extensively in Europe to control broadleaf weeds in small grain crops. Many weed killers can damage the root of the weed as well as the portions above the ground.

2,4-D (2,4-dichlorophenoxyacetic acid) is known for its weed-killing properties. Weedicides, also known as **herbicides**, can be applied to soils or sprayed on weeds to kill them. Such uses have, however, led to controversies about the nature, extent and acceptability of the accompanying risks.

There are 2 types of herbicides: (i) **Selective**, like 2,4-D, permitting elimination of weeds without injuring the crop. (ii) **Non-selective**, such as soil sterilants and silvicides.

All things considered, chemicals seem to be preferred over other methods in weed control. These take less time to spray on a field than de-weeding by tilling or hoeing, and are less expensive. Chemical weedicides are best suited for controlling weeds that emerge with a seeded crop, especially a small-grain crop, in which tillage is not practical and the fields are too large for hand weeding.

There are some disadvantages. Herbicides can drift from the target area and harm non-target plants. Some can persist in the soil and harm subsequent crops or enter the ground water. When used carelessly, these can lead to the denuding of the site resulting in erosion. Some herbicides are toxic and their indiscriminate use can lead to poisoning. In developed countries, herbicide usage is restricted.

A foliage-applied herbicide, to be effective, must (a) reach the plant, (b) be retained on the leaf, (c) penetrate the leaf, (d) move to its site of action, and (e) remain in contact with the weed for long enough to be effective. Soil-applied herbicides are meant for uptake by emerging shoots or the roots of the weeds. Unlike leaves, roots are highly absorbent organs and are effective in taking up herbicides. However, soil-applied herbicides are not always available for uptake by the plant.

Approximately, 200 formulations of herbicides are used commercially under the categories of (a) foliage-active contact herbicides (such as, bipyridiliums, benzonitriles, propanil, bentazon and dinoseb), (b) foliage-active translocated herbicides (such as auxin type, fatty acid synthesis inhibitors, glycophosphate, sulphonylurea and imidazolinones), and (c) soil-active herbicides (such as phenylureas, s-triazines, uracils, pyrazon, dinitroanilines, dinitrobenzeneamines, diphenyl ether, thiocarbamate and substituted amides).

Weed management: See Weeds

Weeds

Weeds are unwanted plants, growing in competition with the cultivated crop for space, light, nutrients, etc. They can be classified on the basis of their leaf forms (narrow leaf weeds or broad leaf weeds), life span (perennials) and growth or habitat. Fig.W.7 shows *Parthenium* grass, a common weed, covering a large area.

Fig.W.7: Congress weed (Parthenium grass) is a very common weed.

Fertilizers do not discriminate - they supply useful nutrients to both the weed and the crop. The problem becomes one of keeping the infestation of weeds below a tolerable limit. Some fertilizers give the crop a competitive advantage over some weeds, but also increase the growth of tall and fast growing weeds, especially perennials.

Frequent planting of winter cereals increases the weed problem. plowing and soil cultivation, or using chemical weed-killers (herbicides) are among the main control measures used for destroying weeds and are parts of **weed management**. Demand for **herbicides** is constantly on the rise for combating perennial weeds. There are also other aspects of weed management which involve removing the weed seeds in the soil, and resorting to, what may be broadly classified as, cultural, biological, chemical and integrated weed control methods.

Weeds can be a major problem in all rice growing areas where a yield reduction of up to 30% is observed. Weeds can be a major constraint in labor-intensive, small-scale farm operations. For instance, on Nigerian savannahs losses of 65 to 92% have been reported due to weeds. A parasitic flowering plant, known as witch weed (*Striga* sp), is a major pest in a large part of sub-Saharan Africa.

Weeds may act as hosts for plant pests, providing an adjacent source of inoculums and allowing pests to survive or proliferate even in the absence of crop plants. Weeds may also serve as alternative hosts to allow for the sexual recombination of specific diseases or as a means of surviving a stress period.

Unwanted plants significantly increase the farmer's work. Weeds can interfere with the yield and the quality of crops, clog waterways and canals, poison livestock, cause dermatitis, induce hay fever and other respiratory problems in humans, create fire hazards, damage pavements in parking lots and roadways, interfere with utility lines and occasionally produce an attractive but poisonous fruit which if eaten can lead to human health problems or even death. Annual losses to society worldwide arising from weeds are estimated to exceed 10 billion dollars.

Most weeds on land are grasses, sedges or broad leaved. Parasitic weed plants like dodders, broomrape, witch weed and certain mosses are among the important weeds found along with agricultural, ornamental and forest plants. Some examples of aquatic plant weeds are cattails, arrowheads, **water hyacinth**, pondweeds and **algae**.

Well

Well is a man-made hole in the ground to tap water, gas or minerals from the earth. Most modern wells are drilled and fitted with a lining, usually of steel, to prevent collapse. Though wells are sunk for natural gas and petroleum oil, the commonest type yields water. Such wells may be horizontal or vertical, but all have their innermost end below the water table. If it should be below the permanent water table (the lowest annual level of the water table) the well will yield water throughout the year. Most wells require pumping, but some work under natural pressure.

Artesian well is one in which water rises under hydrostatic pressure above the level of aquifer in which it has been confined by overlying impervious strata. Often pumping is necessary to bring the water to the surface, but true artesian wells flow without assistance.

Wells are grouped as **gravity well**, artesian well or a combination of the two depending on the aquifer that supplies water.

Well drained soil

The soil having a good drainage system is called a well drained soil. This type of soil has no gleyed spots.

Wet ashing

Wet ashing refers to breakdown of complex compounds into simpler ones by heating with a single or mixed concentrated acid, like perchloric acid, nitric acid or sulphuric acid, in a wet digestion of the mineral compounds. **Aqua regia**, a mixture of nitric acid and hydrochloric acid, is commonly used in wet analysis.

Wet combustion process

The wet combustion process is used to determine the organic matter content of humus and the decomposing matter in the soil. The soil sample is digested in a mixture consisting of sulphuric acid and an excess of potassium dichromate. The unused excess oxidant is titrated. This process is also employed in methods used for the analysis of organic carbon in the soil.

Wetlands

Wetlands comprise swamps, marshes, fens, peat lands, bogs, potholes, bays, riparian zones, flood plains and other shallow areas. These are present between terrestrial and aquatic systems and often possess the characteristics of both.

Wetlands occupy about 2.2% of the earth's surface, contain all critical components of the biosphere because they provide essential ecological functions including habitat for wildlife, groundwater recharge, shoreline stabilization, flood control and water quality improvement through biogeochemical transformations.

Wetland soils specifically function as sinks and as transformers of nutrients, toxic metals and organics. A major food crop like lowland rice, is grown under waterlogged soil conditions which are similar to wetland soils in physical, chemical and biological properties. Recently, the impact of wetlands on the production and consumption of greenhouse gases (CO_2, CH_4, N_2O and methyl sulphides) has been realized.

Hydrology, plants, animals and hydric soils are the parameters to grade the land as wetland. A hydric soil is saturated, or flooded or ponded long enough during the growing season, giving rise to anaerobic condition in the upper part. The most commonly used methods for demonstrating hydric conditions are to monitor soil moisture, water table fluctuation, soil oxygen content and the redox potential or ferrous (Fe^{2+}) and manganous (Mn^{2+}) activity. Wetland soils have low or negative redox potentials. Aerated soils have redox potentials varying from +400 to +700 mv, waterlogged soils have potentials as low as +250 to minus 300 mv. Redox measurements are useful as an index of the oxidation-reduction status of flooded soils.

Several of the oxidized soil components undergo reduction in sequence after oxygen depletes. That is, all of the oxidized components of one system are reduced before any of the oxidized components of another system begins to reduce. Others overlap during reduction. In the presence of a readily available energy source, microbes utilize several of the oxidized soil components and reduce the oxidation number of the oxidized atom.

Upon submergence, the pH of most soils changes toward neutral, with the acid soil pH increasing and the alkaline soil pH decreasing to an equilibrium pH of about 6.5 to 7.5. The pH buffering action of wetland soils is largely due to iron and manganese redox systems and carbonic acid. The influence of the redox potential and the pH, on the reactions (especially on the final chemical equilibrium of a submerged soil) is much greater when these parameters are working together than when acting alone. Microbial reduction mechanisms, as distinguished from chemical processes, are favored by a nearly neutral pH.

In soil taxonomy, wet soils are identified by an aquic moisture regime at the suborder level or by the properties used for defining an **aquic soil moisture region**. A soil that is saturated with water and devoid of oxygen is defined as having an aquic moisture regime. A reducing environment, which is the result of stagnant water, persists for aerobic micro-organisms to deplete the soil oxygen. As the reducing environment is extended, organisms extract chemically bound oxygen.

There are many diverse effects of soil wetness. Anaerobiosis is one, which involves the generation of oxygen-deficient atmosphere. The loss of soil strength is a major physical change. Chemical effects associated with soil wetness include (a) the accumulation of salts at or near the surface in semi-arid or arid regions under high water table conditions, and (b) the changes in solubility and chemical form of nutrients under anaerobic conditions.

Adequate drainage, though expensive, is one of the most effective methods of reclamation. Drainage is not a guarantee against soil degradation by wetness, but it can minimize periods of anaerobiosis, aid flushing salts and reduce soil erosion. Ridge tillage or the use of soil ridges is an alternative tillage method to alleviate high soil water content and low soil temperature on poorly drained soils.

In wetlands, oxygen is introduced into soils from photosynthetic oxygen production sources by diffusion through the flooded water. It is also introduced by diffusion and mass flow from the atmosphere through plants into the root zone and by fluctuations in water table depth. The movement of oxygen through flood water or water-filled soil pores, by diffusion, is about 10,000 times slower than diffusion through air-filled pore-space. Oxygen is crucial in regulating the plant and microbial respiration rates and speciation, mobility and bioavailability of chemicals in soils. However, in wetland soils, oxygen exchange among the air-water-soil phases is severely curtailed. The biological oxygen demands of organisms cannot be met easily because of the pore blockage by water.

Wetland plants adapt to anaerobic soil conditions, uniquely; for example, by developing internal air spaces (parenchyma) for transporting oxygen into the root zone. Depending on the plant species, the air spaces can occupy up to 60% of the total tissue. Oxygen transport in wetland plants occurs through molecular diffusion.

Compared to upland systems, most wetland soils show an accumulation of organic matter, and therefore, wetlands function as global sinks for carbon. Nitrogen is a major nutrient in wetlands and often controls primary productivity.

Unlike carbon and nitrogen, phosphorus accumulates in wetlands because there is no significant gaseous loss mechanism. Wetland soils are effective sinks for many trace metals through precipitation as insoluble metal sulphides, and also through a strong association of metals with insoluble humic substances.

Wet oxidation method

Wet oxidation method, also called **Kjeldhal method**, is used in the analysis of total nitrogen by way of measuring the percentage of nitrogen in organic compounds. The organic compound is digested with concentrated sulphuric acid, which converts the combined nitrogen into ammonium sulphate. Ammonia, liberated by making the solution alkaline, is absorbed in a known excess acid, and determined by titration with a standard alkali.

Wet process phosphoric acid

Two processes, namely the **furnace process** and the wet process, produce orthophosphoric acid. The wet process phosphoric acid is made by reacting phosphate rock with excess sulphuric acid.

The wet process phosphoric acid uses the same ingredients employed for making superphosphate, namely, phosphate rock and sulphuric acid. The main difference is that an excess of sulphuric acid is used. A liquid is produced when an excess of sulphuric acid is mixed with finely ground rock phosphate. Gypsum is formed after the reaction is over (which takes 8 hours), to get phosphoric acid. The crude acid is purified before it is used as liquid fertilizers and in polyphosphate manufacture. Appreciable quantities of fluorine are liberated. The fumes are collected and passed through scrubbers. Fluorine may be used as a by-product to produce sodium silicofluoride, for use in the fluoridation of city water supplies and to reduce tooth decay.

Although the wet process uses sulphuric, nitric and hydrochloric acids for decomposing phosphate rock, the sulphuric acid based process is most common. The main chemical reaction in the wet process (sulphuric acid) is as follows:

$$Ca_{10}F_2(PO_4)_6 + 10H_2SO_4 + nH_2O \longrightarrow 10CaSO_4.nH_2O + 6H_3PO_4 + 2HF$$

where n is 0, 1/2 or 2 depending on the hydrate of calcium sulphate formed. Phosphate rock contains many impurities and these participate in many side-reactions.

Purification of the wet process phosphoric acid is not necessary for most fertilizer production processes, except in the case of liquid fertilizers which need partial purification to prevent the formation of precipitates upon ammoniation or during storage. The **merchant grade acid** should be purified to avoid the formation of insoluble sludge during shipping and storage.

There are two types of furnace processes – the **blast furnace process** and the **electric furnace process**. The blast furnace process has not been in use since 1938. The electric furnace process acid is used for making elemental phosphorus. The furnace process acid is used for the manufacture of phosphate fertilizers. The first step in the production of phosphoric acid is to produce elemental phosphorus in the electric furnace as per the equation:

$$Ca_{10}F_2(PO_4)_6 + 15C + 6SiO_2 \longrightarrow 1.5P_4 + 15CO + 3(3CaO \cdot 2SiO_2) + CaF_2$$

The advantage of this process is that it uses a low-grade phosphate rock. The recovery of phosphorus as elemental phosphorus is 86 to 92 % of the amount charged to the furnace. The main disadvantages of the furnace process are the relatively high capital cost of the plant and the high electricity cost in operating the plant.

The production of phosphoric acid from elemental phosphorus is simple and is done by burning elemental phosphorus in air and hydrating the resulting phosphorus pentoxide to phosphoric acid (86 % recovery).

$$P_4 + 5O_2 + 6H_2O \longrightarrow 4H_3PO_4$$

Wet scrubbers: See Phosphate industry, an environmental perspective

Wet season

In some parts of the world, there is a separate wet or monsoon season. Almost all the rain comes in certain months. In a tropical country like India, the main wet season, the south-west monsoon, occurs during the June to September period. There is another spell of wet season, the north-east monsoon, from October to December. Crop plantation is planned according to the wet season.

Wet sieve analysis: See Particle size distribution of fertilizer

Wet sieve shaker

When sieve analysis of a raw material with micron-sized particles is required to be undertaken, it may be necessary to perform a wet sieve analysis using a wet sieve shaker to avoid powdery particles from flying and creating a pollution problem. (See also Particle size distributors of fertilizer.)

Wet tillage

Wet tillage or **puddling** is a land preparation method which destroys the natural soil structure by intensive tillage when saturated with water.

Puddling increases the bulk density, eliminates the large pores and increases the capillary porosity in the soil above the pressure pan.

Wet tillage is used in wetland rice fields to reduce percolation and to provide a soft puddle for transplanting rice seedlings. Peds that are already weakened by flooding are worked into a uniform mud which becomes a two phase system of solids and liquids. Water promotes rice growth and the near-zero level of the soil oxygen inhibits the growth level of many weeds. The drying of puddle soil promotes ped formation. However, large clods are often formed that are difficult to transform into a good seedbed.

Wetting agent

Wetting agent is the material that decreases the contact angle of a liquid on a surface. It is a substance added to a liquid spray to reduce the surface tension of the applied droplets. It helps the liquid to penetrate more easily into (or to spread over the surface of) another material.

The example of wetting agents are soaps, alcohol, fatty acids, etc. (See also Micelle.)

Wheat

Wheat, along with rice and corn, forms one of the most extensively available foods grown in a wide variety of regions of the world.

Wheat is believed to have been in existence for over a few thousand years, and originated in and around Iran, Iraq and Turkey.

Wheat is a member of the grass family. The plant grows to a height of around a meter and has narrow green leaves. When wheat seeds germinate, they develop a seminal root system. The first leaf, protected by the coleoptile, is thrust through the soil upwards. As other leaves develop, the plant grows in height. At the base of each leaf is a bud which can develop into a tiller. Each tiller can develop into a mature stem which holds the wheat head. The latter contains seeds edible for humans.

The kernel, or the seed, is divided into three parts: the endosperm, the bran and the germ (embryo). The endosperm constitutes over 80% of the seed, and is rich in protein (gluten being an important component), carbohydrates, iron and Vitamin B (riboflavin, niacin and thiamine). Bran constitutes 15% of the kernel weight and holds Vitamin B, fiber, Mg, Zn, Mn, folic acid and protein. Whole wheat flour contains bran. The germ, which has high quality protein, accounts for 2% of the kernel weight, and is also present in whole wheat flour. Foods made out of whole wheat have more vitamin, fiber and proteins.

Ideal conditions for wheat cultivation are temperate grasslands with 30 to 90 cm of rain and relatively cool temperatures, especially during its early growing stages. During the later stages, the kernel growth is encouraged by sunny days.

Today, wheat is grown in many parts of the world. USA, China, the erstwhile USSR and India being the prime producers. India, for instance, produces about 12% of the world wheat.

The modern wheat, as we know it today, is the natural cross between the *Triticum* spp and the goat grass (*Aegilops* spp). The *Triticum monococcum* or the einkorn wheat is believed to have been the first to be cultivated. This later evolved into emmer wheat.

Over years of hybridization, bread wheat (*Triticum aestivum*) and durum wheat (*Triticum turgidum*) are now widely cultivated.

Wheat is used in the making of bread, pastries, breakfast cereal, spaghetti, noodles, pasta, sauces, gravies, etc. These and other wheat products are high in energy and low in fat. But in the process of refining, the bran chaff and the germ are removed, leaving behind only starch in the final product.

There are two crops of wheat worldwide. One is the **winter wheat** (Sept-Oct) and the other is the **spring wheat** (mid-May). Wheat that is grown in limited rainfall areas is called **hard wheat**. It has a higher protein content. Adequate rainfall favors **soft wheat** which has a lesser protein content.

The need to increase the yield per hectare has encouraged research in biotechnology, plant breeding and genetic engineering. These initiatives have opened up a few areas of conflicting view-points which seem to have ethical and moral overtones.

Wheat is prone to many foliar-, soil- and seed-borne diseases throughout its growth. Many fungal, viral and bacterial diseases affect wheat yields worldwide. **Rust diseases** (leaf rust and stem rust), loose smut, powdery mildew, take-all, etc. affect almost all areas. Fungal diseases are categorized on the part of the affected plant, and thus, there are leaf and stem pathogens (like rusts, mildew) and seed related pathogens (like smut and bunts diseases).

Rust disease which is a fungal disease, is of two kinds, namely, leaf rust and **stem rust**. Leaf rust is caused by *Puccinia recondita tritici* and is more common and destructive than stem rust, caused by *Puccinia graminis tritici*. Leaf rust may cause up to 50% of the yield loss, if infection is not controlled in time. The spread of rust occurs in late winter or early spring. The fungi causing the rust disease go through several spore stages in their life cycle and some of the stages are completed on alternate or collateral hosts. Humid and wet conditions, with warm temperatures, favor infection which spreads as strong winds transport the spores.

Since wheat is grown in large areas throughout the world, there may be peculiar management practices prevalent under specific local conditions. However, broadly, there are some recommended practices such as crop rotation, planting management, crop residue management, volunteer wheat, nitrogen management and wheat varieties – which can yield a healthy crop.

The twin objectives of farmers and researchers alike have been to increase productivity of crops, and control the losses by diseases. There are two approaches toward achieving high yields in environment friendly conditions from the same plot of land: **organic farming**, and conventional farming with the use of chemical fertilizers. Both approaches have yielded expected results. Conventional farming methods include the incorporation of synthetic fertilizers and the use of genetically modified varieties of wheat by customizing land races of a plant to suit the local conditions. Such varieties can result into cultivars exhibiting favorable properties of early maturity, heat tolerance, etc. Many research stations, established worldwide, develop **seed banks** and preserve **germplasm** for plant breeding, to produce robust, disease-resistant and high yielding varieties. There are many research institutes that focus on the objective of developing modern wheat cultivars.

Organic farming is cultivation of a crop without the use of synthetic fertilizers. Organic farmers rely on the use of naturally available sources of minerals for supplying nutrients to crop.

Wheat – common diseases of

The common diseases of wheat are listed below:

Leaf rust, which is a common fungal disease in wheat, caused by *Puccinia recondita tritici*, is evidenced by the appearance of circular pustules with red-orange spores, on the upper leaf surfaces and leaf sheaths. These pustules appear first during tillering. The pustules grow to cover the entire leaf stage of wheat growth. They grow in large numbers covering the whole leaf, turning the leaf yellow and eventually killing it. The pustules turn orange-yellow and then black. Leaf rust results in the reduction of tillers, kernels and grain weight.

Stem rust, caused by the fungus *Puccinia graminis tritici,* is seen to occur when dark, reddish-brown pustules (containing spores) appear on the leaf surfaces, sheaths and stems. The pustules are larger in stem rust than in leaf rust and are spindle-shaped with ragged edges. These pustules appear black as the plant matures and spores turn dark brown. Stem rust weakens the stems resulting in lodging and reduced grain weight.

Leaf rust and stem rust detailed above are the two main rust diseases in wheat. Leaf rust is more common and destructive than stem rust and may cause upto 50% of the yield loss, if not controlled. Although it is difficult to eradicate rust diseases, the use of rust-resistant varieties controls both types of the disease for 4 to 5 years till new strains of the pathogen emerge and dominate. Maintaining the soil fertility level and the use of foliar fungicides help to control the spread of the disease. Growing the same variety year after year should be avoided. **Volunteer wheat** and grass should be controlled, as the fungus lives on it while its spores are in their growth stage.

Loose smut is caused by the fungus *Ustilago tritici*. The yield losses caused by smut become heavy if the disease goes unnoticed. The fungus attacks the crop at the flowering stage. It produces spores which germinate and invade the embryo. The seed is completely destroyed and only the bare stem remains.

The use of disease resistant varieties and healthy seeds can control the disease. Fungicides like carboxin or triadimenol contact applied as seed dressing are effective against smut.

Wheat – organic farming techniques

Gene-based technologies and synthetic fertilization have demonstrated occurrence of high yield of wheat and other cereals in short periods of time. Out of the soil nutrients used by the developed world more than 92% are through chemical fertilizers. Indeed the major factor that brought about the green revolution was the use of chemical fertilizers.

However, some believe that genetically engineered food, genetically modified organisms and excessive use of chemical fertilizers are a way of tampering with the forces of nature, destabilizing the ecological balance.

The proponents of organic farming advocate the use of many mechanisms that are available freely in nature. There are many useful micro-organisms in the soil which may be encouraged to grow. Some soil bacteria promote plant growth, especially of wheat and other cereals. These include free-living N-fixing bacteria (*Azotobacter, Azospirillum*), P-solubilizers (*Bacillus* sp.) and biocontrol agents (*Trichoderma, Paecilomyces, Metarrhizium*). Many of the inoculants are available commercially; for example, Nodulaid sterile peat, Bio care, Green guard, etc. An enriched soil-biota is considered beneficial to wheat production.

Azotobacter is a free-living N-fixing bacteria which fixes 20 to 25 kg of N/ha. The bacterium also acts as a biological control agent and produces growth promoting substances like Vitamin B. Hence, the inoculum is grown in wheat, rice and other cereal fields.

Azospirillum encourages root development and water uptake and seem to increase yields by 10 to 15%. It is recommended for wheat, rice and other cereal cultivation.

To extract the best out of the soil, conditions that favor the growth of biota are created. Suitable tillage practices, like retaining the stubble or minimum tillage, increase the organic carbon and conserve the moisture. Inclusion of a legume crop or an oilseed crop with a wheat crop increases the nitrogen content. An oilseed crop also controls weeds. Acid soil may be limed to activate enzyme production. In general, the presence of water (around 60% saturation) and aeration, along with the presence of N, P, K, Fe, Zn, Mo and C encourage microbial activity which is ideal for the growth of most cereals and forage grass. **Earthworms** and **nematodes** also contribute to enriching the soil. **Green manuring** is another economic means of increasing the organic matter in the soil.

A soil with a high salt content (such as boron), or high acidity may reduce yields.

Wheat – recommended cultivation practices

To achieve the desired yield of wheat, it is important to manage soil as well as pathogens. Under unsuitable soil conditions, crops become vulnerable to pathogen attacks. Although a specific field may have its own peculiar requirement, there are broad recommendations for a healthy output. These are listed below.

(i) **Volunteer wheat**: The threat from pathogens harboring among volunteer plants is typical for cereal grains, especially wheat. So, effective disease control entails the removal of volunteer wheat at least a fortnight before planting the new crop.

(ii) **Crop rotation**: Crop rotation is a time-tested practice to control pathogenic activity. Every crop is generally at its best when combined with a specific group of diverse crops. In the case of wheat, if an oilseed crop is planted every third or fourth year, the disease inoculum is restricted. Where rainfall is heavy, pathogenic attacks are a big problem. These attacks could be controlled with crop rotation of wheat, oilseed crop, barley or oats. Crop rotation is seen as a solution to problems originating from the crop monoculture practice.

(iii) Crop residue management: The treatment of crop residues for better management of disease and crop depends on peculiar environmental conditions present in each field. If it is a water-scarce region, **no-till** practice may make the crop develop enough strength to keep off the foliar disease, since no-till practice conserves the soil water and does not cause water stress. Parameters like availability of nitrogen, selection of seed type and quantity and orientation of crop stubble affect the susceptibility of the crop to disease. A keen observation of nutrient deficiencies, environmental patterns and soil fertility are crucial to the management of crop residues.

(iv) Nitrogen management: Nitrogen in a plant builds resistance or tolerance to plant diseases. The total nitrogen available to a plant is the sum of the available soil nitrogen (nitrate-nitrogen), the nitrogen applied through fertigation, and the amount available through organic matter, the crop rotation type, etc. Over-fertilization with N encourages vegetative growth prompting foliar attacks, and also delays maturity of the plant. Similarly, an inadequate supply of nitrogen to a plant makes the plant susceptible to attacks. A fallow land (in a crop fallow system) is likely to have more soil nitrogen than a land under monoculture practice.

(v) Wheat varieties: A wheat variety is considered ideal when it is resistant to a wide range of soil and foliar diseases. If a cultivar exhibits resistance to attacks despite the absence of adequate nutrients, (especially nitrogen), then it is considered ideal. Care should be taken to ensure that only healthy and resistant seeds are used in any crop rotation system to avoid the loss to the present and subsequent harvests of all participating crops.

(vi) Planting management: Wheat crops are susceptible to diseases in hot and wet conditions. Time is the essence as far as planting is concerned. Winter wheat should be planted at the first opportune time during early September. Mean soil temperatures should be below 13°C. Warmer soil temperatures may make the crop prone to pathogen attack. If heat is high (above 24°C) at the leaf development stage and the kernel development stage, it reduces the yield by 25 to 40%. Planting rate is another critical parameter to ensure minimum competition between the plants for nutrients, sunshine, water, etc. Planting rates should be less than 1.5 bu/acre and the plant rows should be more than 15 cm apart, for healthy crop growth.

Whiptail of cauliflower

Whiptail of cauliflower is a disease caused due to **molybdenum deficiency**. It is characterized by malformed leaves due to a reduced rate of cell expansion near the leaf margin, as compared to that in the center of the leaf. The leaves also tend to be longer and slender. The plant becomes stunted and has pale yellow leaves with marginal chlorosis.

White acid

Phosphoric acid made by burning phosphorus is termed white acid or **furnace acid**. White acid is used in chemical industries.

White alkali

Saline soils are known as white alkali because of white deposits of salt on the surface. Their high salinity keeps humus flocculated and immobile. In non-saline sodic soils, called **black alkali**, humus is dispersed, which moves with water and forms a black coating on the ground surface when the water evaporates.

White bud

White bud is a disease of corn caused by **zinc deficiency**. Zinc deficient plants show stunted internodes along with chlorotic and necrotic leaves.

White fishmeal

White fishmeal is a dried, crushed or powdered **fishmeal** produced from non-oily 'white' fish like cod or haddock. It usually contains about 66% protein.

White gasoline: See Gasoline

White grubs

White grubs are larvae of May beetle or June bug. The grubs are round, white and about 2 to 3 cm long. They curl up into a C-shape when disturbed. The head is black and there are three pairs of legs just behind the head.

White grubs feed mainly on grass roots and cause dead spots in lawns. A wide variety of other plants are also attacked, making white grubs an important agricultural pest. Moles feed on insect larvae and earthworms, leading to a stronger possibility of mole damage in lawns, when white grubs are present.

White mica

White mica, also called **potash mica** or **muscovite**, is a mineral of the mica group. It is abundant in pegmatites and also occurs in some granite. It is used in the manufacture of electrical equipment, as a filter and as a source of soil potassium. (See also Muscovite.)

White muscle disease

White muscle disease or **muscular dystrophy** is a disease caused in animals by selenium deficiency in forage. (See also Selenium.)

White rendzinas

Rendzina is a young, weakly developed soil, recognized by the FAO system of soil classification. White rendzina which is rich in carbonate, is one of the sub-classes of rendzina. The other two rendzinas are **black forest rendzina** and **brown rendzina**. (See also Rendzinas.)

White rice

White rice is one of the end results of a process carried out on the rice grain to make it edible. Milling of brown rice to remove the entire bran and most of the germ layer creates unpolished white rice. Further processing involves polishing this rice. Polished white rice removes even the essential fat component (aleurone layer).

There is increasing awareness that white rice is devoid of nutritional value. It can now be further processed to enrich it with valuable minerals and vitamins and make it nutritious.

White vitriol

White vitriol is another name for **zinc sulphate heptahydrate**, and is a commonly used zinc salt. It is widely used as a fertilizer for overcoming **zinc deficiency**.

WI

WI is short for **weathering index**. It is the ratio of stable soil minerals to unstable soil minerals, and speaks about the changes that have occurred in the soil due to wind, temperature, vegetation and animal life through the passage of time.

Wiesenboden: See Black soils

Wild flooding method of irrigation

Irrigation is done by many methods, of which wild flooding method is one. In this method, water is released from high points in the field, without controlled distribution, to pond over the whole ground surface. The ponded water is contained by banks or levees which follow the contour on sloping land or form a rectangular basin in the flat land. The basin can be large, if the land is flat and uniform. Large basins can thus be irrigated and farmed with little labor. Sloping lands require small basins or border strips, contained between the contour levees or furrows. Water is allowed to flow gently down the slope from inlets at the top, with some surplus tail water escaping into a drainage ditch at the foot. The application rate of water exceeds the rate of infiltration during most of the irrigation operation. Soils with extremely slow infiltration may require several days to irrigate, causing high labor costs, evaporation losses and plant damage from waterlogging.

Extremely fast infiltration often makes uniform watering by wild flooding very difficult because most of the water infiltrates near the top of the run before moving over downhill. Achieving uniform and adequate penetration of water over the whole field requires uniform soil properties, uniform slope and a proper match among the delivery rate, length of run, slope and infiltration rate.

William Nernst equation for dissolution: See Nernst equation for dissolution

Wilt diseases

Certain **fungi** or **bacteria** cause diseases in plants by damaging the water-conducting tissues inside the roots and stems, leading to **wilting**. Such fungal and bacterial diseases are known as wilt diseases. Typically, these occur in vascular plants that are angiosperms. The symptoms of wilting include chlorosis, stunting, loss of turgidity and death of the infected plant. In short, the soil-borne disease organisms extensively impair plant growth, by interfering with the root development and the uptake and movement of water and nutrients.

Wilting

The phenomenon of drooping of the plant structure is called wilting and is usually caused by water loss through evaporation (Fig.W.8). This can be due to lack of available moisture or physiological disorders or the action of fungi (or bacteria) which damage water-conducting tissues inside the roots or stems. In the case of physiological wilting due to lack of water, plants can recover from wilting if water is added to the soil but permanent wilting or death of the plant occurs in the absence of water for a long period. The wilting point increases with the fineness of the soil texture; hence it is low for sand, and high for clay.

Fig. W.8: Normal plant (left), and wilted plant. Temporary wilting is due to excessive transpiration.

On a hot day, plants transpire heavily and cannot absorb water speedily to keep pace with transpiration loss, even when there is enough water. In such a situation, plants wilt temporarily and recover after sundown. This is called **temporary wilting**.

When water potential is lower than minus 1500 kPa, plants do not recover unless water is added anew to the soil and this leads to **permanent wilting**. The **wilting point** or the **permanent wilting point** is the point at which the plant roots cannot absorb the stored soil water for their needs. It is the lower limit of available water. As roots absorb water over a period of time, the soil water content decreases, and the water films become thinner. A sandy soil may have 4% water at this point, whereas a clayey soil may have 8 times as much as for a sandy soil. The roots now get water with a decreasing mobility or energy content. At some point, the water may move so slowly to the roots that the plant will wilt for want of water. If the wilted plant placed in a humid chamber fails to recover, the soil is at a permanent wilting point. This occurs when the cohesion water has been adsorbed. Irrigation is suggested well before this point to retain the crop performance.

In certain plants wilting is important as a mechanism to avoid overheating. The drooped leaves get shielded from the sun's rays. When the sun sets, plants begin to transpire at the normal rate and the cells of the leaves regain their turgor.

In haymaking and silage making, plants are often crimped or lacerated to increase the wilting and to reduce the moisture; this is man-made wilting.

Wilting point: See Wilting

Winchester bushel

Winchester bushel was a cylinder kept in the Town Hall of Winchester, England. The weight of grain that filled the cylinder was considered as the standard or reference bushel weight. The bushel was a standard measure for cereal grain weight, developed during the Anglo-Saxon times. Presently one bushel is 36.4 liters.

Wind

Wind is the body of air moving relative to the earth's surface. The term usually refers to horizontal air motion, as distinguished from vertical motion, and to air motion averaged over a chosen period of 1 to 3 minutes.

The direct effects of wind near the surface of the earth are manifested by soil erosion, adaptation in vegetation, the extent of structural damage and the production of waves on water surfaces. At higher heights, wind directly affects aircrafts, missiles and rocket operations, and discharge of industrial pollutants, volcanic debris and other materials. Wind is directly or indirectly responsible for the production and transport of clouds and precipitation, and for the transport of cold and warm air masses from one region to another.

The world's major wind systems are set up to counter the equal heating of the earth's surface and are modified by the rotation of the earth. Surface heating is greatest near the equator. It creates an equatorial belt of low pressure, known as doldrums, and a system of convection currents transporting heat toward the poles. The earth's rotation deflects the current of north hemisphere to the right and that of the south hemisphere to the left of the directions in which they would blow. This results in creation of the north east and the south east trade winds, the westerlies and the polar easterlies. The other factors influencing the general wind pattern are the different rates of heating and the cooling of land and sea, and the seasonal variations in surface heating. Mixing of air along the boundary between the westerlies and the polar easterlies, the polar front causes depressions in which winds follow circular paths, counter clockwise in the northern hemisphere and clockwise in southern hemisphere. Superimposed on the wind systems are the local winds, such as the Chinooks, caused by temperature differentials associated with local topographical features (such as mountains and coastal belts), or winds associated with certain cloud systems.

Wind breaks

Wind breaks are some kind of barriers, such as trees hillocks and shrubs that reduce the speed and turbulence of the wind near the ground. They also retain snow during the winter and the early spring, and the melting snow recharges the soil moisture storage. The distance sheltered by a windbreak is a multiple of its (windbreak) height. A porous wind break reduces the wind turbulence more than a dense wind break does.

The disadvantages of the wind breaks like trees and shrubs are that they occupy land and decrease crop productivity because they shade the crop and compete for water.

Wind erosion

Wearing away of the land surface by wind is called wind erosion. It occurs mostly in arid and semi-arid climates. In most countries, wind erosion is a natural calamity, occurring during dry seasons. Wind erosion is fast when wind speeds are high, the soil cover is thin and the particles are loose and small.

Wind erosion, makes the soil shallower and removes organic matter and nutrients. In addition, blowing soil particles can damage plants, particularly young seedlings, by sand blasting. Blowing sand can damage plants. Blowing sand can also cause air pollution and a detrimental deposition. For instance, soil particles and pollens in the atmosphere contribute to poor visibility and may cause allergies; the wind blown particles pile up around plants, fence posts and houses, and such **dunes** may damage or destroy whatever they bury.

Soil particles move in three ways during wind erosion: saltation, suspension and surface creep.

Following are some types of soil movement:

(i) **Saltation**: It refers to lifting and bouncing of particles and is the most important of the three ways of soil movement. It moves the largest number of particles and initiates creep and suspension. The wind blowing over the ground surface exerts a force on the particles, making them rise and fall back to the ground, where they may dislodge other particles. The saltating particles are not lifted high into the air.

(ii) **Suspension**: Suspension refers to the lifting of clay sized and silt-sized particles high up into the air, from where they may be carried to long distances. It is the most visible mechanism of wind erosion though it does not carry as much soil as saltation does.

(iii) **Creep**: Coarse and very coarse grains move by creep because they are too large to be lifted, except by very strong hurricane winds. In normal circumstances, they are rolled down or pushed short distances across the ground surface.

Wind erosion can be controlled if (a) soil particles can be built up into peds or granules too large to be moved by saltation, (b) the wind velocity near the soil surface is reduced by ridging the land, or (c) vegetation or stubble can cover the land, thus holding the potentially saltating particles. Tree shelter belts (like *Casuarinas* plantation near the seashore), mulching, **windbreaks**, wetting the soil, creating soil roughness and minimum tillage are the other ways to control wind erosion, and these also act as barriers for severe wind erosion conditions.

A **wind erosion equation**, similar to the **USLE** summarizes the major factors important to wind erosion.

$$E = f(I, C, K, L, V)$$

where E is the soil loss in tons per hectare, I is the soil erodibility, C is the climatic factor, K is the soil roughness, L is the field length and V is the vegetative cover.

Soil erodibility by wind is related primarily to soil texture and structure. As the clay content of soils increases, the increased aggregation creates clods or peds too large to be lifted by wind to long distances. Rough soil surfaces reduce wind erosion by reducing the surface wind velocity and trapping soil particles. Surface roughness can be increased with tillage operations. Tillage rows are positioned at right angles to the dominant wind direction for maximum effectiveness. Climate is a factor which has effect on wind erosion through wind frequency and velocity, and wetness of soil during high wind periods. Furthermore, climate affects the amount of vegetative cover. The lowest yields and highest soil erosion occur during years of least rainfall.

Wind erosion increases from zero, at the edge of an open field to a maximum, with increasing distance of soil exposed to the wind. Stubble mulch tillage, popular in wheat producing regions, leaves behind plant residues on the soil surface.

Deep plowing has been used to control wind erosion where sandy surface soils are underlain by Bt horizons containing 20 to 40% clay. Organic soil areas of appreciable size are frequently protected from wind erosion by planting trees in rows as windbreaks. This must be limited because of the large amount of soil that they take out of crop production. The lightness of organic soils contributes to the wind erosion hazard. Moist organic soils are heavier than dry organic soils as they tend to adhere more, thus reducing the wind erosion hazard.

Wind erosion equation: See Wind erosion

Winkler method for coal gasification: See Ammonia production processes

Winter annuals

A winter annual refers to a plant that completes its life cycle during the winter season of the year. Many ornamental plants like dahlia and carnations are winter annuals (Fig.W.9).

Fig. W.9: Carnations are examples of winter annuals.

Winter wheat: See Wheat

Wischmeier and Smith equation for water erosion prediction

Wischmeier and Smith's equation is widely used in the USA and other countries to predict the severity of water erosion from farm fields. This universal equation uses six factors to describe the erosion process.

The universal soil loss equation (**USLE**), developed by Wischmeier and Smith is as follows:

$$A = RKLSCP$$

where A is the computed soil loss per unit area as tons per hectare; R is the rainfall factor, K is the soil erodiblity factor, L is the slope length factor, S is the slope gradient factor, C is the cropping management factor and P is the erosion-control practice factor. R is a measure of the erosive force of a specific rainfall and is related to both the quantity and intensity of the rainfall. K, the soil erodibility factor, is influenced by factors that affect infiltration, permeability, water retention capacity and soil resistance to dispersion, splashing, abrasion and transporting forces of rainfall and run-off. LS, the slope length and the slope gradient factor indicate that erosion increases as the power of the slope length ($L^{0.5}$) increases. Doubling of the run-off water velocity increases the erosive power, four times as much, and causes 32 times as much increase in the amount of material that can be carried in the run-off. The vegetative factor C measures the combined effect of all interrelated crop cover and management variables including the type of tillage, residue management and the time of soil protection by vegetation. The erosion control practice factor P is dependent on tillage practices and the presence of terraces. The most important of the practices for crop lands are contour tillage, strip cropping on the contour and terrace systems. Contour farming is most effective on slopes, for controlling erosion. Getting the values of R, K, L, S, C and P from tables and charts, it is possible to calculate the soil loss in agricultural land. (See also Erosion prediction.)

Witches' broom

An abnormal proliferation of shoots in trees caused by the infection of fungus, mites or viruses is called witches' broom. In the disease, a single shoot of the tree is replaced by a large number of shoots or twigs, growing in one direction and giving the appearance of broom. An interwoven cluster of shoots resembling a birds nest (rather than a broom), is also one of the symptoms of the disease, for example, that caused by '*Taphrina betudina*' in birch trees. The term witches' broom is less suitably applied to diseased conditions in herbaceous plants, characterized by increased branching, production of large number of slender shoots and by much reduced leaves, as for instance, witches' broom of potato.

Witch weed

Witch weed (*Striga* spp.) is an important root parasitic weed plant found on agricultural, ornamental and forest plants. It is native to the tropical regions and southern Africa. The root parasite can cause serious damage to crops like maize.

Withholding period

Withholding period is the recommended minimum period that should elapse between the last application of a fungicide to any crop or pasture and the harvesting, grazing or cutting.

Wood

Wood is a hard, dead tissue obtained from the trunks and branches of trees and shrubs. Woody tissue is also found in some herbaceous plants.

Botanically, wood consists of xylem tissue which is responsible for the conduction of water around the plant. A living tree trunk is composed of (beginning from the carter) the pith (remains of the primary growth), wood (xylem), cambium (a band of living cells that divide to produce new wood and phloem), phloem (conducting nutrients made in the leaves), and the bark. The wood nearest to the cambium is termed sapwood because it is capable of conducting water. However, the bulk of the wood is **heartwood** in which the xylem is impregnated with lignin, which gives the cells extra strength but prevents them from conducting water in temperate regions. The age of a tree can be found by counting its **annual rings**. Commercially, wood is divided into hardwood (from deciduous angiosperm trees) and softwood (from gymnosperms). Wood is mainly used in paper and pulp industry, construction, furniture making, rayon and cellophane manufacture. It is also used in places as domestic fuel for cooking. The fuel value varies widely around 7000 to 14000 J/g according to the wood variety, moisture content, etc.

Wood is a mixture of three natural polymers **cellulose**, **hemicellulose** and **lignin**. Chemicals derived from wood include bark products, cellulose, cellulose esters, cellulose ethers, charcoal, dimethylsulphoxide, ethyl alcohol, fatty acids, furfural, hemicellulose, kraft lignin sulphonates, pine oil, rayons, resin, sugars, tar oil, turpentine and vanillin. Most of these are direct products or by-products of wood pulping, in which the lignin, that cements the wood fibers together and stiffens them, is dissolved away from the cellulose. The other materials developed from wood are solid wood products (including lumber, veneer and plywood laminated timbers, insulation board, hardboard and particle board) and fiber wood products (paper and paperboards).

Wood ash

Wood ash results from burning of organic materials and is rich in potassium (in the form of potassium carbonate).

Wood ash is used to increase the soil pH. Its repeated use may tend to cause dispersion of the soil structure. The alkalinity effect may excessively increase the soil pH which is undesirable, as many plants grown in alkaline soils are prone to iron deficiency.

Wood rotting organisms

An organism can avoid competition if it can adapt to specially difficult conditions like, for example, using a food source that others cannot use. Wood rotting fungi and bacteria are examples of such types of organisms. Organisms that rot wood must produce and release extra-cellular enzymes that break down macromolecules of cellulose and lignin into smaller molecules that can be assimilated. The extra-cellular enzymes deprive the organism of energy, but give it access to ample food with little competition from the common fast-growing species.

Wood's metal

Wood's metal is a type of **fusible alloy** containing Pb-Sn-Cd-Bi elements. It has a eutectic temperature of 70°C.

Wood's metal bath is used for carrying out reactions at a constant temperature above 70°C and below 300°C. (See also Eutectic solutions.)

Woody coal

Woody coal or **humic coal** is a type of **coal** obtained from plant remains.

Woody perennials

Woody perennials are generally trees and shrubs that survive for three or more years (Fig. W.10). They have a permanent aerial form, which continues to grow year after year, and have the capacity to withstand the winter season by reducing their metabolic activity.

Work

In scientific terms, work (W) is the result of a force (f) acting on a body, causing it to move through a distance (d) in the direction of the force and defined as:

Fig. W.10: Forest trees like teak are woody perennials.

$$W = f \times d$$

Work of one joule is done when a force of 1 newton acts through a distance of 1 meter. Work is an alternative name for energy, used particularly in discussing mechanical processes.

Any activity involving physical (or mental) effort carried out by a person or a thing to achieve something is called work.

Working sample

Working sample is a sub sample drawn from a submitted seed sample for the purpose of carrying thorough analysis for purity, germination, health conditions, etc.

Worm-type auger

Worm-type auger is a tool used for taking out soil samples for analysis.

WUE

WUE is short for **water use efficiency**.

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The FERTILIZER ENCYCLOPEDIA

X

Xantham gum

Xantham gum is a heat-stable material with good tolerance to acidic and basic conditions. It is a suspending and thickening agent with a tendency to swell and is used as a suspending agent in **suspension fertilizers**. Adding 1 to 2% of xantham gum to a fertilizer makes the latter a fairly stable suspension; for example, a sulphur fertilizer as suspension in water. Fermenting carbohydrates leads to a synthetic water-soluble biopolymer. Its viscosity remains stable over a wide temperature range.

Xantham gum is used as a thickening agent in drilling fluids, and in ore floatation processes. It is also used in pharmaceuticals and in the food industry.

Xanthophyll

Xanthophyll is the yellow pigment in leaves containing oxygen and is derived from carotens, which is sometimes absorbed by insects. It is present, for instance, in the skin of caterpillar of cabbage and of white butterfly and in the cocoons of silkworms.

Xeralfs

Xeralfs are **alfisols** which have a xeric soil moisture regime. They are brownish or reddish throughout and are associated mainly with the Mediterranean climate. They become dry for extended periods during summer, but occasionally, and in some cases every year, the moisture moves through the soil in winter to the deeper layers.

Xererts

Xererts are **vertisols** of the Mediterranean climate which means areas with cool, wet winters and warm to hot, arid summers.

Xererts have wide, deep cracks which open and close once each year and usually remain open continuously for more than 2 months. They have a mean annual soil temperature of less than 22°C.

Xeric moisture regime

Soils, in areas where winters are cool and moist and summers are hot and dry, have a xeric soil moisture regime, also known as xeric regime. This kind of climate is known as the **Mediterranean climate**. Precipitation occurs in cool months when evapotranspiration is low and surplus water may readily accumulate. This frequently results in considerable soil wetness during winter. Leaching and weathering may occur during winter even though summers are long, very dry and hot. The soil control section is dry for more than 45 consecutive days and moist for more than 45 consecutive days in the four months after summer solstice and winter solstice, respectively. With limited water storage and little, if any, summer rainfall, large water deficit can occur in summer.

Plant growth is restricted by the limited available moisture. Irrigation or summer fallow is commonly necessary for crop production. Xeric soils are typical of valleys where a large variety of crops, including vines, fruits, nuts, vegetables and seeds are produced (with irrigation facilities, when necessary). In some places, xeric soils are used for winter wheat. They provide a good match between the time when the wheat needs water and when soil water is available.

Xerolls

Xerolls are mollisols that have a xeric soil moisture regime. Xerolls may have a calcic, petrocalcic or gypsic horizon, or a duripan.

Xerophillic plants

Plants that grow in arid places, subsisting with a small amount of water are called xerophillic plants.

Xerophytes

Xerophytes or **dry land plants** grow and survive in unfavorable habitats, such as dry soils in extremely dry or arid conditions. Xerophytes include succulent plants which store water in specialized, modified, spongy tissues. Such plants are categorized as **leaf succulents, stem succulents** (Fig.X.1), **root succulents** and stem and root succulents. They have special structural and functional modifications like swollen stems, leaves or roots, from which they derive names like leaf succulent, and so on. The specialized leaves with hairy, rolled or reduced spines or a thick cuticle lower the rate of transpiration (as in the case of desert cacti).

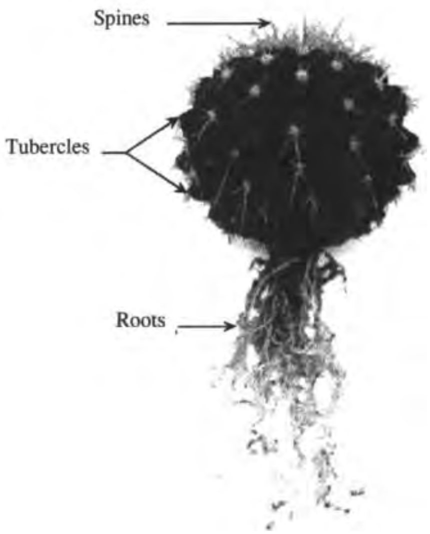

Fig.X.1: Golden barrel cactus, a xerophyte, is an example of a stem succulent.

To retain moisture, desert annuals germinate, grow and reproduce only during the rainy season. Other desert plants have long taproots, which tap into underground water supplies.

Xerosols

Xerosols is one of the 106 major soil units as described by the FAO-UNESCO legend of the soil map of the world. Xerosols are somewhat more developed desert soils. This soil is found in an aridic moisture regime. It has a weakly developed ochric A horizon and one or more of the characteristics of cambic B horizon, an argillic B horizon, a calcic horizon, a gypsic horizon and no other diagnostic horizons.

Xerosols has neither the diagnostic features of vertisols nor a high salinity. Its subsoil does not remain below the freezing point throughout the year, as found in the polar regions (**permafrost**) at less than 2 meter depths.

In recent times, xerosols have been removed from the revised FAO soil map legend. These and yermosols are now classified as calcisols and gypsisols. These soils can be haplic, luvic, petric (soil units).

Xerults

Xerults are **ultisols** that have low or moderate amounts of organic carbon and are found in the Mediterranean climates. They have a xeric soil moisture regime and also have ochric epipedons resting on a brownish or reddish argillic horizon.

XLPE

XLPE is the trade abbreviation for Cross-Linked Polythene which is used as a material for making bags to store fertilizers and grains.

X-radiation

X-rays are electromagnetic radiation of extremely short wavelength (0.06 to 120 Å), emitted as a result of electron transitions in the inner orbits of heavy atoms bombarded by cathode rays in a vacuum tube. Those of the shortest wavelength have the highest intensity and are called 'hard' x-rays. x-radiation was discovered by Roentgen in 1898. x-rays have the following properties: (i) They penetrate solids of moderate density, such as human tissue; they are retarded by bone, barium sulphate, lead and other dense materials. (ii) They act on photographic plates and fluorescent screens. (iii) They ionize gases through which they pass. (iv) x-rays damage or destroy diseased tissue. There is also a cumulative deleterious effect on healthy tissue.

X-rays find wide use in medicine both for diagnosis and treatment and in engineering where radiographs are used to show up minute defects in structural members. X-ray tubes must always be carefully shielded because the radiation causes serious damage to living tissue.

Xylem

Xylem is one of the two conductive tissues in plants. It has tube-like cells that transport water and the dissolved mineral nutrients in vascular plants from the roots to the leaves, flowers and fruits (Fig.X.2).

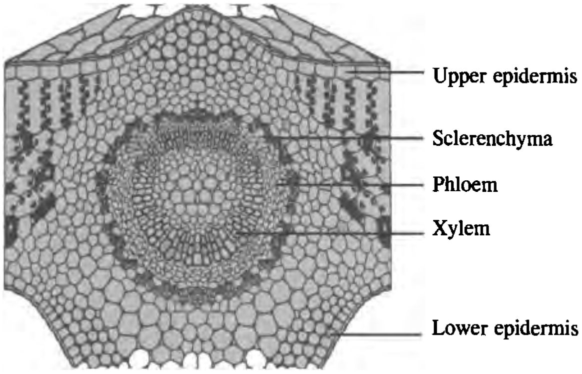

Fig.X.2: Schematic showing conductive tissues on cross-section of the midrib of a leaf.

In flowering plants, xylem consists of hollow vessels, formed from cells that are joined end to end with perforations in the end walls of vessels to allow the passage of water.

In less advanced vascular plants, such as conifers and ferns, the constituent cells of the xylem are called **tracheids**. In young plants and at the shoot and root tips of the older plants, xylem is formed by the apical meristems.

In most plants showing secondary growth, xylem is replaced by secondary xylem, formed by the vascular cambium. The walls of xylem cells are thickened with lignin, the thickening being highest in secondary xylem.

Xylem contributes greatly to the mechanical strength of the plant. Wood is mostly made up of the secondary xylem.-developed ochric A horizon and one or more of the characteristics of cambic B horizon, an argillic B horizon, a calcic horizon, a gypsic horizon and no other diagnostic horizons.

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Y

Yeasts

Yeasts are single-celled microscopic plants classified as one of the forms of fungi. Some yeasts cause diseases of skin and mucous membranes, whereas some others (notably the strains of *Saccharomyces cerevisiae*, baker's yeast) are used in baking and brewing.

Yeasts employ one or both of the metabolic processes of fermentation and respiration, fermentation involving anaerobic decomposition of hexose sugars into alcohol and carbon dioxide, and respiration involving exothermic decomposition of various sugars, in the presence of oxygen, to give carbon dioxide and water.

Yeasts are grown also for use as a source of food rich in B-complex vitamins.

Yellow-green algae

Yellow-green algae are members of the division Xanthophyta with the genus *Tribonema*. These tribophytes have green or yellow-green chloroplasts and are sometimes mistaken for green algae.

Yellow-green algae contain lipid droplets in their cytoplasm, but lack starch. They also contain beta-carotene.

Yellowing

Yellowing (or chlorosis) of old leaves or all leaves may indicate deficiencies of nitrogen or sulphur; it may also be indicative of waterlogging, old age or lack of light.

Yellowing is a familiar sight in pastures and lawns. Yellowing gets highlighted by deep green patches in the same area, indicating that these green patches have received extra nitrogen from gardeners or animals.

Chlorosis of part of the mature leaves is sometimes a significant sign of deficiency in phosphorus or magnesium.

In short, yellowing (or yellows) may be caused by viruses, fungi, insects or toxins and nutrient deficiency. For example, yellows in walnut is caused by **zinc deficiency**.

Yellow leaf of cashew

Yellow leaf spot on a cashew plant is the manifestation of **molybdenum deficiency**.

Yermosols

Yermosols, which are sandy desert soils, are one of the FAO prepared soil maps of the world. According to the revised FAO-soil map legend, **xerosols** and yermosols are classified as calcisols and gypsisols.

Yield

In agriculture, yield means the economic part of the plant used for human or animal consumption. The grain yield is the product of the number of ears per unit area, the number of grains per ear and grain size, all of which are also measures of the yield.

Earlier, each country had its own way of measuring the yield. For example, the bushel, developed during Anglo-Saxon times, was the standard measure for cereal grain weight. It was based on the **Winchester bushel**, a standard cylinder which used to be kept in the Town Hall of Winchester, England.

However, bushel weight varied in different countries. It also varied with crops, which led to difficulties in comparisons of yield among cereal crops. For example, in the USA itself, wheat and rice were standardized at 60 lb/bu; corn, sorghum and rye at 51 lb/bu; barley at 48 lb/bu and oats at 32 lb/bu. In Canada, oat was standardized at 34 lb/bu. All these discrepancies have been eliminated with the acceptance of common SI units.

The SI unit for yield is hectoliter. Yields are expressed in kilograms or tons (amount) per hectare (unit area).

The **crop yield** arises from photosynthesis which converts the sunlight energy into chemical energy that fixes atmospheric carbon. The leaf area index determines the extent of photosynthesis and is represented by an index called the **leaf area index** (LAI) for crop plants.

Several variables affect plant yield, as put forth by Justus Liebig in his "Law of minimum",

$$Y = f(x_1, x_2, x_3 \ldots\ldots x_n)$$

where Y is the amount of crop output, f is a function, and $x_1, x_2, \ldots x_n$ are growth factors or inputs.

The growth factors x_i embodies a variety of inputs. Some factors can be controlled by the farmer (like the choice of seed, fertilizers and pesticides) and some are not controllable (like solar energy, genetic yield potential, water in rain-fed agriculture, etc.). The output level is thus determined by the number of inputs as well as their magnitude, wherein some inputs are minimal compared to the other inputs. If the output increases proportionately with the increase of one of the many inputs, this particular input would be the limiting (minimum) factor, until some other factor replaces it. When a fertilizer is the variable input, the relationship is conveniently represented by a linear response and plateau function.

The grain yield may vary widely in different countries and in different agro-climatic regions. The supply of sufficient nutrients to crops is essential for a high yield of the desired quality. Modern crop varieties depend more on the supply of nutrients to improve the grain yield than the traditional varieties. In addition, the improved varieties have been bred to sustain higher tolerance to stresses such as drought, infestation and disease. Therefore, the improved varieties of crops reduce the farmer's risk of year-to-year yield variability.

High temperatures and drought limit the yield. An excess of water is also detrimental. Paddy-wheat rotation is common in southern Asia. Agronomic practices such as planting wheat on raised beds for better drainage to reduce waterlogging are common for these rotations.

Large regions of the tropics and sub-tropics experience soil conditions that are characterized by some peculiarities such as zinc deficiency, aluminum toxicity, boron toxicity, etc. Such constraints which limit the production have been largely overcome by the development of cultivation practices suited to the specific situation.

One of the serious impediments to maximizing the crop yield, especially in intensively cropped areas (which are irrigated or have a high rainfall) is diseases. Crop rotation is the main strategy for preventing pathogen accumulation. The planting of varieties tolerant to pests is another important defense measure. The deployment of seeds at the correct moisture level and temperature allows the crop to outgrow weeds, thereby improving the yield.

The increased effort for the development and use of the following leads to increased production: (a) improved technologies, and (b) better fertilizers and pesticides to control weeds, insects and diseases.

Yield can be evaluated in biological and economic terms. Biological yield refers to the total dry matter, whereas economic yield refers to the economically useful part of the biological yield, such as the seed or a root in crops like potato, sugar beet, etc.; however, the term economic yield is usually applied to the total weight of the material above the ground which is more readily recovered.

The biological yield, the **economic yield** and the **harvest index** are interrelated thus:

$$\text{Economic yield} = \text{Biological yield} \times \text{Harvest index}$$

Table-Y.1 shows the average yields of some important agricultural crops, in different countries, in the year 2007.

Table-Y.1: Average yields of some agricultural crops (tons/hectare).

Country	Rice	Wheat	Corn	Potato	Sugarcane
India	3.207	2.671	2.159	16.425	72.555
China	6.34	4.78	5.413	14.4	86.05
Australia	8.15	1.056	5.691	35.9375	85.7143
United Kingdom	–	7.341	–	40.53	–
France	5.166	6.25	8.85	43.248	–
Germany	–	7.109	9.085	41.999	–
Italy	6.422	3.568	9.1444	25.537	–
USA	8.0538	2.596	9.482	38.714	77.6156
Canada	–	2.385	7.7543	31.278	–
Mexico	4.929	4.983	2.884	24.677	74.529
Brazil	3.819	2.199	3.73	23.7108	76.593
Argentina	6.5522	2.545	7.665	28.675	66.206
South Africa	2.285	2.779	2.8759	32.7586	48.88
Egypt	9.972	6.478	8.116	24.761	119.557
Kenya	3.567	1.766	2.025	6.666	88.3929

(Source: FAOSTAT, Statistics Division, Food and Agriculture Organization of the UN. Above table is an extract from en.wikipedia.org/wiki/maize; en.wikipedia.org/wiki/International_wheat_production_statistics; en.wikipedia.org/wiki/Rice#Production_and_export; faostat.fao.org/site/567/DesktopDefault.aspx on October 21, 2008.)

Yield components

The components of grain yield are the number of ears (in the case of cereals) per unit area, the number of grain per ear, and the grain weight. The grain yield is a product of these components.

Generally, as one component is increased or decreased, one or more of the remaining components compensate appropriately. The variation in the yield is determined not by the components of the yield but by the amount of photosynthate synthesized by the plants and made available for distribution, and for being partitioned in the crop plant.

Under the requirement of achieving a constant rate of **photosynthesis**, the components of the yield cannot be manipulated successfully to increase the yield. Only when the total photosynthate available for distribution is increased, can the components of the yield be simultaneously increased. Hence, one has to concentrate on factors that improve photosynthesis or the **harvest index**.

The amount of photosynthate available for distribution among the yield components is a product of the rate and the duration of photosynthesis. Many factors, including the environmental factor, may influence both the rate and the duration of photosynthesis. Physiological factors are also important and include partitioning of the plant development into vegetative and reproductive phases, leaf area, photorespiration, grain filling duration and rate, and the nitrogen absorbed.

The crop growth and the yield depend upon complex interactions between the crop and several conditions in its environment. Most crop management practices are aimed at balancing these variable factors to achieve optimum yields.

Some specialists have identified 52 factors that affect crop growth and have assigned mathematical values to each. These include (a) temperature, (b) sunlight, (c) violent storms, (d) flooding, (e) rainfall, (f) carbon dioxide, (g) altitude (h) organic matter of the soil, (i) clay concentration, (j) cation exchange capacity, (k) quantity and intensity of light, (l) slope and topography, (m) percent sunshine, (n) evaporation and transpiration ratio, (o) relative humidity, (p) temperature, (q) the number of days with more than 35°C temperature, (r) irrigation, (s) tiles, (t) water percolation rate, (u) rainfall amount and distribution, (v) altitude, (w) latitude, (x) specific crop growth characteristics, (y) aeration factor, (z) carbon dioxide, (aa) wind velocity, (ab) available soil water, (ac) depth of root zone, (ad) manure, (ae) insects and diseases, (af) days grown, (ag) seed quality, (ah) fertilizers, (ai) number of plants, (aj) timely operations, (ak) variety, (al) compaction, (am) soil and air temperature, and (an) frost-free period.

The growers have the capability of controlling up to 45 of the factors, but are obviously unable to manage the first seven of them. They can, however, modify the rainfall factor by irrigation and increase the carbon dioxide supply by applying fresh decomposable animal manures and crop residues.

The two major factors often acknowledged as establishing the upper limit of the potential yield of crops are (a) the amount of moisture available during the growing season, and (b) the length of the growing season.

Yield gap

The yield gap is the difference between the yield that is possible to be achieved under optimal conditions and the actual yield harvested by different farmers. This gap is indicative of the scope for improvement in technology and agricultural practices for increasing the yield. A large yield gap obviously calls for improvement in agricultural practices such as, replacing low-yielding, less-responsive and mal-adapted crops by high-yielding ones. Agriculturists are, however, not always sure how exactly to achieve the required increase.

Under controlled conditions, the yield can be as high as 14,500 kg/ha for wheat as achieved in the US, but the actual harvested yield in some countries is of the order of 2000 kg/ha. This shows that a vast genetic potential exists to increase the yield in cereal crops. Efforts should thus be directed to bring productivity closer to the high genetic potential demonstrated. If 50% of the improvement arises genetically, the other 50% should arise from improved agronomic practices. Sustainability of agriculture, in contrast to simply maximizing the yield, is receiving increasing attention, unlike in the past. Such a preference represents a desirable shift in thinking.

Yield point of clays

The property of clay to change permanently in size or shape, as a result of the application of stress above a certain value, is called the yield point.

Yield potential

The maximum possible yield from a soil for a given crop, under the most favorable conditions, is known as the yield potential. It is, in fact, the most optimistic estimate of the crop yield based on the present knowledge and the available biological material, under ideal management practices and soil conditions.

The actual yield which is normally lower than the potential yield, generally increases with increasing rainfall activity and with meeting nutrient requirements. Different crops often respond differently to the applied nutrients. As technology and management practices improve, or as economic incentives get better, the yield also improves, getting closer to the yield potential. Only the farmer can judge what management practices are economical for him. The fertilizer dealer can help him to obtain higher yields; and encourage him to test on his own farms the economical feasibility of employing newer techniques.

The maximum achievable economic yield, based on several cost-related considerations of inputs vis-à-vis outputs, is obviously lower than the maximum theoretical yield. To a commercial grower, the consideration of nutrients may not be a limiting factor from the emergence of the plant to its maturity.

The soil, crop, climate and the management practices are among the main determinants for maximizing the yield. The yield potential is determined by calculating the effect of photosynthesis during the grain-filling period, after considering the respiratory losses of moisture and the relocation of materials assimilated before the grain-filling stage. In growing rice, with a daily solar radiation of 16.7 MJ/m^2, the calculated net carbohydrate production in a 40-day grain-filling period is 16.4 tons/ha, assuming a 26% photosynthetic efficiency; the actual realized yields are a little more than 10 t/ha.

In the case of wheat in England, during a 40-day grain-filling period in which the daily solar radiation received was 16.7 MJ/m^2, the dry matter available for grain-filling was 9.2 t/ha. To this was added 7% of the expected net assimilation over a 15 day period before synthesis (0.5 t/ha), giving a potential grain dry matter yield of 9.7 t/ha, equivalent to 11.4 t/ha at 15% moisture. The yield potential of annual crop species can be increased at a faster rate than that derived from the empirical selection for the yield, if suitable ideotypes are identified.

The principal characteristics of the ideotype for the annual seed crops proposed are: (a) strictly annual habit, (b) erect growth form, (c) dwarf status, (d) strong stems, (e) unbranched or non-tillered habit, (f) reduced foliage, (g) erect leaf disposition, (h) determinate habit, (i) non-photoperiodism for most situations, (j) early flowering for most situations, (k) high population density, and (l) narrow rows or square planting.

Yield targeting concept

Yield targeting concept is a technique used to estimate fertilizer requirement for a crop to get the **targeted yield** from a particular soil. The technique is based on soil tests, and requires the knowledge of yield that can be achieved from a crop.

Soil test laboratories do not consider the yield goal while making recommendations for fertilizers. The basic equation given below is used for the determination of potassium build-up and its maintenance when the potassium soil test level is less than the desired or optimum soil test plus five times the **cation exchange capacity (CEC)**.

$$X_k = 75.5[(X_d + 5\,\mathrm{CEC})^{0.5} - X_o{}^{0.5}] / 4 + (Y_g)(K_r)$$

where X_k is the annual potassium fertilizer rate (kg of K_2O per ha.), X_d is the desired or optimum potassium soil test level (kg of potassium per ha.), CEC is the cation exchange capacity, meq per 100 g, X_o is the observed soil test level (kg of potassium per ha), Y_g is the yield goal and K_r is the potassium removal (kg of K_2O per yield unit). If the measured soil test potassium exceeds the optimum plus five times the CEC, the following equation is used instead of the one above.

$$X_k = 75.5\{X_d + 5\ \mathrm{CEC}\}^{0.5} - X_o^{0.5} + (Y_g)(K_r)$$

The values of X_k, being less than 20 but greater than 0, are rounded to 20. If X_k is less than 0, it is recorded as 0.

Yolo series

Yolo series is defined as certain horizons, each with a specified color, structure, texture and other properties. For a soil to be in yolo series, it must have all the properties of the modal yolo soil and be within each property's acceptable range.

The central or modal yolo pedon has two horizons, A and C, and is 100 cm thick with a thickness in the range of 80 to 120 cm. A soil, resembling the yolo in every other property, but only 70 cm thick or thicker than 120 cm, is not yolo. In this way, an infinite variety of individuals can be categorized into units that, though numerous, are understandable and useful.

The Yolo series consists of nearly level, well-drained soils on alluvial fans. These soils are formed in mixed alluvium derived from sedimentary rocks. Grasses and forbs are a common vegetation on the uncultivated yolo soils. The average annual temperature of yolo series is around 17°C, the average rainfall is 45 to 65 cm, and the frost-free season is of 240 to 260 days.

Yolo soils are used for orchards, irrigated row crops, truck crops, dry-farmed small grain, wildlife habitat and recreation.

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Z

Zaid

During monsoons, especially in countries like India, there are two main crop seasons - ***rabi*** and ***kharif***. *Zaid*, a relatively short crop season between these main seasons, stretches approximately from April to June. Crops of short duration are grown in *zaid*.

Zeigler-Natta catalyst

Zeigler-Natta catalyst is usually a chemical complex derived from a transition metal halide and a metal hydride of metal alkyl for use in stereo specific polymerization. The transition metal chloride may be from Groups IV to VII of the Periodic Table and the hydride or alkyls from Groups I to III. Typically, titanium halide is added to aluminum alkyl in a hydrocarbon solvent.

Zeigler-Natta catalyst, also referred to simply, as Zeigler catalysts are suitable for reactions at room temperature and atmospheric pressure. They are generally used for stereo specific polymerization of ethylene or propylene to get the crystalline varieties.

Zeolite

Zeolite is a generic term used for any of the large group of minerals, comprising hydrated aluminosilicates of Na, K, Ca and Ba. These can readily be dehydrated and re-hydrated, and find application as molecular sieves and cation exchangers.

Natural zeolites are analcite, chabazite, heulandite, natrolite, stilbite and thomsonite. Artificial zeolites are made in many forms (ranging from gelatinous, to porous, to sand like varieties) and are used as gas absorbents, drying agents, catalysts and water softeners. Zeolites include a diverse group of compounds of sulphonated organic or basic resins.

Zeolites are low-temperature and low-pressure minerals occurring commonly in basalts, denitrification products and as alteration products of feldspars and nepheline.

Zeolites are also present in volcanic ash clay minerals. When applied to land or similar fields, they have a strong capacity for holding ammonium ions which reduce the leaching of the nitrate ions.

Zeolites are called **molecular sieves** because of their use in separating mixtures by selective absorption. They are also used in sorption pumps for vacuum systems (e.g., In permutil), ion exchange systems (for water softening) and as catalysts.

Zeoponics

The word zeoponic is derived from two words, zeolite and hydroponic. Zeoponics are a new kind of growth materials developed by NASA for space travel.

Zeoponics act as a growth medium for plants, and as a nutrient delivery system. They increase the nutrient retention capacity and reduce the loss of nutrients and fertilizers to the environment, by establishing a replenishable and balanced supply of nutrients in the root zone of plants.

Zeoponics have zeolite minerals as important constituents. These zeolite substrates contain essential cations required for plant-growth in their exchange sites and minor amounts of mineral phases and/or anion exchange resins which supply anions essential for plant growth. The charged zeolite interacts in the plant rhizosphere with slowly dissolving substances to provide nutrients by slow release through a combination of ion exchange reactions and chemical dissolution reactions. The result is a growth medium or speciality fertilizer which, when added to any other media, improves the plant performance.

Crop yields from zeoponics have occasionally shown yields higher than those from traditional synthetic media. Bulgarian scientists have shown that zeoponics stimulated the growth of the roots of softwood cuttings, pepper and strawberries.

Activation of zeoponic substrates of specific particle size supplements nitrogen and phosphorus fertilizers.

Zero-order

Most reactions involving a single reactant show either first-order or second-order kinetics. Sometimes, however, such a reaction can be a zero-order reaction. For a zero-order reaction, the rate is constant. It does not change with concentration as it does for the first-order or second-order reactions.

The rate law for a zero-order reaction is:

$$\text{Rate} = k\,[A]^0 = k\,(1) = k$$

where k is a constant and A is the concentration of the reactant.

Zero-order reactions are most often encountered when a substance, such as a metal surface or an enzyme, is required for the reaction to occur. For example, the decomposition reaction in the presence of a platinum catalyst follows a zero-order reaction.

$$2N_2O(g) \longrightarrow 2N_2(g) + 2O(g)$$

The half-life (T½) for a zero-reaction is given by:

$$T_{1/2} = [A]^0/2k$$

where $[A]^0$ is the initial concentration of reactant and k is the rate constant.

Radioactivity decay follows a zero-order reaction and the isotope life is given by its half-life period.

Zeroth law

Zeroth law states that two bodies, which are individually in equilibrium with a third body, will be in equilibrium when placed in contact with each other; that is, they will have the same temperature.

Zero tillage

Zero tillage is a procedure whereby a crop is directly planted into the soil with no preparatory tillage after the harvest of the previous crop.

Usually, a special planter is necessary to prepare a narrow and shallow seedbed, immediately surrounding the seed being planted. The press wheels behind the planter shoes pack soil only where the seed is placed, leaving most of the soil surface in a state conducive to water infiltration. In zero tillage or **no tillage**, the field is not plowed and the plant residues remain standing during cultivation. In such a field, opening a small slit for the seed, or punching a hole into the soil for placing a seed at the required depth is done.

A zero tillage system involves lesser time, energy and costs for land preparation. It provides for a higher soil organic matter content because of relatively slower decomposition. This system also helps control erosion, especially on a sloping land. Zero tillage is observed to work better on large-seeded crops, like corn and soybean than on small-seeded ones.

On the other hand, any reduced tillage system demands better management of planting time, fertilization programs and weed attacks than in the conventional system. Zero tillage system is also observed to need more seeds for the same yield since plant emergence and stand density are reduced. Zero tillage usually involves high cost and frequency of use of weedicides and herbicides.

Zeta potential

Zeta potential or electrokinetic potential is a potential across the interface of all solids and liquids. Specifically, it is the potential across the diffuse layer of ions surrounding a charged colloidal particle which is largely responsible for colloidal stability.

Discharge of zeta potential accompanied by precipitation of the colloid occurs by addition of polyvalent ions of sign opposite to that of the colloidal particles. Zeta potential can be calculated from electrophoretic mobilities, that is, the rates at which colloidal particles travel between charged electrodes placed in the solution.

Zinc

Zinc (Zn) is a bluish-white metal belonging to the 12th Group of the Periodic Table. It occurs naturally as sphalerite, smithsonite, hemimorphite and wurzite, and is extracted by roasting the oxide and reducing with carbon. It is used for galvanizing, as cathodes in dry cells, and in alloys including brass.

Zinc is one among the seven plant micronutrients (Fig.Z.1). Like the other micronutrients, it is toxic except in small quantities.

Zinc is considered deficient when its concentration is less than 20 ppm in plants; toxicity occurs when its concentration exceeds 400 ppm. The concentration of zinc relative to other heavy metals like copper is more important than its absolute concentration.

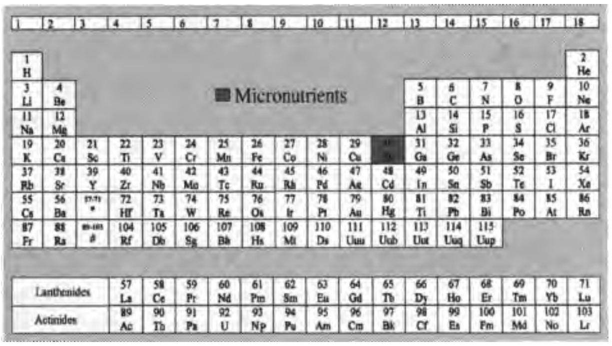

Fig.Z.1: Position of zinc, a micronutrient, in the Periodic Table.

Zinc is involved in many enzymatic activities in plants. It functions generally as a metal activator of enzymes, such as aldolase, lecithinase, cysteine desulphhydrase, histidine deaminase, carbonic anhydrase, dihydropeptidase and glycyl-glycine dipeptidase.

Zinc improves crop productivity almost as much as major nutrients do. It ranks as the third most important limiting nutrient element, next to nitrogen and phosphorus, in crop production.

Zinc is involved in the synthesis of the amino acid tryptophane and the production of growth regulating substances (**auxins**). Zinc is vital for the oxidation processes in plant cells and for improving the content of protein, tannin, sugar and lipid in plants and seeds.

In soils, zinc exists in water-soluble, exchangeable and complexed forms, and is readily available to plants. The zinc content in soils, all over the world, ranges from 10 to 300 ppm and its critical concentration in plants is 15 to 20 ppm. In Indian soils, for instance, zinc ranges from a few ppm to 1000 ppm. The available zinc, as extracted with diethylenetriaminepenta-acetic acid (**DTPA**), is generally between 0.08 and 20.5 ppm with an average of around 0.6 ppm.

Zinc is absorbed by plant roots as divalent ions (Zn^{2+}) or as zinc chelates. It exists in a hydrated form in acidic and neutral aqueous solutions. Zinc salts or complexes are also applied to plant leaves to correct the deficiency.

Zinc availability to plants depends on several factors, such as the pH, phosphorus level, organic matter content, adsorption on clay surfaces, interaction with other nutrients and climatic conditions. A maximum uptake of zinc, both native and applied, seems to take place at the lowest pH of the soil solution, whereas zinc deficiency is induced in plants within the pH range of 6.0 to 8.0. The more the phosphate in the soil, the larger the zinc deficiency. The formation of insoluble zinc phosphate due to zinc interaction (P-Zn) in the soil results in phosphorus-induced zinc deficiency. But recent research has proved zinc phosphate ($ZnNH_4PO_4$) to be a good zinc source for crops as it contains zinc, phosphorus and N nutrients.

Zinc adsorption on the surface of clay minerals, aluminum oxide, iron oxides, organic matter and carbonates of calcium and magnesium increases with pH. Zinc is strongly adsorbed by magnesite ($MgCO_3$) and least by calcite ($CaCO_3$). The other cations like Cu^{2+}, Fe^{2+} and Mn^{2+} inhibit the Zn^{2+} uptake owing to the competition for the same carrier site. Zinc deficiencies are more pronounced during cool and wet seasons than during the warmer ones.

Plant species and varieties differ in their susceptibility to **zinc deficiency**. The deficiency can be identified generally from the visual symptoms appearing most frequently in the leaves and sometimes in the fruits or branches. It is first seen in younger leaves as an interveinal chlorosis (Fig.Z.2) followed by the reduction in the rate of root growth.

Fig.Z.2: Zinc deficiency symptoms. Dead spots on chlorotic leaves, as against healthy leaves.

Zinc deficiency in plants retards photosynthesis and nitrogen metabolism which give rise to a fall in the quality of flowering, fruit development and yield. The deficiency symptoms normally appear in the first four weeks and are evident in the characteristic little leaf and rosetting or clustering of leaves at the top of the branches of fruit trees.

Zinc deficiency is called (a) **white bud** in corn and sorghum, (b) **little leaf**, in cotton, grapes and stone fruits, (c) **mottle leaf** or **frenching** in citrus crops, (d) **fern leaf** in potato, (e) **bronzing** in tung nut trees, (f) **yellows** in walnut, and (g) **rosette** in apples and pecans.

Zinc deficiency in tobacco appears as dead spots all over the leaf and is called ***khaira* disease**. Areas of chocolate-brown, burned-up plants in rice fields also indicate the same.

Zinc deficiency is common in basic and limed soils. It is more pronounced if the topsoil is eroded or removed in land grading and levelling. Sands and anaerobic soils may also have a lower soluble zinc content than do clays or soils. Corn, onions, pecans, sorghum and deciduous fruits require zinc in large quantities.

Zinc sulphate is a popular fertilizer, applied to the soil at the rate of 5 to 15 kg/ha. It can be sprayed over vegetables, fruits and field crops. Zinc ammonium sulphate, zinc chelates, zinc oxide, zinc ammonium phosphate, zinc sulphide, zinc ammonium nitrate and zinc frits are other potential fertilizer materials.

Zinc deficiency can be corrected by foliar sprays of zinc sulphate or chelates. **EDTA** (ethylene diaminetetraacetic acid), a di-sodium salt complex of zinc, is also applied. The other methods of applications include top dressing, seed coatings with zinc oxide or zinc sulphate solution or paste, root dips and tree injections. Among all these methods, the soil application is so far found to be the best.

Soils, in view of the limited mobility of zinc in them, should be thoroughly incorporated with zinc by broadcasting, while band application of zinc may be more effective in fine-textured and low-zinc soils. The quantities of zinc required by plants being small, a diluent is usually necessary, which is a multinutrient or a compound fertilizer. Zinc is mixed with water for foliar applications.

Generally, four extractants are used for determining zinc salts in soils. These are 0.1N hydrochloric acid (HCl), ethylenediaminetetraacetic acid-ammonium carbonate (EDTA-$(NH_4)_2CO_3$), dithiazone-ammonium acetate (NH_4OAC) and diethylenetriaminepentaacetic acid-triethanol amine (DTPA-TEA). The critical values of DTPA-TEA in the soil range between 0.5 and 0.8 mg zinc/kg for corn, 0.48 mg/kg for green gram and 0.86 mg/kg for rice. However, it varies with the pH and clay content.

Zinc is chemically active, forming zinc salts (Zn^{2+}) and zincates $(ZnO_2)^{2+}$ in an alkaline solution. It forms many stable complexes. Zinc oxide and sulphide are used as white pigments. Zinc chloride is used as a flux. It is also used in dentistry and in the manufacture of batteries and fungicides as well as for fire-proofing. Zinc sulphate and EDTA complex are used as fertilizers to cure zinc deficiency.

Zinc ash

Zinc ore, like the zinc blend (**sphalerite**), is sometimes called zinc ash. It contains 66% zinc and is used in the preparation of zinc sulphate. It is widely used as a zinc fertilizer.

Zincated single superphosphate

Zincated single superphosphate contains 2.5% zinc and is a modified form of single superphosphate. It is a very useful fertilizer for field crops and for soils deficient in phosphorus and zinc.

Zincated urea

Zincated urea is a mixture of urea containing zinc as a micronutrient material or a mixture of urea with zinc sulphate heptahydrate. It can be made either by dry mixing, bulk blending or coating common fertilizers, such as ammonium nitrate or urea.

Zincated urea is used for basal application of rice to provide 1 kg of zinc/hectare. Such practice is generally followed in the Philippines.

Zinc chelates

Zinc chelate is an inorganic complex in which a ligand like ethylenediaminetetraacetic acid (EDTA) is bound to the zinc ion at more than two points, so that the metal ion becomes part of the ring of atoms. The zinc-EDTA complex is stable and difficult to be broken down in the soil but remains readily available to plants.

Zinc chelates are made with other chelating agents as well, but they do not get fixed in the soil. At pH 6.0, and with a low concentration of ferrous and ferric ions, the application of zinc chelates becomes very effective. Zinc chelates are also applied as foliar sprays for quick recovery of zinc-deficient seedlings and plants.

Zinc deficiency

Plants are said to be deficient in zinc when the zinc concentration in plants is less than 20 ppm. When its concentration exceeds 400 ppm, it is said to exist in toxic proportion. Its deficiencies are more prevalent than those of copper and are virtually global in nature.

Zinc deficiency appears most frequently on the leaves and sometimes in the fruits or branches of plants. Its symptoms are first seen on the younger leaves as an interveinal chlorosis, followed by reduction in the rate of root growth. Retardation in plant processes, like photosynthesis and nitrogen metabolism, resulting in the reduction of flower quality, fruit development and yield, are some of the symptoms appearing normally within four weeks.

Little leaf and rosetting or clustering of leaves at the top of fruit tree branches are some of the common symptoms of zinc deficiency (Fig.Z.3). These deficiencies are common in basic and limed soils. (See also Zinc.)

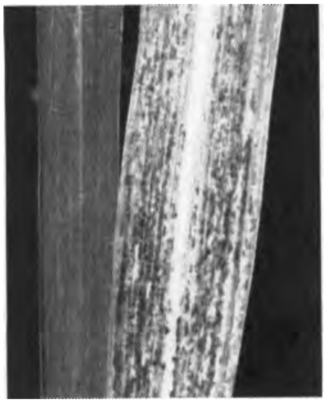

Fig.Z.3: Zinc deficiency symptoms in sugar cane.

Zinc frits

Zinc frits are **frits** with zinc as the main micronutrient. Fusing salts of zinc with glass or glass components forms zinc frits.

Zinc oxide

Zinc oxide (ZnO) is a zinc fertilizer. It is a white powder when cold and yellow when hot, and contains approximately 78% zinc.

Zinc oxide occurs in nature as a reddish-orange colored zincite, and is made by oxidizing hot zinc in air. It is an amphoteric oxide forming zincates, by reacting with bases and zinc salts with acids. It is used as a white pigment and as a mild antiseptic in ointments. An archaic name of zinc oxide is **philosopher's wool**.

Foliar applications with zinc oxide reduce the foliage damage. Zinc oxide, applied by way of seed coatings, root dips or tree injections, corrects the zinc deficiency. Dipping potato seeds in 2% zinc oxide suspension overcomes zinc deficiency satisfactorily. A similar method is used for pre-plant dipping of the roots of rice seedlings.

Zinc sulphate

Zinc sulphate is a white, crystalline, water-soluble compound (Fig.Z.4) made by heating zinc sulphide ore in air and dissolving the sulphate formed, and crystallizing it.

$$ZnS + 2O_2 \longrightarrow ZnSO_4$$

Zinc sulphate is the most common zinc salt (about 35% of zinc) used for preventing zinc deficiency in plants. It is sprayed on the foliage as a water solution or added in large quantities directly to the soil.

Fig.Z.4: Zinc sulphate fertilizer.

Zinc sulphate heptahydrate

Zinc sulphate heptahydrate ($ZnSO_4 \cdot 7H_2O$), also called **white vitriol**, is the most common form of zinc sulphate. It forms **zinc sulphate monohydrate** above 70°C and anhydrous salt at 280°C, and is used as a mordant and a styptic (to check bleeding).

Zinc sulphate monohydrate: See Zinc sulphate heptahydrate

Zinc toxicity

Zinc toxicity occurs when the concentration of zinc exceeds 400 ppm in plants.

Zymase

Zymase is an enzyme present in yeasts, which converts sugars to alcohol and dioxide.

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Appendices

Organizations and Their Acronyms

African Priority Program of Economic Recovery	APPER
American Society for Testing and Materials	ASTM
Arab Potash Company	APC
Association of American Plant Food Control Officials	AAPFCO
Badische Anilin-und Soda-Fabrik	BASF
Beladune Fertilizers Limited	BFL
British Petroleum	BP
Chambal Fertilizers and Chemicals Limited	CFCL
Chemetics International Ltd	CIL
Commission on Phytosanitary Measures	CPM
Co-operative Farm Chemical Association	CFCA
Coromandel Fertilizers Limited	CFL
Duncans Industries Limited	DIL
Environmental Protection Agency of the USA	EPA
European Fertilizer Manufacturers' Association	EFMA
Fertilizantes Mexicanos	FERTIMEX
Fertilizer Association of India	FAI
Fertilizer Corporation of India	FCI
Fertilizer Development and Consultative Organization	FDCO
Fertilizers and Chemicals Travancore Limited	FACT
Food and Agricultural Organization of the United Nations	FAO
Godavari Fertilizers and Chemicals Limited	GFCL
Gujrat Narmada Valley Fertilizers Company Limited	GNFC
Gujrat State Fertilizers Company, Limited	GSFC
Hind Lever Chemicals Limited	HLCL
Hindustan Fertilizer Corporation Limited	HFCL
Hydro Agri International Licensing	HAIL
Imperial Chemical Industries Limited	ICI
Indian Farmers Fertilizer Co-operative Limited	IFFCO
Indo Gulf Corporation Limited	IGCL
Industrial Development Decade for Africa	IDDA
Institut Mondial du Phosphate	IMPHOS
International Crop Research Institute for Semi-Arid & Tropics	ICRISAT
International Fertilizer Development Center	IFDC
International Fertilizer Industry Association	IFA
International Organization for Standardization	ISO
International Phosphate Company	IPC
Israel Mining Industry	IMI
Krishak Bharati Cooperative Limited	KRIBHCO
Madras Fertilizers Limited	MFL

Mangalore Chemicals and Fertilizers Limited	MCFL
Nagarjuna Fertilizers and Chemicals Limited	NFCL
National Fertilizers Limited	NFL
Paradeep Phosphates Limited	PPL
Potash Company of America	PCA
Potash Corporation of Saskatchewan	PCS
Rashtriya Chemicals and Fertilizers Limited	RCF
Rashtriya Ispat Nigam Limited	RINL
Shriram Fertilizers and Chemicals	SFC
Southern Petrochemical Industries Corporation Limited	SPIC
Steel Authority of India Limited	SAIL
Tata Chemicals Limited	TCL
Tennessee Valley Authority	TVA
The Fertilizer Institute	TFI
Tuticorin Alkali Chemicals and Fertilizers Limited	TAC
U.S. Bureau of Mines	USBM
U.S. Environmental Protection Agency	EPA
United Nations Conference on Environment and Development	UNCED
United Nations Environment Program	UNEP
United Nations Industrial Development Organization	UNIDO
United States Department of Agriculture	USDA
World Health Organization	WHO

Abbreviations

A	Angstrom, 10-10 of meter
AAPFCO	Association of American plant food control officials
ADP	Adenosine diphosphate
AEC	Anion exchange capacity
AM	2-amino-4-chloro-6-methyl pyrimidine
AP	Ammonium phosphate
APP	Ammonium polyphosphate
Ark	Activity ratio
ATP	Adenosinetriphosphate
BOD	Biological oxygen demand, mg/l
BPL	Bone phosphate of lime (1% P_2O_5 = 2.185%BPL)
Bq	Becquerels
C	Degree Celsius
CAN	Calcium ammonium nitrate
CCE	Calcium carbonate equivalent
CEC	Cation exchange capacity, meq/100 g of soil
cm	Centemeter
C/N	Carbon-nitrogen ratio
CNC	Critical nutrient concentration
COD	Chemical oxygen demand
CPM	Commission on phytosanitary measures
CRH	Critical relative humidity
CSP	Concentrated superphosphate
2,4-D	2,4-dichlorophenoxyacetic acid
DAP	Diammonium phosphate
DCD	Dicyandiamide, nitrification inhibitor
DCP	Dicalcium phosphate
DDT	1,1'-(2,2,2-trichloroethylidiene) bis (4-chlorobenzene)
DNA	Deoxyribonucleic acid
DRIS	Diagnosis and Recommendation Integrated System
dS/m	DeciSiemens per meter
DTPA	Diethylenetriaminepentaacetic acid
DW	Drainage water
EC	Electrical conductivity, S/m
ECP	Exchangeable cation percentage
EDDHA	Ethylenediaminedi-o-hydroxyphenylacetic acid
EDTA	Ethylene diamminetetraacetic acid
ES	Exchangeable sodium, meq/100 g soil
ESP	Exchangeable sodium percentage
ESR	Exchangeable sodium ratio
ET	Evapotranspiration
FAO	Food and agriculture organization
FC	Field capacity
FYM	Farmyard manure
g	Gram
GDD	Growing degree days
GIS	Geographical information system
GPC	Gel permeation chromatograph
GPS	Global positioning system
GR	Gypsum requirement
ha	Hectare
HPLC	High pressure liquid chromatograph
IAA	Indol-3-ylacetic acid
IBA	4-Indol-3-ylbutyric acid
IFA	International Fertilizer association
IPM	Integrated pest management
IPPC	International plant protection convention
IW	Irrigation water
J	Joule
kg	Kilogram
kV	Kilovolt
kW	Kilo watt
kWh	Kilo watt hour
l	Liter
LAI	Leaf area index
LF	Leaching fraction
LISA	Low input sustainable agriculture
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LR	Leaching requirement
LSD	Least significant difference
M	Million
MAP	Monoammonium phosphate
Meq/l	Milliequivalent per liter
mg	Milligram
mm	Millimeter
Mmho	Millimho
mV	Millivolt
µm	Micrometer
NAD	Nicotinamide adenine dinucleotide
NI	Nitrification inhibitor
NPK	Nitrogen, phosphorus and potassium
NUE	Nitrogen use efficiency
OM	Organic matter
OSHA	Occupational safety and health administration
OSP	Ordinary superphosphate
PARP	Partially acidulated rock phosphate
pH	Potential hydrogen - a measure of acidity or basicity of a liquid
ppb	Parts per billion, 1/1000 of ppm
ppm	Parts per million, mg/kg or mg/l
ppmv	Parts per million in volume ml/l
ppmw	Parts per million in weight mg/kg
RH	Relative humidity
RNA	Ribonucleic acid
RSC	Residual sodium carbonate, meq/l
SAR	Sodium absorption ratio
SSP	Single superphosphate
ST	2-sulphanilamido thiazole, a nitrification inhibitor
t	Ton
TDS	Total dissolved solids
TSP	Triple superphosphate
TVA	Tennessee valley authority
UAN	Urea ammonium nitrate
USG	Urea super granule
VAM	Vesicular arbuscular mycorrhizae
WHO	World health organization
WP	Wilting point

APPENDIX - III

Periodic Table of Elements

▨ Metals

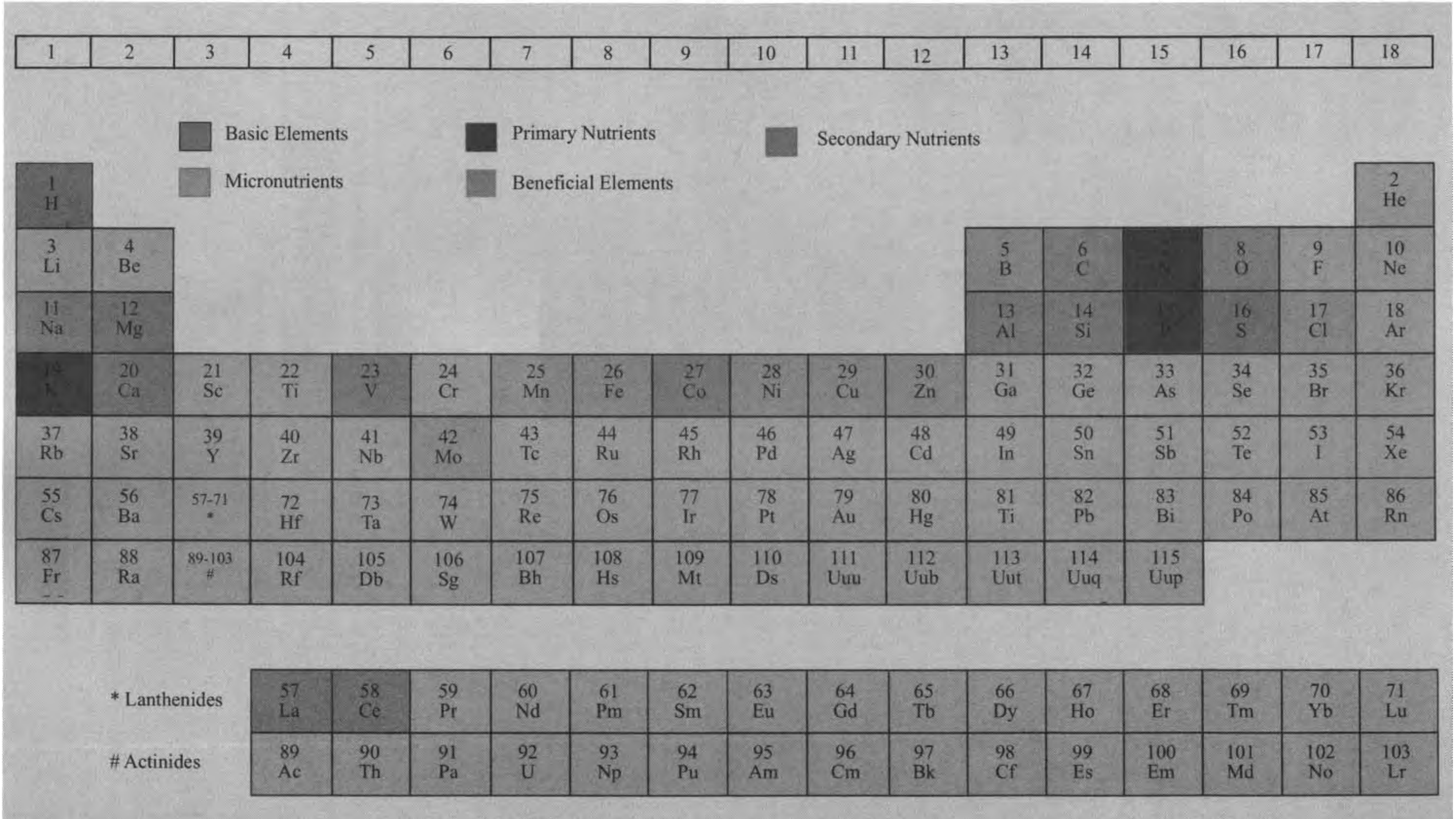
■ Nonmetals

□ Transition metals

▨ Elements of the f-series column labeling

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71 *	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Ti	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103 #	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Uuu	112 Uub	113 Uut	114 Uuq	115 Uup			
			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Em	101 Md	102 No	103 Lr

Periodic Table of Plant Nutrients



▨ Basic Elements
▨ Micronutrients
■ Primary Nutrients
▨ Beneficial Elements
▨ Secondary Nutrients

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71 *	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Ti	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103 #	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Uuu	112 Uub	113 Uut	114 Uuq	115 Uup			

* Lanthenides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
# Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Em	101 Md	102 No	103 Lr

Position of plant nutrient elements in the Periodic Table

Chemical Elements

Element	Symbol	Atomic number	Element	Symbol	Atomic number
Actinium	Ac	89	Mercury	Hg	80
Aluminum	Al	13	Molybdenum	Mo	42
Americium	Am	95	Neodymium	Nd	60
Antimony	Sb	51	Neon	Ne	10
Argon	Ar	18	Neptunium	Np	93
Arsenic	As	33	Nickel	Ni	28
Astatine	At	85	Niobium	Nb	41
Barium	Ba	56	Nitrogen	N	7
Berkelium	Bk	97	Nobelium	No	102
Beryllium	Be	4	Osmium	Os	76
Bismuth	Bi	83	Oxygen	O	8
Boron	B	5	Palladium	Pd	46
Bromine	Br	35	Phosphorus	P	15
Cadmium	Cd	48	Platinum	Pt	78
Caesium	Cs	55	Plutonium	Pu	94
Calcium	Ca	20	Polonium	Po	84
Californium	Cf	98	Potassium	K	19
Carbon	C	6	Praseodymium	Pr	59
Cerium	Ce	58	Promethium	Pm	61
Chlorine	Cl	17	Protactinium	Pa	91
Chromium	Cr	24	Radium	Ra	88
Cobalt	Co	27	Radon	Rn	86
Copper	Cu	29	Rhenium	Re	75
Curium	Cm	96	Rhodium	Rh	45
Dysprosium	Dy	66	Rubidium	Rb	37
Einsteinium	Es	99	Ruthenium	Ru	44
Erbium	Er	68	Samarium	Sm	62
Europium	Eu	63	Scandium	Sc	21
Fermium	Fm	100	Selenium	Se	34
Fluorine	F	9	Silicon	Si	14
Francium	Fr	87	Silver	Ag	47
Gadolinium	Gd	64	Sodium	Na	11
Gallium	Ga	31	Strontium	Sr	38
Germanium	Ge	32	Sulphur	S	16
Gold	Au	79	Tantalum	Ta	73
Hafnium	Hf	72	Technetium	Tc	43
Helium	He	2	Tellurium	Te	52
Holmium	Ho	67	Terbium	Tb	65
Hydrogen	H	1	Thallium	Tl	81
Indium	In	49	Thorium	Th	90
Iodine	I	53	Thulium	Tm	69
Iridium	Ir	77	Tin	Sn	50
Iron	Fe	26	Titanium	Ti	22
Krypton	Kr	36	Tungsten	W	74
Lanthanum	La	57	Uranium	U	92
Lawrencium	Lr	103	Vanadium	V	23
Lead	Pb	82	Xenon	Xe	54
Lithium	Li	3	Ytterbium	Yb	70
Lutetium	Lu	71	Yttrium	Y	39
Magnesium	Mg	12	Zinc	Zn	30
Manganese	Mn	25	Zirconium	Zr	40
Mendelevium	Md	101			

Some Common Chemical Compounds and Their Formulae Used in This Encyclopedia

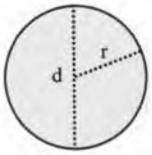
Compound	Formula
Acetic acid	CH_3COOH
Acetylene	C_2H_2
Aluminum fluoride	AlF_3
Aluminum sulphate	$Al_2(SO_4)_3$
Amino group	$-NH_2$
Ammonia	NH_3
Ammonium	NH_4
Ammonium bicarbonate	NH_4HCO_3
Ammonium dihydrogen phosphate	$NH_4H_2PO_4$
Ammonium hydroxide	NH_4OH
Ammonium molybdate	$(NH_4)_6Mo_7O_{24}\cdot 4H_2O$
Ammonium nitrate	NH_4NO_3
Ammonium polyphosphate	$(NH_4)_3HP_2O_7\cdot H_2O$
Ammonium polysulphide	$(NH_4)_2Sx$
Ammonium sulphate	$(NH_4)_2SO_4$
Ammonium thiosulphate	$(NH_4)_2S_2O_3$
Aqua ammonia	NH_4OH
Basic Slag	$5CaO\cdot P_2O_5\cdot SiO_2$
Blast furnace slag	$CaSiO_3$
Borate	$NaBO_3$
Borax	$Na_2B_4O_7\cdot 10H_2O$
Calcite	$CaCO_3$
Calcitic limestone	$CaCO_3$
Calcium ammonium nitrate	$NH_4NO_3+Ca(NO_3)_2$
Calcium carbonate	$CaCO_3$
Calcium chloride	$CaCl_2$
Calcium cyanamide	$CaCN_2$
Calcium dihydrogen phosphate	$Ca(H_2PO_4)_2$
Calcium hydrogen phosphate	$CaHPO_4$
Calcium metaphosphate	$Ca(PO_3)_2$
Calcium nitrate	$Ca(NO_3)_2$
Calcium sulphate	$CaSO_4$
Carbon dioxide	CO_2
Carboxyl group	$-COOH$
Carnallite	$KCl\cdot MgCl_2\cdot 6H_2O$
Colemanite	$Ca_2B_6O_{11}\cdot 5H_2O$
Crandallite	$CaAl_3(PO_4)_2OH_5\cdot H_2O$
Cryolite	Na_3AlF_6
Cuprous oxide	Cu_2O
Diammonium hydrogen phosphate	$(NH_4)_2HPO_4$
Dimethyl disulphide	$(CH_3)_2S_2$
Dipotassium hydrogen phosphate	K_2HPO_4
Dolomite	$CaMg(CO_3)_2$
Ethanamide or acetamide	CH_3CONH_2
Ethylene	C_2H_4
Ferric sulphate	$Fe_2(SO_4)_3\cdot 9H_2O$
Ferrous ammonium phosphate	$Fe(NH_4)PO_4\cdot H_2O$
Ferrous ammonium sulphate	$(NH_4)_2SO_4\cdot FeSO_4\cdot 6H_2O$
Fluorapatite	$Ca_{10}F_2(PO_4)_6$
Fluosilicic acid	H_2SiF_6
Formic acid	$HCOOH$
Garnierite	$(Mg.Ni)H_2SiO_4$
Gypsum	$CaSO_4\cdot 2H_2O$
Hydrated lime	$Ca(OH)_2$
Hydrochloric acid	HCl
Hydrogen sulphide	H_2S
Kieserite (magnesium sulphate)	$MgSO_4\cdot H_2O$
Langbeinite	$K_2SO_4\cdot 2MgSO_4$
Magnesite	$MgCO_3$
Magnesium ammonium phosphate	$MgNH_4PO_4$
Magnesium carbonate	$MgCO_3$
Magnesium hydroxide	$Mg(OH)_2$
Magnesium nitrate	$Mg(NO_3)_2\cdot 2H_2O$
Magnesium oxide	MgO
Magnesium oxysulphate	$MgO, MgSO_4$
Magnesium potassium phosphate	$MgKPO_4$
Magnesium sulphate (Epsom salt)	$MgSO_4\cdot 7H_2O$
Manganese chelate	MnEDTA
Manganese oxide	MnO
Manganese sulphate	$MnSO_4\cdot 4H_2O$
Methyl mercaptan	CH_3SH
Molybdenum dioxide	MoO_2
Molybdenum trioxide	MoO_3
Monoammonium phosphate	$NH_4H_2PO_4$
Nitrate	$-NO_3$
Nitric acid	HNO_3
Nitric oxide	NO
Nitrite	$-NO_2$
Nitrogen-S solution	$CO(NH_2)_2\cdot NH_4NO_3\cdot (NH_4)_2SO_4$
Nitrous oxide	N_2O
Olivine	$(Mg, Fe)_2SiO_4$
Orthophosphoric acid	H_3PO_4
Phlogopite mica	$[K(Mg,Fe)_3AlSiO_3O_{10}(OH,F)_2$
Phosphate rock	$[Ca_3(PO_4)_2]$
Phosphoric acid	H_3PO_4
Phosphorus pentoxide	P_2O_5
Potassium bicarbonate	$KHCO_3$
Potassium bisulphate	$KHSO_4$
Potassium carbonate	K_2CO_3
Potassium chloride	KCl
Potassium dihydrogen phosphate	KH_2PO_4

Compound	Formula	Compound	Formula
Potassium hydroxide	KOH	Superphosphate normal	$Ca(H_2PO_4)_2$ + $CaSO_4\cdot 2H_2O$
Potassium magnesium sulphate	$K_2SO_4 + MgSO_4$		
Potassium metaphosphate	KPO_3	Superphosphoric acid, polyphosphate	$H_3PO_4 + H_4P_2O_7$
Potassium nitrate	KNO_3		
Potassium oxide	K_2O	Syngenite	$K_2Ca(SO_4)_2\cdot H_2O$
Potassium sulphate	K_2SO_4	Tetrapotassium pyrophosphate	$K_4P_2O_7$
Pro/Mesium	$3MgOSiO_2\cdot 2H_2O$	Tricalcium phosphate	$Ca_3(PO_4)_2$
Pyrite	FeS_2	Triple superphosphate	$Ca(H_2PO_4)_2\cdot H_2O$
Pyrophosphoric acid	$H_4P_2O_7$	Tripolyphosphoric acid	$H_5P_3O_{10}$
Pyrrhotite	Fe_5S_6	Urea	$CO(NH_2)_2$
Serpentine	$Mg_3H_4Si_2O_9$	Urea phosphate	$CO(NH_2)_2\cdot H_3PO_4$
Silicon oxide	SiO_2	Urea-formaldehyde	$CO(NH_2)_2$-CH_2O
Sodium molybdate	$Na_2MoO_4\cdot H_2O$	Varisite	$AlPO_4\cdot 2H_2O$
Sodium molybdate	$Na_2MoO_3\cdot 2H_2O$	Zinc ammonium phosphate	$ZnNH_4PO_4$
Sodium nitrate	$NaNO_3$	Zinc chelates	$Na_2ZnEDTA$
Strontium sulphate	$SrSO_4$	Zinc chelates	$NaZnTA$
Sulphate of potash magnesia	$K_2SO_4\cdot 2MgSO_4$	Zinc chelates	$NaZnHEDTA$
Sulphur dioxide	SO_2	Zinc oxide	ZnO
Sulphur-coated urea	$CO(NH_2)_2$-S	Zinc sulphate	$ZnSO_4\cdot 7H_2O$
Sulphuric acid	H_2SO_4		
Superphosphate (0-20-0)	$Ca(H_2PO_4)_2$		

Units of Measurement

Metric unit	**Equivalent**	**Imperial unit**	**Equivalent**
		Area measure	
1 square centimeter (cm^2)	100 square millimeters (mm^2)	1 square inch (in^2)	6.45 square centimeters
1 square meter (m^2)	10,000 square centimeters	1 square foot (ft^2)	144 square inches
1 are	100 square meters	1 square yard (yd^2)	9 square feet = 0.836 m^2
1 hectare	10,000 square meters	1 acre	4840 square yard = 0.405 hectare (ha)
1 square kilometer (km^2)	1,000,000 square meters	1 square mile	259 hectares
		Capacity measure	
1 centiliter (cl)	10 milliliters (ml)	1 fluid ounce (fl oz)	0.0296 liter
1 deciliter (dl)	10 centiliters	1 gill (gi)	5 fluid oz = 0.1480 liter
1 liter (l)	10 deciliters	1 pint (pt)	20 fluid oz = 0.568 liter
1 decaliter (dal)	10 liters	1 quart (qt)	2 pints = 1.136 liters
1 hectoliter (hl)	10 decaliters	1 gallon (gal)	4 quarts = 4.546 liters
1 kiloliter (kl)	10 hectoliters	1 peck (pk)	2 gallons = 9.092 liters
		1 bushel (bu)	4 pecks = 36.4 liters
		Linear measure	
1 centimeter (cm)	10 millimeters (mm)	1 inch (in)	25.4 millimeters
1 meter (m)	100 centimeters	1 foot (ft)	12 inches = 0.3048 meter
1 kilometer (km)	1,000 meters	1 yard (yd)	3 feet = 0.9144 meter
		1 rod (rd)	5.5 yards
		1 mile (mi)	1,760 yards = 1.609 km
		1 nautical mile	1.852 kilometers
		Weight	
1 centigram (cg)	10 milligrams (mg)	1 grain (gr)	0.065 gram
1 decigram (dg)	100 milligrams	1 dram (dr)	1.772 grams
1 gram (g)	1,000 milligrams	1 ounce (oz)	28.35 grams
1 decagram (dag)	10 grams	1 pound (lb)	0.4536 kilogram
1 hectogram (hg)	100 grams	1 stone	6.35 kilograms
1 kilogram (kg)	1,000 grams	1 hundred weight (cwt)	50.80 kilograms
1 ton (t) or metric ton	1,000 kilograms	1 ton (short)	0.907 ton
		1 ton (long)	1.016 ton
		Volume measure	
1 cubic centimeter (cc or cm^3)	1 milliliter	1 cubic inch (in^3)	16.4 cubic centimeters cm^3
1 liter	1,000 milliliters	1 cubic foot	1,728 cubic inches = 0.0283 cubic meter
1 cubic meter (m^3)	1,000 liters	1 cubic yard	27 cubic feet = 0.765 m^3

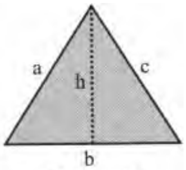
Areas and Volumes



Circle

Radius (r)
Diameter (d) = 2 × r
Circumference = 2 × π × r
Area = p × r2
(p = 3.1416)

Height (h)
Sides (a, b, c)
Perimeter = a + b + c
Area = $^1/_2$ × b × h

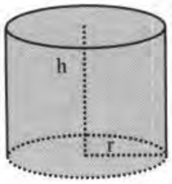


Triangle

Rectangle

Sides (a, b)
Perimeter = 2 × (a + b)
Area = a × b

Height (h)
Radius (r)
Surface area = 2 × π × r × h
(excluding ends)
Volume = $\pi \times r^2 \times h$

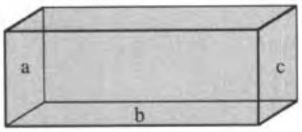


Cylinder

Cone

Height (h)
Radius (r)
Side (l)
Surface area = π × r × l
(excluding base)
Volume = $^1/_3$ × π × r2 × l

Sides (a, b, c)
Surface area = 2 × (a × b + b × c + a × c)
Volume = a × b × c



Rectangular block

Temperature Scales

Fahrenheit (F): under standard conditions, water boils at 212°F and freezes at 32°F.
Centigrade or **Celsius (C)**: water boils at 100°C and freezes at 0°C.
Kelvin (K): water boils at 373.15K and freezes at 273.15K.

To convert from Celsius (C) to Fahrenheit (F):	F = (C × 9 / 5) + 32
To convert from Fahrenheit (F) to Celsius (C):	C = (F − 32) × 5 / 9
To convert from Celsius (C) to Kelvin (K):	K = C + 273
To convert from Kelvin (K) to Celsius (C):	C = K − 273

Fahrenheit (°F)	Celsius/Centigrade (°C)	Kelvin (K)
−4	−20	253
14	−10	263
32	0	273
50	10	283
68	20	293
86	30	303
104	40	313
122	50	323
140	60	333
158	70	343
176	80	353
194	90	363
212	100	373

SI Units

Base units		
amount of substance	mole	mol
electric current	ampere	A
length	meter	m
luminous intensity	candela	Cd
mass	kilogram	kg
temperature	kelvin	K
time	second	s
Supplementary units		
plane angle	radian	rad
solid angle	steradian	sr
Derived units with special names		
electric capacitance	farad	F
electric change	coulomb	C
electric conductance	siemens	S
electric resistance	ohm	O
electromotive force	volt	V
energy	joule	J
force	newton	N
frequency	hertz	Hz
illumination	lux	lx
inductance	henry	H
luminous flux	lumen	lm
magnetic flux	weber	Wb
magnetic flux density	tesla	T
power	watt	W
pressure	pascal	Pa
Units permitted for use		
time	minute	Min
time	hour	h
time	day	d
time	year	a
area	hectare	ha
volume	liter	L or l
volume	hectoliter	hl
mass	metric ton	t

Prefixes for Units in SI System

Name	*Prefix*	*Abbreviation / symbol*	*Factor*	*Example*
Quintillion	exa	E	10^{18}	
Quadrillion	peta	P	10^{15}	
Trillion	tera	T	10^{12}	
Billion	giga	G	10^{9}	gigawatt (GW)
Million	mega	M	10^{6}	megahertz (MHz)
Thousand	kilo	k	10^{3}	
Hundred	hector	h	10^{2}	
Ten	deka	Da	10	
One tenth	deci	d	10^{-1}	
One hundredth	centi	c	10^{-2}	
One thousandth	milli	m	10^{-3}	milligram (mg)
One millionth	micro	μ	10^{-6}	microgram (μg)
One billionth	nano	n	10^{-9}	nanosecond (ns)
One trillionth	pico	p	10^{-12}	picofarad (pf)
One quadrillionth	femto	f	10^{-15}	
One quintillionth	atto	a	10^{-18}	

Some fundamental physical constants

Constants	**Symbol**	**Value**
Speed of light in vacuum	c	3×10^{8}
Gravitational constant	G	6.63×10^{-11} Js
Planck's constant	h	6.63×10^{-34}
Universal gas constant	R	8.31 J/ mol K
Boltzman constant	k	1.38×10^{-23} J/K
Stefan - Boltzman constant	o	5.67×10^{-8} W/m^{2} K^{4}
Avogadro's number	NA	6.02×10^{23} mol^{-1}
Faraday constant	F	9.65×10^{4} C/mol
Solar constant	S	1.38 kW/m^{2}
Bohr radius	ao	5.29×10^{-11} m

The Greek Alphabet and Roman Numbers

The Greek alphabet

Name	Capital	Lower case
alpha	A	α
beta	B	ß
gamma	Γ	γ
delta	Δ	δ
epsilon	E	ε
zeta	Z	ζ
eta	H	η
theta	Θ	θ
iota	I	ι
kappa	K	κ
lambda	Λ	λ
mu	M	μ
nu	N	ν
xi	Ξ	ξ
omicron	O	ο
pi	Π	π
rho	P	ρ
sigma	Σ	σ
tau	T	τ
upsilon	Y	υ
phi	Φ	φ
chi	X	χ
psi	Ψ	ψ
omega	Ω	ω

Arabic and Roman numerical

1	I
2	II
3	III
4	IV
5	V
6	VI
7	VII
8	VIII
9	IX
10	X
11	XI
12	XII
13	XIII
14	XIV
15	XV
16	XVI
17	XVII
18	XVIII
19	XIX
20	XX
21	XXI
30	XXX
40	XL
49	XLIX
50	L
60	LX
70	LXX
80	LXXX
90	XC
99	XCIX
100	C
101	CI
144	CXLIV
200	CC
400	CD or CCCC
500	D
900	CM or DCCCC
1000	M
1900	MCM or MDCCCC
1995	MCMXCV
1999	MCMXCIX
2000	MM

Conversion Factors

(for nutrient concentration in fertilizers)

S.N.	Fertilizer / Nutrient	Multiplication factor	Nutrient / Fertilizer
	A (amount of fertilizer or nutrient)	B (multiply by)	A x B (to get amount of fertilizer or nutrient)
1	Ammonia	0.823	Nitrogen (N)
2	Ammonium nitrate	0.350	Nitrogen (N)
3	Calcium	3.397	Calcium sulphate ($CaSO_4$)
4	Calcium	2.794	Calcium chloride ($CaCl_2$)
5	Calcium carbonate	0.560	Calcium oxide (CaO)
6	Calcium chloride	0.358	Calcium (Ca)
7	Calcium oxide	1.785	Calcium carbonate ($CaCO_3$)
8	Calcium phosphate	0.458	Phosphorus pentoxide (P_2O_5)
9	Calcium sulphate	0.294	Calcium (Ca)
10	Copper	2.759	Copper sulphate monohydrate ($CuSO_4.H_2O$)
11	Copper sulphate monohydrate	0.358	Copper (Cu)
12	Diammonium sulphate	0.212	Nitrogen (N)
13	Diammonium sulphate	0.243	Sulphur (S)
14	Iron	2.720	Iron sulphate ($FeSO_4$)
15	Iron sulphate	0.368	Iron (Fe)
16	Magnesium carbonate	0.478	Magnesium oxide (MgO)
17	Magnesium oxide	2.092	Magnesium carbonate ($MgCO_3$)
18	Magnesium oxide	2.987	Magnesium sulphate ($MgSO_4$)
19	Magnesium oxide	3.434	Magnesium sulphate monohydrate ($MgSO_4.H_2O$)
20	Magnesium oxide	6.116	Magnesium sulphate heptahydrate ($MgSO_4.7H_2O$)
21	Magnesium sulphate	0.266	Sulphur (S)
22	Magnesium sulphate	0.335	Magnesium oxide (MgO)
23	Magnesium sulphate heptahydrate	0.130	Sulphur (S)
24	Magnesium sulphate heptahydrate	0.164	Magnesium oxide (MgO)
25	Magnesium sulphate monohydrate	0.232	Sulphur (S)
26	Magnesium sulphate monohydrate	0.291	Magnesium oxide (MgO)
27	Manganese	1.582	Manganous oxide (MnO)
28	Manganous oxide	0.632	Manganese (Mn)
29	Nitrate	0.226	Nitrogen (N)
30	Nitrogen	2.857	Ammonium nitrate (NH_4NO_3)
31	Nitrogen	4.716	Diammonium sulphate [$(NH_4)_2SO_4$]
32	Nitrogen	2.143	Urea [$CO(NH_2)_2$]
33	Nitrogen	1.216	Ammonia (NH_3)
34	Nitrogen	4.426	Nitrate (NO_3)
35	Phosphorus	2.292	Phosporus pentoxide (P_2O_5)
36	Phosphorus pentoxide	0.436	Phosphorus (P)
37	Phosphorus pentoxide	2.185	Calcium phosphate [$Ca_3(PO_4)_2$]
38	Potassium	1.907	Potassium chloride (KCl)
39	Potassium	1.205	Potassium oxide (K_2O)
40	Potassium chloride	0.632	Potassium oxide (K_2O)
41	Potassium chloride	0.524	Potassium (K)
42	Potassium oxide	0.830	Potassium (K)
43	Potassium oxide	1.583	Potassium Chloride (KCl)
44	Sulphur	4.121	Diammonium sulphate [$(NH_4)_2SO_4$]
45	Sulphur	3.754	Magnesium sulphate ($MgSO_4$)
46	Sulphur	4.316	Magnesium sulphate monohydrate ($MgSO_4.H_2O$)
47	Sulphur	7.688	Magnesium sulphate heptahydrate ($MgSO_4.7H_2O$)
48	Urea	0.467	Nitrogen (N)
49	Zinc	4.398	Zinc sulphate heptahydrate ($ZnSO_4.7H_2O$)
50	Zinc	2.745	Zinc sulphate monohydrate ($ZnSO_4.H_2O$)
51	Zinc sulphate heptahydrate	0.227	Zinc (Zn
52	Zinc sulphate monohydrate	0.364	Zinc (Zn)

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