Scientific Greenhouse Gardening

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EP PUBLISHING LIMITED

ISBN 0 7158 0663 7

First edition 1982

Published by EP Publishing Limited, Bradford Road, East Ardsley, Wakefield, West Yorkshire, WF3 2JN, England

Printed and bound in Great Britain by Butler & Tanner Ltd, Frome, Somerset

Design: Krystyna Hewitt

Illustrations: Tony Gardiner

Photographs
ADAS, Ministry of Agriculture, Fisheries and Food/Crown copyright: pp. 29, 30, 119, 120
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Halls Homes and Gardens Ltd., Tonbridge: p. 25
Douglas Hewitt: cover
ICI Ltd., Plant Protection Division: pp. 57, 58, 61
Pershore College of Horticulture: pp. 189, 190
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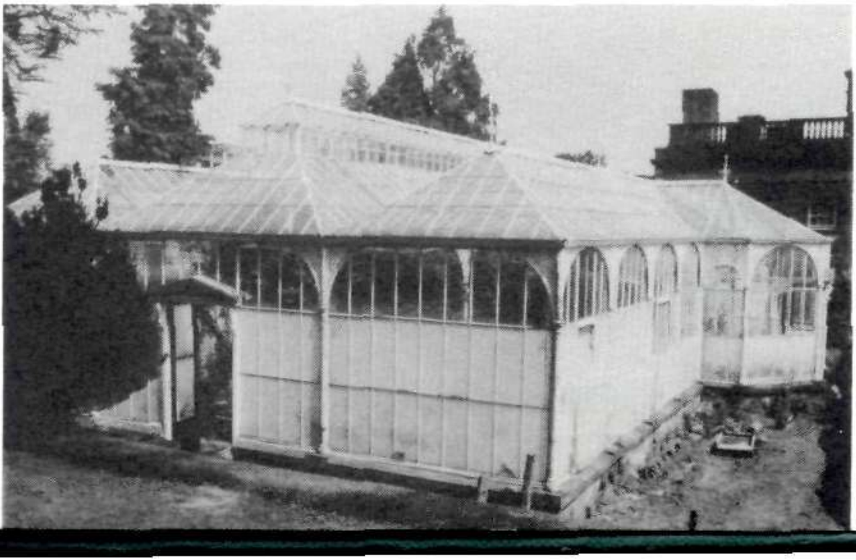
Chapter 1

Introduction

Greenhouses became an essential part of the garden from the latter part of the eighteenth century onwards. Such structures had long been in the minds of gardeners but their development had had to await the invention and production of cheap sheet glass. This in its turn had to wait upon the industrial revolution and the development of the necessary techniques.

Readers of Jane Austen's *Northanger Abbey* will recall General Tilney, with great pride, showing young Catherine Moreland his greenhouses. Jane Austen was writing this novel in about 1800, clearly showing that in the gardens of the great houses of that time greenhouses were well established. By the middle of the last century they were very much a status symbol among the gentry, and there was competition to see who could own the biggest. The prize probably went to the Duke of Devonshire whose head gardener, Joseph Paxton, built the famous glasshouse at Chatsworth, a project of such success that he went on to design and supervise the erection of the Crystal Palace in Hyde Park for the Great Exhibition of 1851.

The designs worked out in the early days changed little until the 1950s. Houses, some 8.5–9 m (*28–30 ft*) wide with eaves at 1.5 m (*5 ft*) and a span roof with a ridge at 4.0–4.3 m (*13 or 14 ft*), were developed for growing vines, and were later found equally suitable for tomatoes. Half a vinery was often erected against a wall to form a lean-to house, very popular against the walls of kitchen gardens. Smaller houses, some 4–4.3 m (*13 or 14 ft*) wide and 2.5–3 m (*8 or 9 ft*) to the ridge, also proved extremely useful for a whole variety of purposes. Market gardeners found them especially useful for cucumbers, and although commercial gardeners had used them before that time for producing pot plants of the kind favoured by the Victorians, they became known as cucumber houses. Greenhouses with very low walls were sometimes constructed over excavations and were



The exterior of the Victorian Winter Garden at Wentworth Castle in South Yorkshire. Note the glazed ridge capable of accommodating quite tall palms or other trees.

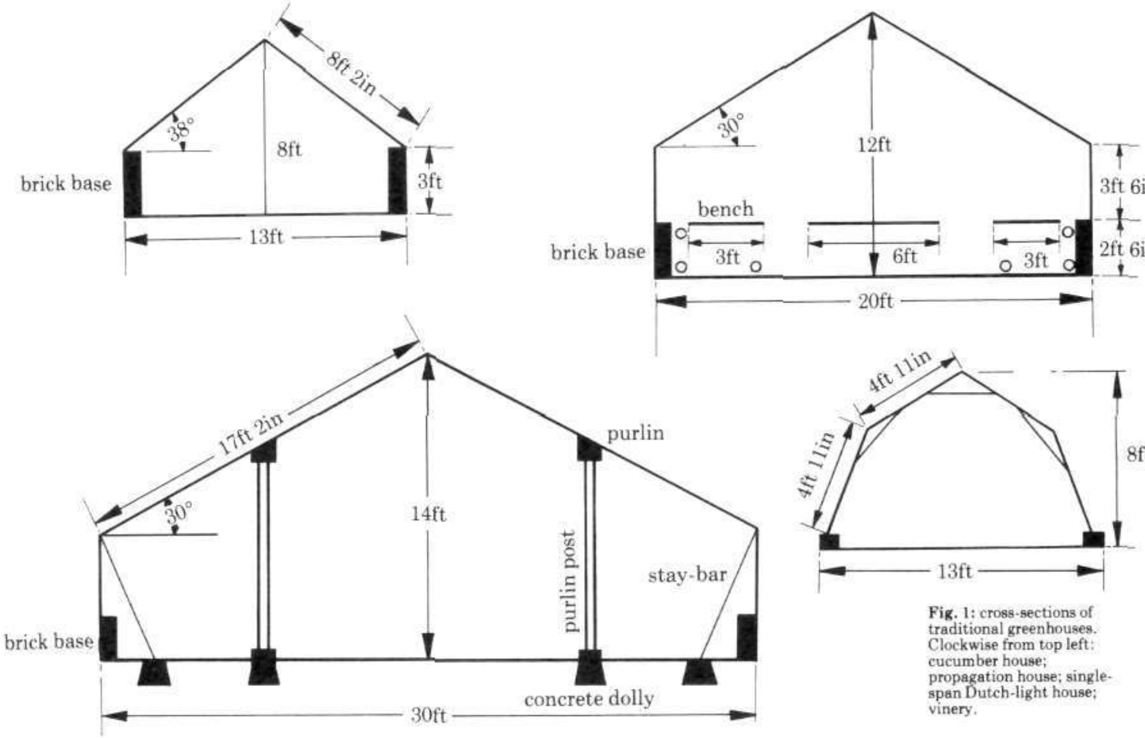


Fig. 1: cross-sections of traditional greenhouses. Clockwise from top left: cucumber house; propagation house; single-span Dutch-light house; vinery.

known as pits. This clumsy arrangement, now extinct, was largely a method of trying to conserve heat before central heating had been invented by a later generation of greenhouse growers. Another totally obsolete idea was that of a glass frame of sufficient size leaned against a wall to forward the growth of a peach or nectarine trained underneath. This was a peach case, which featured quite often in garden literature written before the Second World War.

Once reliable heating systems were available, the conservatory became a necessary addition to the gentleman's garden. Here were displayed flowering plants which a host could show off to his guests throughout the year. Most grand of all was the Winter Garden, a greenhouse of very generous proportions where a whole variety of temperate plants could be permanently planted safe from the frost. Sometimes it adjoined the dwelling itself so a stroll in a tiny simulated Mediterranean world was a pleasant alternative to one in the garden outside when the weather was too cold.

The age of the great garden has probably gone for ever, and with it its variety of glasshouses. The pineapple pit, the stove (an early name for a tropical house), the orchid house, the cool vinery, the heated vinery, the peach case, the conservatory and all the rest have passed into history. But the fascination of growing plants under glass remains, and is being enjoyed by amateur gardeners all over the country more and more.

So popular has the small greenhouse become, and so eager for knowledge its owner, that an attempt is made in the following pages to explain as straightforwardly as possible the management of a small greenhouse and the methods of growing the widest possible range of plants, both edible and decorative.

Chapter 2

The greenhouse microclimate

When a greenhouse is constructed, the space inside constitutes a special environment possessing its own miniature climate, known as the greenhouse microclimate. The properties of this microclimate are somewhat different from those of the general climate outside.

Temperature and humidity

The first of these differences is that the temperature within the greenhouse is always higher than that of the air outside. When the sun is shining brightly the difference may be very great indeed, but on clear winter nights it can be as little as 2 or 3 C° (centigrade degrees) (*3–5 F°*), still a little warmer. The explanation for this is that heat enters the greenhouse by means of radiation from the sun and leaves it by means of radiation from the ground which it covers. The radiant heat from the sun is of short wavelengths and passes readily through glass, while that from the earth is of longer wavelengths and passes much less readily through glass. There is, therefore, a net gain due to the fact that glass behaves rather like a non-return valve for radiant heat. This is called the 'greenhouse effect' and is a well-known phenomenon in buildings with large windows and in closed motor cars. The need to remove excess heat from greenhouses during periods of bright sunshine led, at a very early stage in their development, to the inclusion of ventilators in their construction.

An obvious difference between the greenhouse microclimate and the general climate is that no rain falls on the soil it covers. If this soil is used for growing plants serious consequences can arise if it is not irrigated by approximately the same amount of water it would have received naturally as rain.

The relative humidity of the air within the greenhouse is usually higher than outside it and this, coupled with its stillness when the vents are closed, provides conditions very favourable for the germination and rapid development of the spores of the fungi causing mildews and rots. Exerting some control over relative humidity (R.H.) is yet another task forced upon the gardener if he is to manage his greenhouse successfully.

Light transmission

Another way in which the microclimate is different is in respect of light. By no means all of the light coming from the sun is able to penetrate into the greenhouse, and so it is always darker within the house than outside it. In summer, provided it is not shaded by trees or buildings, there is light in abundance and sufficient enters the house to provide for all the needs of the plants.

During the winter there is insufficient natural light for plants to grow in the open, let alone under glass, so it is obvious that everything possible must be done to allow the maximum amount of light to enter the greenhouse.

It would be quite simple, albeit expensive, to provide sufficient heat within a greenhouse during the winter months to make it warm enough for tomatoes, but while they might survive they would certainly not grow satisfactorily, neither would they set and provide ripened fruit. This would be entirely due to insufficient light energy reaching their leaves to enable them to photosynthesise, the process by which plants manufacture sugars and starches which they use for growth and energy production.

If a greenhouse is to be used only from mid-April to mid-October the light problem is greatly reduced. But if it is heated and to be used in the winter months the problem is acute. There are five factors which control light transmission into the house: the shade cast by buildings and trees; the shade cast by opaque parts of the greenhouse such as glazing bars; the design of the house; its orientation; and last but by no means least, the cleanness of the glass.

It is a matter of common sense that the greenhouse should have an unobstructed view of the southern sky and also the southern halves of the eastern and western ones. While this may be common sense, it may be almost impossible to achieve in some gardens. Hedges, trees, fences and neighbouring houses cannot be removed and may affect the decision whether or not to have a greenhouse, or at least whether to heat it. For eight weeks either side of Christmas the mean height of the sun above the horizon is about 12 degrees at 52° latitude (southern England). Before buying a greenhouse, then, stand where you intend to put it and take a look to the south, trying to estimate what angle of elevation you need to get a clear view of the sky. If it exceeds 12 degrees most of the winter sunshine will be lost, and heating in winter would be a doubtful proposition. If it exceeds 25 degrees all the winter sunshine will be lost and unless you intend to grow ferns or other shade-tolerant plants heating would be folly. If it exceeds about 40 degrees the greenhouse will be at a permanent

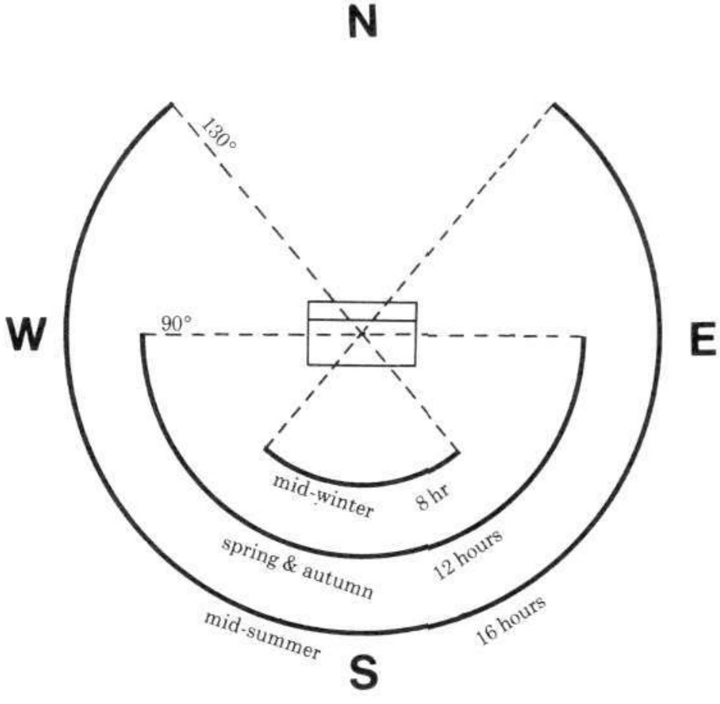


Fig. 2: the traverse of the sun relative to the southern horizon throughout the year. (After Lawrence, 1948.)

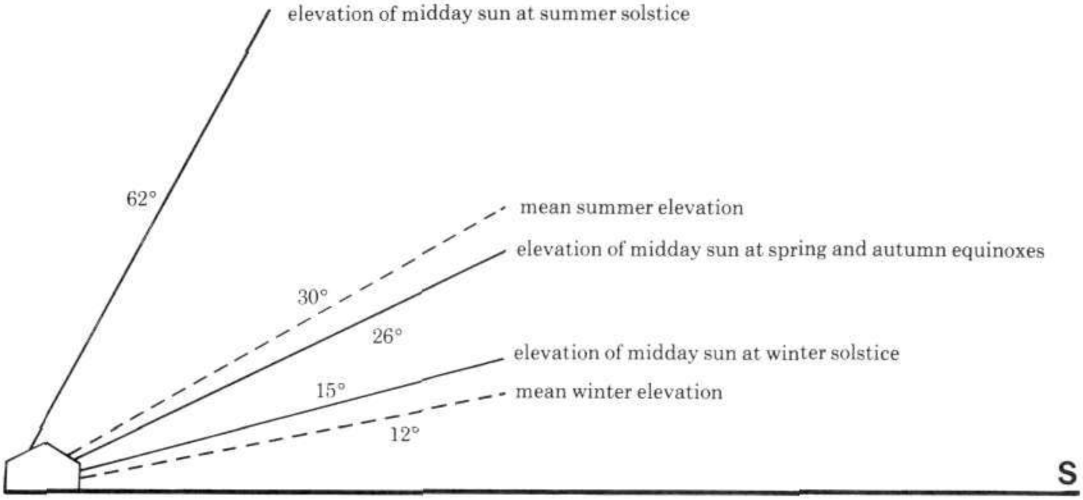


Fig. 3: the elevation of the sun in the four seasons (latitude 52°).

disadvantage even in midsummer, and not really worthwhile if frustration and disappointment are to be avoided.

The shadows cast by the opaque parts of the greenhouse structure cannot be avoided, but a considerable amount of effort has gone into designs which reduce them to the minimum. It all boils down to using the largest sheet of glass together with the smallest size of glazing bar and other structural parts consistent with strength and safety. The smallest sheet of glass acceptable today is one measuring 600 × 600 mm (*2 ft × 2 ft*). Best is the sheet of glass used for a Dutch light which measures 1423 × 731 mm (*56 × 28¾ in*), but unless this is supported on all four sides by a glazing bar, the glass needs to be of very heavy gauge. This combination of large size of glass with a small size of bar is now achieved by building the house with metal, using glazing strips which are made of aluminium alloy (which never requires painting). If the house exceeds a certain size the most successful arrangement is to have a framework of zinc-galvanised steel

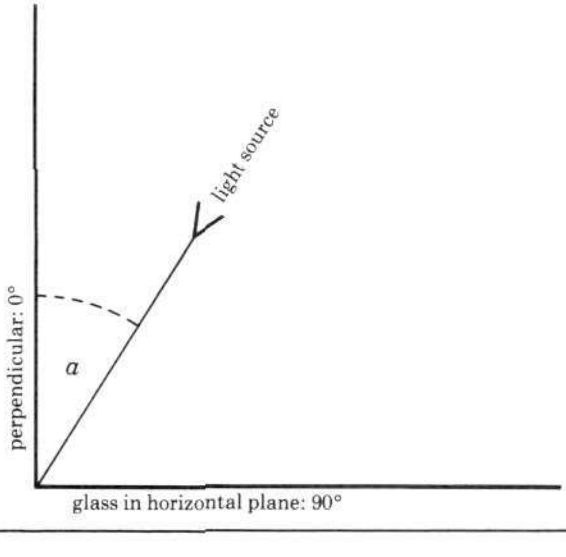


Fig. 4: the angle of incidence (*a*) of a light-ray on a sheet of glass.

with aluminium-alloy cladding. Few garden greenhouses, however, exceed the size where they cannot be made entirely of glass and aluminium alloy.

The design, insofar as its shape is concerned, has a direct bearing upon light transmission because it determines the angle at which rays of light from the sun strike the glass. This angle is known as the angle of incidence (see Fig. 4) and it can vary from 0° to 90°. If the light strikes the glass at 0°, that is to say perpendicularly, then 90 per cent of it will pass through the glass. There is no appreciable loss of light transmission until the angle of incidence exceeds 40° after which it drops very rapidly to a point where more light is reflected back than passes through (see Fig. 5). The importance of having the smallest possible angle of incidence between glass and sunbeam is easy enough to understand, but it must be considered along with the fourth factor, which is the orientation of the greenhouse.

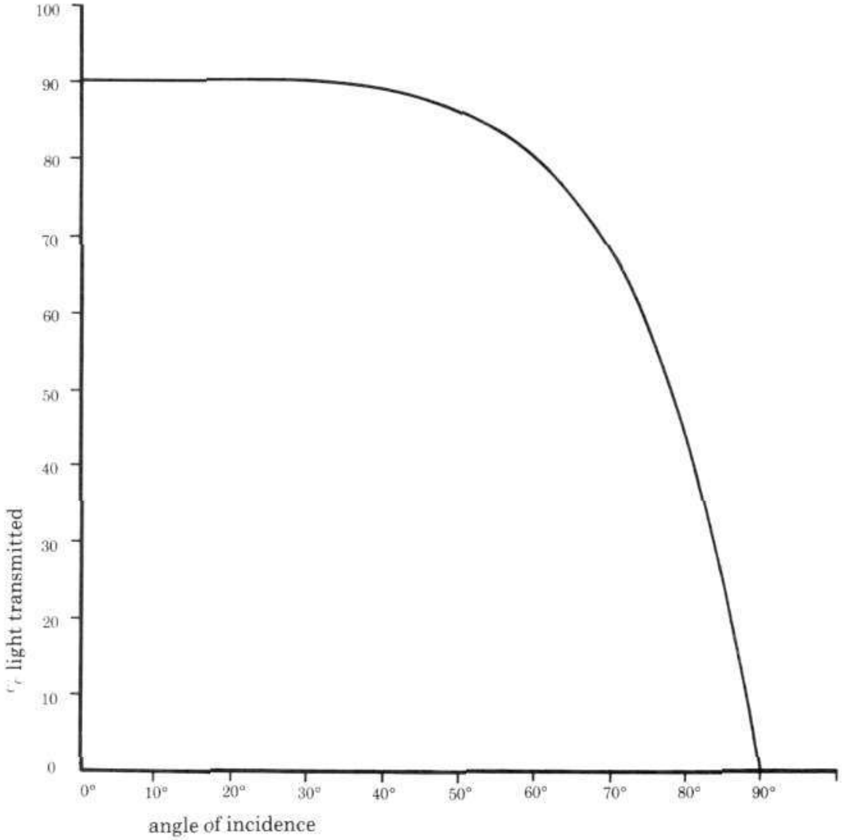


Fig. 5: the percentage of light transmitted through a pane of glass as a function of the angle of incidence. Most of the light not transmitted is reflected off. (After Lawrence, 1948.)

Orientation

Traditionally greenhouses were orientated north–south on the correct assumption that each side of the greenhouse would receive an equal amount of sunshine during the course of a day provided that the weather stayed more or less the same. Unfortunately it means that in the winter each side gets a more or less equal share of very little. This is because the mean angle of incidence will be 78°, when less than 50 per cent of the incident (direct) light will get through the glass. Things are much worse than this, however, because the lower the angle of the sun the greater is the

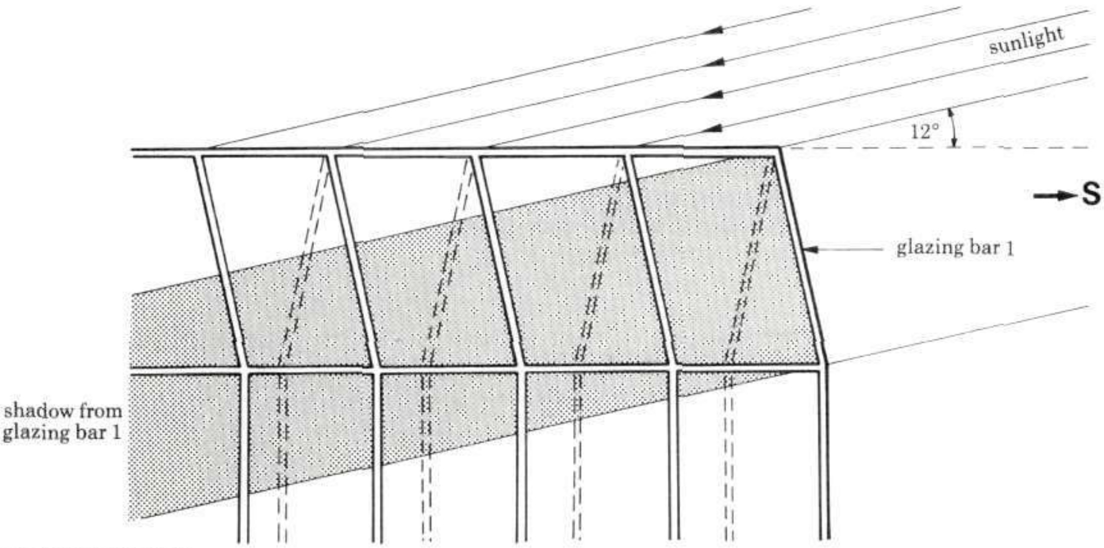
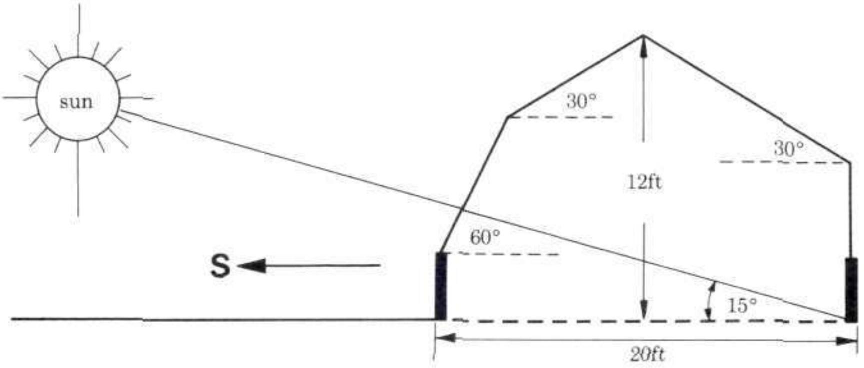


Fig. 6: the shadow cast by wooden glazing bars in winter in a house oriented north-south. The lower the elevation of the sun, the greater the shade.
The shading effect can be greatly reduced by orienting the house east-west, or by using smaller aluminium glazing bars.

shadow cast by the glazing bars (see Fig 6).

Our attention was first drawn to these facts by one of this century's *greatest gardeners, Mr W. J. C. Lawrence, when he was the Head of the* Garden Department at the John Innes Horticultural Institution at Merton, England. (Incidentally he, with his colleague J. C. Newall, devised the John Innes Composts; see page 32.) Lawrence became convinced that it was far more sensible to orientate greenhouses east–west. He was able to show that a greenhouse so orientated transmitted at least 27 per cent more of the winter light. He was by no means satisfied with this and went on to prove that by having a greenhouse with an uneven span (see Fig. 7) the light transmission could be increased by 63 per cent. In spite of his great enthusiasm the uneven span houses never really caught on, because it was found to be easier to construct houses with higher eaves (see Fig. 9), and get almost the same advantage. Orientation east–west, on the other hand, is now universally accepted wherever it is possible and is considered essential for propagating houses. The cautionary words 'wherever possible' are put in because the commercial grower who has

Fig. 7: this uneven-span greenhouse allows the best transmission of winter sunlight, but is much more expensive than houses of conventional design.



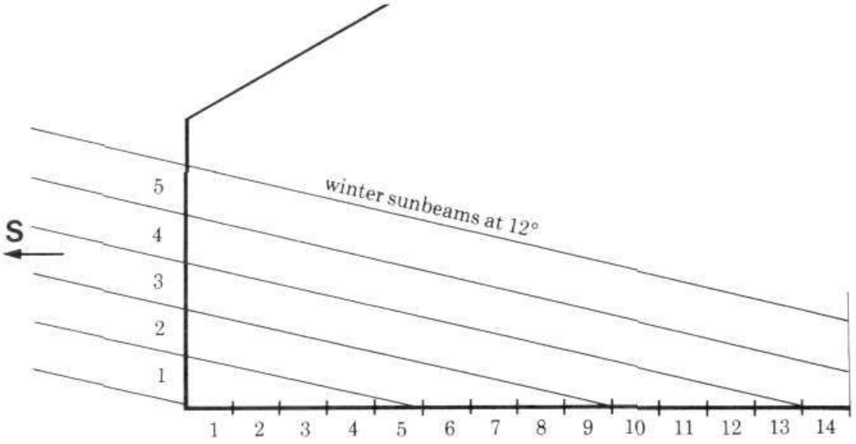


Fig. 8: winter light transmission through the south wall of an east-west oriented greenhouse. For every 4½ units of width the south wall should be one unit high in order to make best use of the winter sunshine.

several greenhouses faces a considerable problem. If he orientates his houses east–west the most southerly house will shade the one behind it and this in its turn, the next one, and so on. This dilemma can only be avoided by placing the houses sufficiently far apart to avoid mutual shading. This, unfortunately, is greedy of expensive land and increases heating costs, both installation and running costs. This kind of difficulty does not really concern the amateur who is rarely in a situation where he cannot orientate his greenhouse east–west.

If you wish to have two greenhouses and do not have sufficient room in the garden to site them so that no mutual shading occurs, then you are best advised to orientate them north–south as an adjacent pair.

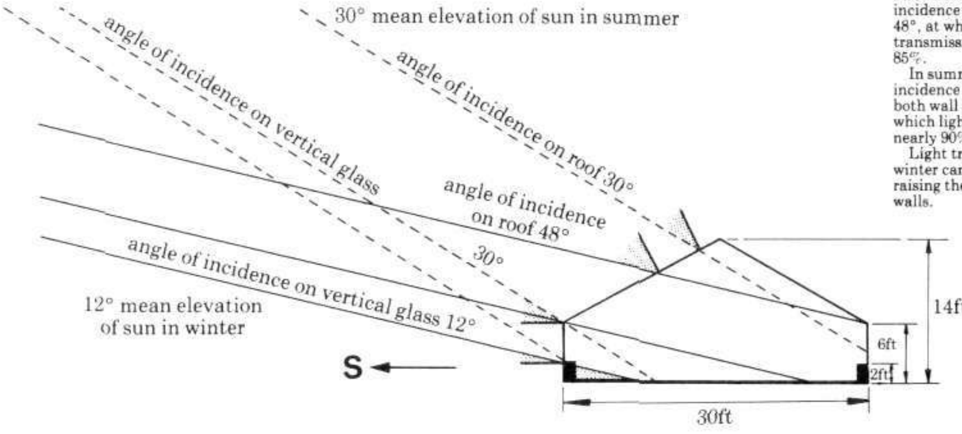


Fig. 9: sunlight falling on a vinery-style greenhouse oriented east-west.

In winter the angle of incidence on the vertical south wall is 12°, at which light transmision is nearly 90%. But the angle of incidence on the 30° roof is 48°, at which light transmission is reduced to 85%.

In summer the angle of incidence is about 30° on both wall and roof, at which light transmission is nearly 90%.

Light transmission in winter can be improved by raising the height of the walls.

Dirty glass

If the best possible greenhouse has been bought and orientated east–west with an unobstructed view of the southern sky, all the gains can be brought to nothing if the glass is allowed to become dirty. In urban areas, in spite of smoke abatement measures, glass will have become sufficiently dirty within about six weeks for 10 per cent of the available light to be lost, and in twice this length of time the loss could have reached 20 per cent.

It all starts with dust settling on the glass. This happens very quickly and after a few days it starts to bond together onto the glass to form a skin which requires the physical effort of wet brushing to remove it. In urban areas, effluent from chimney and car exhausts adds to the dust an oily ingredient (like traffic film) making the deposit even more difficult to shift. In the country the problem is by no means absent. The dust settles just the same and very soon forms a surface on which algae can take hold to form a green film, and where the glass abuts to the glazing bar and water lingers even moss will start to appear. This 'country dirt' is just as opaque as 'town dirt' and as difficult to shift. The only cure, albeit a temporary one, is to scrub the glass clean with a stiff brush or broom. (Detergent may be needed for town dirt.) Prevention is by far the best answer, and can be achieved by frequent hosing down of the glass before the dust has had time to stick firmly to it.

Keeping the inside of the greenhouse clean is less important for light transmission, but is a task that will be done regularly by the conscientious gardener.

Diffused and direct light

The 'doubting Thomases' may well say that their greenhouse is obstructed to the south and the glass is not all that clean, yet there is still plenty of light in it. This is perfectly true because they are talking about diffused or reflected light which comes in through the glass from all parts of the sky. It has never been possible to say precisely to what extent diffused light assists the plants to grow. It certainly does not give the leaves anything like the same amount of light energy as direct light, as can readily be demonstrated by bringing a plant from where it can receive direct unimpeded light into a well-lit room in a house, and watching its deterioration. All the evidence we have confirms beyond doubt that it is direct sunshine which is all-important in making plants grow, and the greenhouse gardener who grows plants under glass must make this the first article of his faith.

Chapter 3

Types of small greenhouse

Timber

Greenhouses were traditionally constructed from selected well-seasoned softwood. This was cheap, plentiful and readily machined to give lengths of timber with variable cross-sectional shapes (see Fig. 10). Two kinds of timber proved themselves superior for the purpose: the first, Baltic Redwood, is the wood of the Scots Pine (*Pinus sylvestris*), but comes from continental Europe; and the second, British Columbian pine (*Pseudotsuga taxifolia*), comes from Canada.

Baltic Redwood is of even grain, easily nailed without splitting and with good strength-to-weight ratio, enabling load-bearing members to have relatively small cross-sectional areas. British Columbian pine has the disadvantages that it splits easily when nailed, has a lifting grain when planed and does not readily absorb preservatives, but its great advantage is that it can be obtained in long straight-grained lengths. A common joinery timber that should be avoided because it has a very low durability is deal or whitewood, the timber of Norway Spruce (*Picea abies*).

Timber is now very expensive, but its main drawback is that being an organic material it will rot, or in modern jargon is biodegradable, unless carefully preserved and protected. Wood for greenhouses is usually protected by means of painting. The first coat, or primer, is of a paint made of linseed oil and white lead which is well worked into all surfaces and joints. It is the most important coat and provides a seal round the timber to protect it both from rot-causing fungi and from absorbing water. After the primer, an undercoat is applied to provide the correct colour base for the topcoat. In the case of greenhouses the topcoat will be white in order to give maximum reflection of light, but even so it is usual to tint the undercoat slightly so that any areas missed when applying the topcoat will readily show, and enable an even cover to be obtained. Many modern priming paints are not lead-based but they appear to be equally or even

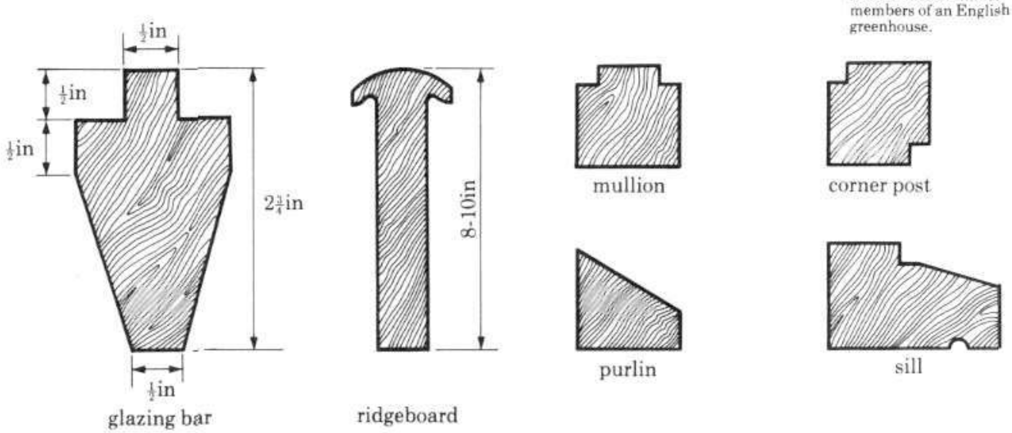


Fig. 10 cross-sections of some common timber members of an English greenhouse.

more satisfactory. Topcoats have a gloss finish which makes them water-repellent.

Paints are themselves biodegradable, and after three or four years they crack and flake and so need rubbing down and repainting to protect the priming underneath. Paint is only effective so long as it provides a seal and failure to maintain this quickly leads to deterioration of the wood.

To guard against the shortcomings of paint it is highly desirable that softwood is given preservative treatment before painting commences. The amateur is restricted to brushing or spraying wood with a copper-based preservative. This must be applied liberally, particularly to the ends of all pieces before they are erected. When the preservative is dry the painting can begin. However, it is possible to purchase worked timber impregnated with fungicidal and insecticidal preservatives. Such wood is described as having been 'pressure-treated'. It has a very long life particularly if subsequently painted. If pressure-treated timber is sawn the ends must be dipped in a copper preservative.

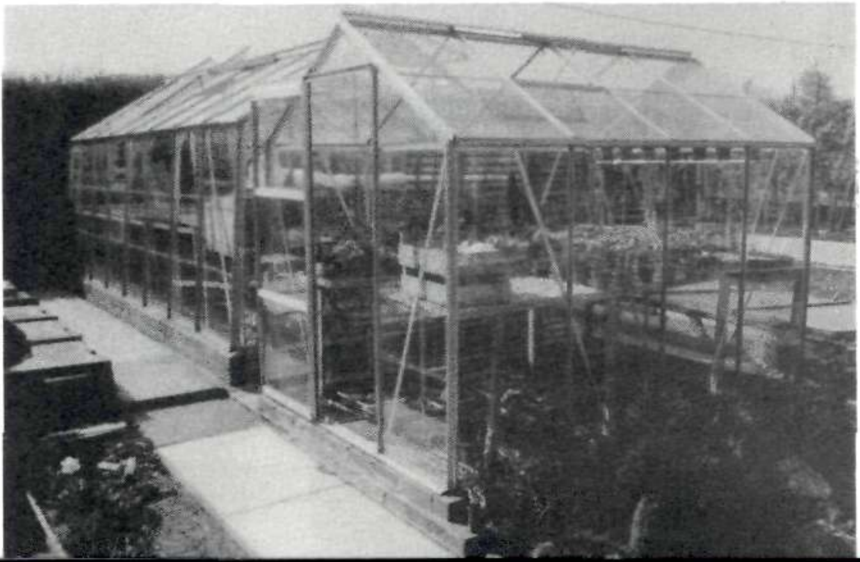
Western Red Cedar *(Thuja plicata),* although now expensive, is popular for small greenhouses. It is known as cedarwood, is of attractive appearance and does not need painting or preserving. It is a weak timber and consequently unsuitable for large houses. It splits easily and as it will remain unpainted only non-corrosive nails or screws should be used. The same applies to teak except that its cost is such that its use is virtually extinct.

Styles of greenhouse

There are two styles of modern greenhouse: the first is often described as an English greenhouse, and the second is known as a Dutch light house.

The English greenhouse usually stands on low brick walls, its woodwork is painted white and glazed with overlapping sheets of glass set in putty and secured with sprigs. Provided it has sheets of glass 600 × 600 mm *(2 ft × 2 ft)* it has much to commend it, except the disadvantage of having to paint it inside and out every third year.

Aluminium-alloy greenhouses are constructed in the style of the English greenhouse. Their advantage of high light transmission has already been stressed but the fact that they do not require any painting makes them highly attractive. The overlapping sheets of glass usually rest on plastic cushions and are secured by stainless-steel clips or metal clamping strips. They are mass-produced and are, therefore, highly competitive in price.



Two all-metal English-style greenhouses in an amateur's garden. These are full of plants, all arranged in a tidy fashion, and the whole is scrupulously clean in the interests of good hygiene.

The second style is the Dutch light house which is of less pleasing appearance. It is usually assembled from prefabricated frames of pressure-treated timber glazed with sheets of Dutch light glass and all supplied as a kit. Precast concrete slabs are usually included and form the base on which the house stands. The sheets of glass slide into the wooden frames and are secured by wooden cleats, nailed onto the frame with galvanised nails. Putty is not required. Dutch light houses are very serviceable. The pressure-treated timber never requires painting and has a known life of thirty years. Also it is a relatively simple matter to take the house to pieces and re-assemble it on another site if the need arises.

There are then three choices: English greenhouses, pleasing in appearance, but which must be painted both inside and out at regular and frequent intervals; Dutch light houses with the advantages of relative cheapness, low maintenance and excellent light transmission; aluminium alloy houses, easily cleaned with virtually no maintenance and good light transmission. The latter two have really superseded the first, but the choice between them to some extent depends upon the purpose to which the house is to be put; the Dutch light type is highly suitable for tomatoes, cucumbers and lettuce grown as unheated crops, and the aluminium-alloy house comes into its own if it is to be heated or if it is intended to provide it with staging for plants in containers.

Both Dutch light and metal houses can be obtained in the so-called 'Gazebo style' (Fig. 11) which is very useful for small gardens where space is at a premium. A domed house in the metal range is of geodetic design and is again especially useful for small areas.

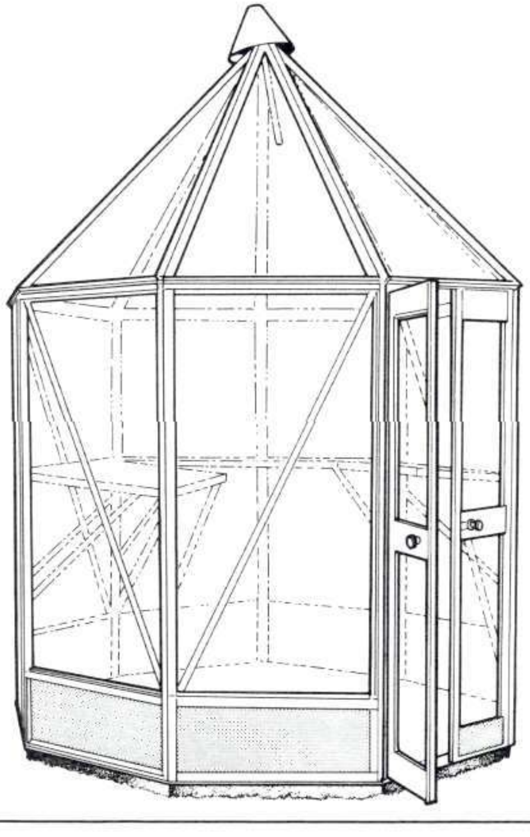


Fig. 11: gazebo-style greenhouse.

It is impossible to give prices for the different types of greenhouse because of the effects of inflation, quality differences between manufacturers and the increasing costs per unit area the smaller the house becomes. Some guidance may come from some rather generalised statistics which have averaged the list prices of small greenhouses and presented them on a percentage basis.

If the cost per square metre of a Dutch light house is taken as 100 per cent, then the comparisons are as follows:

Dutch light house	100%
Traditional English (softwood)	107%
Traditional English (Western Red Cedar)	112%
Aluminium alloy	93%

These figures exclude delivery, site work, erection, painting and glazing. When these are taken into account the disparity between the traditional English types and the others is increased.

The round, tower or gazebo style of greenhouse which has excellent properties of light transmission and can be accommodated in a very small area.

Chapter 4

Plastic structures

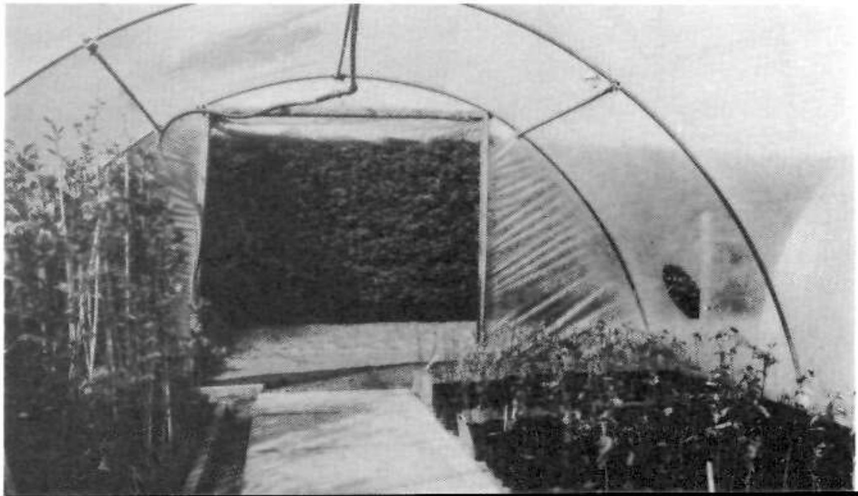
Plastic film is often described as a glass-substitute and to some extent this is true, although enthusiasts prefer to think of it as a substance in its own right commanding its own disciplines within horticulture.

The best known, cheapest and most widely used of all is, of course, polyethylene chloride, better known as 'polythene'. The low-density form of the material which is used in horticulture is naturally flexible, and although not biodegradable it rapidly deteriorates under the influence of ultra-violet light to become brittle and readily torn, particularly so at warmer temperatures. To delay deterioration horticultural polythene has ultra-violet-light absorbers added to it during manufacture. The fact that it then no longer allows ultra-violet light to be transmitted through it is of no consequence as in this respect it is comparable with glass. Another of its advantages is that it remains flexible over the range of temperatures which occur in temperate countries (middle latitude climate).

It transmits about 86 per cent of the visible light and so compares well with glass which transmits about 90 per cent, and also allows nearly 80 per cent of the radiant heat from the sun to pass through it. Unlike glass it allows the long-wave radiation from the earth to pass through it readily, so that on clear nights the temperatures in polythene houses drop rapidly and on occasions a lower temperature has been recorded inside the house than the air temperature outside. This fact, while it is a considerable disadvantage when it comes to frost protection, also means that the greenhouse effect is reduced so that 'poly-houses' do not get as hot as glasshouses in bright sunshine and thus can manage with less ventilation.

Finally polythene has the special properties of being permeable to oxygen and carbon dioxide and almost impermeable to water. It is these qualities which make it such a useful material for covering seed trays, sealing grafts, air layers and beds or boxes of cuttings.

Polyvinyl chloride (PVC) is also a well-known material. It is a rigid



The interior of a walk-in polythene tunnel, which in this case is being used for growing-on nursery stock but could equally well be used for the production of lettuces, tomatoes, or other food crops. The circular hole in the polythene is for ventilation.

material but can be plasticised to produce a flexible film. Like polythene it deteriorates under the influence of ultra-violet light and if used as a cladding material for plant houses has to have ultra-violet absorbers added during manufacture. It has a longer life than polythene, some claiming it to be twice as long. It transmits light marginally better but transmits radiant heat to a much lesser extent. Because of this the long-wave heat radiation from the soil it covers is largely held back thus giving much warmer conditions at night, particularly on clear nights. It is only slightly permeable to oxygen and carbon dioxide and is, therefore, of much less use to the propagator. PVC is more expensive than polythene and has not seriously rivalled it.

There are a number of other clear plastic films with interesting properties but it is beyond the scope of this book to describe them as they are still subject to trial and experiment. At the moment it seems unlikely that polythene will be superseded.

When polythene was first used as a glass substitute it was on structures of more or less orthodox greenhouse design where it performed well enough except that it was very prone to deterioration where it passed over wooden supports and could become very warm in sunshine. As time went by the small plastic cloche, or tunnel, which had achieved considerable success, was enlarged into the 'walk-in' tunnel. This was originally a semi-circle 4.3 m (*14 ft*) wide and half as high, but is now available in a variety of widths up to 9 m (*30 ft*). Such tunnels are covered with 500 or 600 gauge polythene and are available from many manufacturers.

Walk-in tunnels are used in commerce for the production of lettuces

Fig. 12: walk-in plastic tunnel.

(sometimes throughout the whole year), tomatoes, peppers and other crops, and by nurserymen both for propagation from cuttings and for raising young plants in containers. For the amateur gardener a walk-in tunnel is not without its attractions for use as an unheated structure for growing tomatoes or any plant that might otherwise be grown in a cold greenhouse. There is the attraction of the low capital cost compared with glass and the ease with which it can be erected on a fresh site in order to avoid soil problems. The possibility of heating is not ruled out but, on the other hand, it runs somewhat counter to the low-cost production concept by which tunnels are characterised. The modern tunnels can be fitted with ventilation provision, proper doors and so on. The life of the cladding does not normally exceed 18 months, and its replacement should really be regarded as an annual maintenance routine.

One interesting idea for plastic houses was the 'bubble' house, consisting of a single large sheet inflated with air by means of a pump. Several were constructed for trial purposes but proved to have shortcomings which eventually led to their abandonment. Other sophistications are double-skinned houses where a layer of air between the two skins acts as an insulator and reduces considerably the radiation and conduction losses. In some versions the two skins are kept apart by tension of the film over separators, and in some sophisticated designs by pressurised air from a pump.

The plastic house or structure is still in the developmental stage, and it is possible that further advances will be made. It is difficult, however, to see how the curvilinear tunnel with its excellent light-transmitting properties could be improved upon.

Trials are now in progress to evaluate the use of rigid plastic sheets as an alternative to glass on greenhouses of permanent and conventional construction. The cladding is fabricated in the form of panels consisting of two or three sheets of rigid plastic (polycarbonate) sealed all round their edges to provide condensation-proof and dust-proof double or triple glazing. Greenhouses so cladded have extremely good properties of heat retention when compared with those using glass, which compensates for their higher costs of construction: so their ultimate success will depend upon the lasting qualities of the plastic in respect of light and temperature.

Polythene film is available as follows:

1. 600 gauge (*150μm*) containing an ultra-violet-light inhibitor and used for tunnel houses. Sizes of sheet normally quoted are:

6.5 × 50 m	*21.3 × 164 ft*
7.5 × 50 m	*24.6 × 164 ft*
9.25 × 40 m	*30.3 × 131.2 ft*
11.25 × 40 m	*36.9 × 131.2 ft*

2. 500 gauge (*125μm*) containing an ultra-violet-light inhibitor and used for the same purposes as 600 gauge, which has now largely superseded it because of its greater strength and longer life (two years).

3. 150 gauge (*38μm*) used for a variety of purposes, e.g. covering seed containers and cuttings. It is available as clear, opaque, green and black film; one type used for greenhouse lining is treated to reduce condensation.

4. 200 gauge (*50μm*), dense black, used for blacking-out plants for day-length control.

5. Bubble polythene, a film containing air bubbles and used for lining greenhouses for fuel saving in winter.

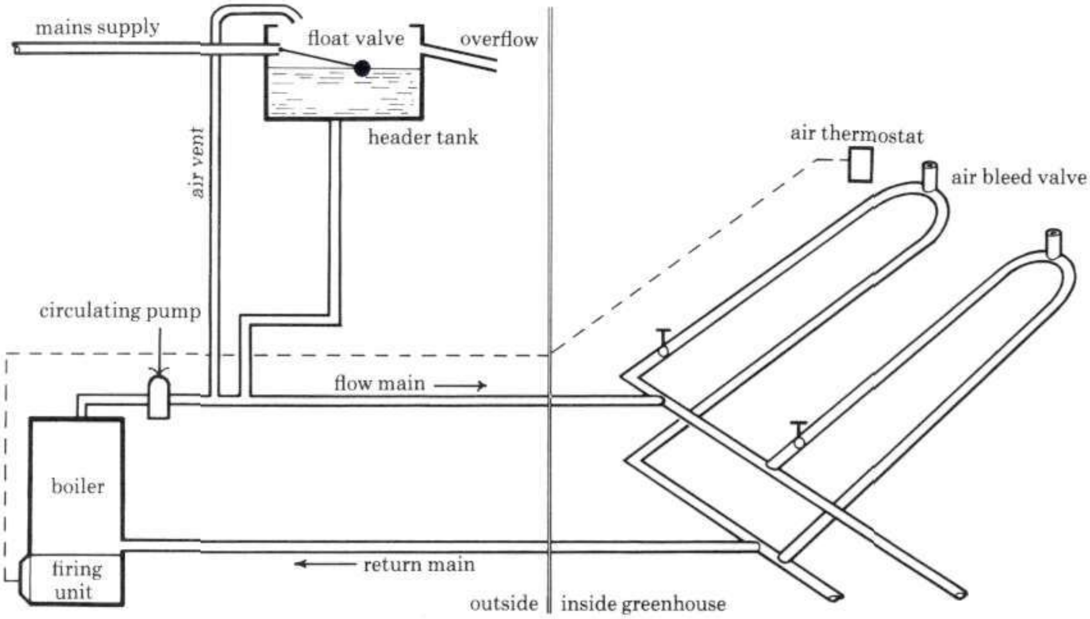
Chapter 5

Heating and ventilation

Heating greenhouses makes it possible to extend the range of plants grown as well as making their yields earlier and greater. The advantage, however, is one for which a fairly high price has to be paid. Tables in Appendix I show comparisons of estimated heating costs using different heat sources. In the United Kingdom gas is the cheapest, oil and solid fuel are more expensive and electricity has become too expensive to be considered. Oil and gas systems have advantages over solid fuel: they are more convenient to manage, and have a very rapid response to automatic controls. It is, of course, possible to heat greenhouses from an extension of a domestic central-heating system, a method which avoids the cost of a separate boiler and boiler house.

Heat can be supplied to the greenhouse in various ways. When using fossil fuels (coal, oil, gas) it is usual to burn the fuel outside the greenhouse in a furnace, known as the boiler, and to convey the heat produced, or as much of it as possible, into the house by means of hot water or steam. The heat then passes into the atmosphere of the greenhouse through the walls of the pipes which carry the water or steam. The steam will condense back into water and will be returned to the boiler, or the water will return to be re-heated.

Fig. 13: diagrammatic representation of a hot-water heating system. The height of the header tank above the boiler determines the water-pressure in the system.



The size of the pipes through which hot water circulates has a profound effect on the properties of the heating system. The 100 mm (*4 in*) diameter cast-iron pipes which were used almost universally until the 1950s give a system with what is called 'high thermal inertia'. This means that the system contains a large amount of water which takes a long time to heat and an equally long time to cool down, and is thus slow to respond to automatic control. Modern systems use small-bore pipes made of mild steel with diameters of 38 mm (*1½ in*) or less. Such systems hold a small amount of water and heat and cool rapidly, that is to say they have a low thermal inertia and are thus highly responsive to automatic control. Because of the greater viscous resistance that small pipes offer to the flow of water, an electric pump is essential to bring about the rapid circulation of the water required. Small-bore systems are usually described as high-speed hot water systems and are very similar to modern central-heating systems.

Another method is to circulate the air in the glasshouse through a heater by means of a fan. In large commercial glasshouses the air is sometimes circulated through ducts made with plastic film from which it escapes at intervals through holes along their lengths. Air heating systems, using fan electrical heaters, have been used in garden greenhouses but because of the higher cost of electricity their popularity is in decline.

An attractive alternative to heating systems which require the installation of heating pipes is that of natural-gas heaters. These stand in the centre of the greenhouse, and are chimneyless. They require no connections other than to a gas main. Pilot flames ignite the gas when the thermostat indicates that heat is required. The gas burns completely, producing carbon dioxide and water as the combustion products. The former assists the plants in efficient photosynthesis, and the water vapour increases the relative humidity. Condensation may be an inconvenient consequence when the temperature falls. There is negligible danger from phytotoxic waste products of combustion such as carbon monoxide or sulphur dioxide. Householders with gas central-heating systems who benefit from special tariff arrangements will find natural gas an attractive proposition. Before committing yourself to a direct gas-fired heater, however, you would be well advised to check that the cost of the heater is less than the cost of extending your domestic heating system into the greenhouse.

Bear in mind also that some efficiency is lost at the lower end of the greenhouse temperature range—below 10°C (*50°F*)—because of the pilot-jet gas consumption.

Various units are available with different ratings. The 3 kW (*10,000 Btu*) is the most widely supplied.

Propane heaters are worth considering in areas where natural gas is not available. The gas cylinders require to be fitted with a pressure-regulating valve. 'Bottled' gas is much more expensive than natural gas, but competitive in price compared with electricity.

Great caution must be exercised in the use of any chimneyless paraffin heater which burns inside the greenhouse, because unless the burner mechanism is such that total combustion of the fuel takes place the plants will be killed by carbon monoxide poisoning. Only the highest grade of paraffin can be used, in which the sulphur content is low enough to prevent the formation of levels of sulphur dioxide sufficient to be phytotoxic (poisonous to plants).

A direct gas-fired greenhouse heater. In such heaters combustion is complete, there are no toxic waste products, and, because the heater is inside the greenhouse and does not have a flue, the efficiency is extremely high.

Heat loss

The heat that is released into the greenhouse by the heating system is lost to the outside atmosphere by convection of the warm air through the overlaps in the glass. This loss is greatest when it is dry and windy and least when it is wet and still because then water tends to seal the gap where the sheets of glass overlap. Losses also take place by conduction of the heat through the shell of the house, a loss that is roughly proportional to the difference between the inside and outside temperatures. Finally heat is lost by radiation, which is greatest during clear nights and least during cloudy ones.

The total heat loss from the house per hour represents the amount of heat which must be put into it in order to maintain a steady temperature. There are simple methods for calculating heat requirements and these are explained in Appendix I.

During the daytime when the house needs to have as much light entering it as possible nothing very much can be done to reduce heat losses, other than the creation of some kind of shelter to reduce windspeed. Cold winds greatly increase heat loss, and shelter belts of trees and hedges acting as a windbreak have a considerable effect in reducing heat loss. They must not, however, intercept the light from the sun or any gain provided in fuel saving is lost by the shade they cast. At night the erection of a screen a few inches away from the glass brings about a very substantial reduction in heat loss. Much effort is being expended by engineers to devise effective means of installing thermal screens, as they are called, which can be put automatically into position at dusk and similarly removed at dawn. Polythene and other plastic film, and special fabricated plastic cloths, are all effective but plastic film is the cheapest. It is not too difficult for the amateur to install a thermal screen of plastic film suspended over his crop during the hours of darkness, at times of the year when heat losses are high.

Thermostats

It is very necessary these days because of the high cost of all fuels to have a heating system that is controlled automatically so that as soon as the desired temperature is reached the burner is shut off until heat is required again. Therefore it is necessary to install a thermostat to control the boiler. This is simple enough if oil or gas boilers are being used but is rather more difficult when solid fuel is used, for the simple reason that a coal fire cannot be switched off and on like gas or oil burners. It must be allowed to die down but given enough fuel and air to keep it alight and hot enough to prevent corrosion of the boiler.

Thermostats must be positioned carefully so that they control the temperature of the greenhouse where the plants are actually growing, but more important is the necessity of protecting them from radiation effects. During the daytime an unprotected thermostat is receiving radiation from the sun which may cause it to become warmer than the surrounding air by as much as 6 C° (*10 F°*), thus shutting off the heat supply before it should; but, much more seriously, at night-time it is radiating heat itself and so may become much colder than the surrounding air, thus bringing on the heating system before it is necessary. Not only does this prove expensive, but it results in incorrect temperatures in the greenhouse.

This difficulty is avoided by housing thermostats and thermometers in what are called aspirated screens (Fig. 14). An aspirated screen is an insulated box, covered with metal or foil to reflect radiation. A small electric fan sucks air out of the box, which enters it through a louvre at its

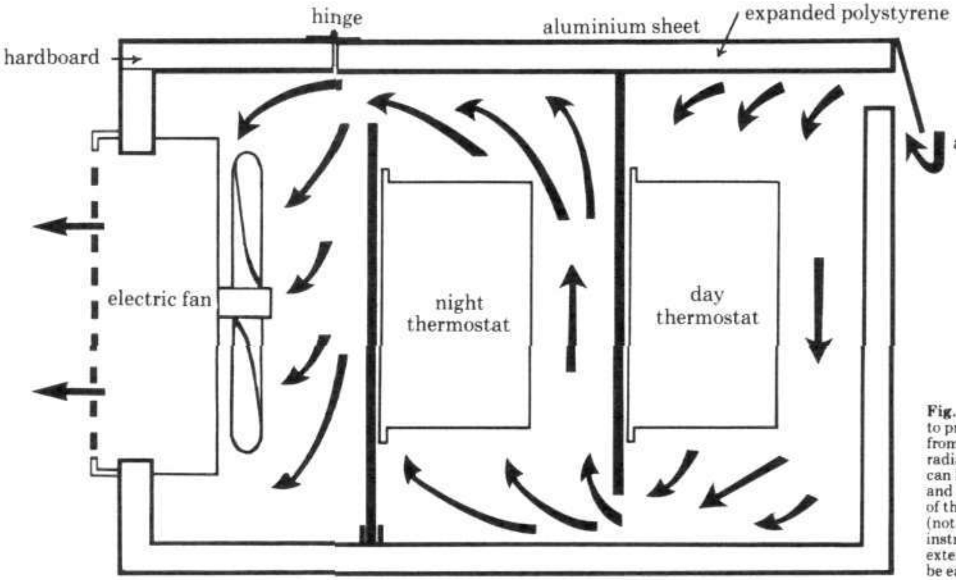


Fig. 14: aspirated screen, to protect the instruments from receiving or emitting radiation. Larger models can house a thermometer and thermograph. Because of the electricity supply (not shown) to the fan and instruments, the metal exterior of the screen must be earthed.

other end so that a sample of the greenhouse air is flowing over the instruments. These are then able accurately to measure ambient temperatures. Aspirated screens suitable for amateurs are available.

Ventilation

Much mystery used to surround the subject of ventilation of greenhouses, but the facts are quite simple. Ventilators exist for the sole purpose of providing openings through which excess heat in the house can be dissipated. The other advantages which follow are purely incidental but nonetheless useful.

When a ventilator on the ridge of a house is opened the more buoyant warm air floats up through it and its place is taken by colder air from outside. This air has to come in through the overlaps in the glass and round the edges of doors, or sinks in through the ventilator opening past the warm air which is going out.

If as well as having ventilators at the ridge of the house there are also ventilators in the walls as low as possible, then the warm air escapes through the ridge vents and the cool air comes in through the side ones, creating what is called the 'chimney effect' and making the whole ventilation process much quicker and more effective.

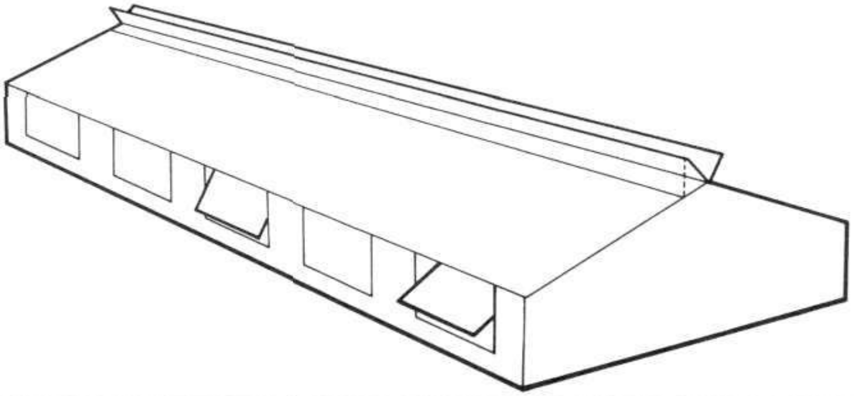


Fig. 15: modern greenhouses have continuous ventilators which open through 60° and which give a larger total aperture than single vents.

In designing a greenhouse the provision made for ventilation needs to be sufficient to cool the house to within a few degrees of the outside temperature on the hottest summer days. In a large commercial greenhouse this means enough ventilator openings to permit the entire greenhouse atmosphere to be changed completely once every minute (see Appendix IV). To achieve the same degree of cooling in a very small house the rate has to go up to as much as once every three-quarters of a minute because the smaller the house the more ventilation it requires to achieve the same result. Ideally the greenhouse should be built with ventilators each side of the ridge running the entire length of the roof with a number of side vents in both side walls. As few houses are built with such generous provision, amateurs are urged to provide extra ventilation by securing the doors in an open position in hot weather. Sliding doors are particularly useful for this purpose. Ventilation, in many ways, is the opposite of heating: ventilation has to be designed to cope with the hottest weather and heating with the coldest.

As most of the excess heat which ventilation is designed to dissipate comes from solar radiation, i.e. sunshine, and this tends to fluctuate throughout the day, ventilators need to be constantly adjusted. In practice this is not possible and has led commercial growers to invest in automatic ventilation equipment. Automatic ventilation controls are available for small greenhouses and are well worth considering.

Before the need for adequate ventilation became properly understood in the early 1950s, greenhouses were built with totally inadequate ventilation and to prevent over-heating in sunny weather shading the houses with whitening was the rule. This was unsatisfactory because the shading excluded the light essential for proper development of the crop. Shading is nowadays regarded by the professional gardener as something required only by plants which naturally grow in shade or by cuttings in the process of rooting.

The incidental advantages of ventilation must be understood. The first of these is that the air contains a small amount of carbon dioxide (0.03 per cent or 300 parts per million) which is essential for plants if they are to photosynthesise at the maximum rate possible in the prevailing light intensity and temperature level. When the air is still the carbon dioxide in the atmosphere surrounding the leaf becomes depleted and photosynthesis slows down. The movement of air through the foliage caused by ventilation maintains the concentration at the normal level. Commercial growers even go to the extent of enriching the atmosphere of their houses with carbon dioxide from artificial sources.

Ventilation also has the effect of reducing relative humidity in the greenhouse to a level close to that of the external atmosphere (but only when the latter is lower than that of the house). This lowering of relative humidity is desirable because it can prevent the condensation of water on the internal surfaces of the house should the temperature suddenly drop. The existence of still moist air around the plants is ideal for the germination of fungus spores, but this will not occur when ventilation is taking place.

Ventilation is quite a problem for the amateur gardener and tedious to monitor, but the golden rule is to err on the side of generosity throughout the summer.

Chapter 6

The greenhouse soil

Soil sickness

If a greenhouse is built on an area of soil not previously used for such a purpose it is invariably found that no matter what is grown in it the first year's crop is magnificent but subsequent ones deteriorate until they become totally unacceptable. This decline in soil fertility is called 'soil sickness' or (by tomato growers, who were the first to experience it) 'tomato sickness'.

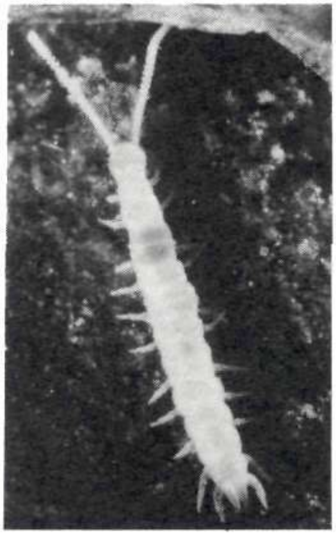
For many years the cause of this problem was a mystery and ingenious theories were advanced to account for it. The mystery is now fairly well solved; the trouble does not have a simple cause; it is a combination of a number of factors of which some or all may apply.

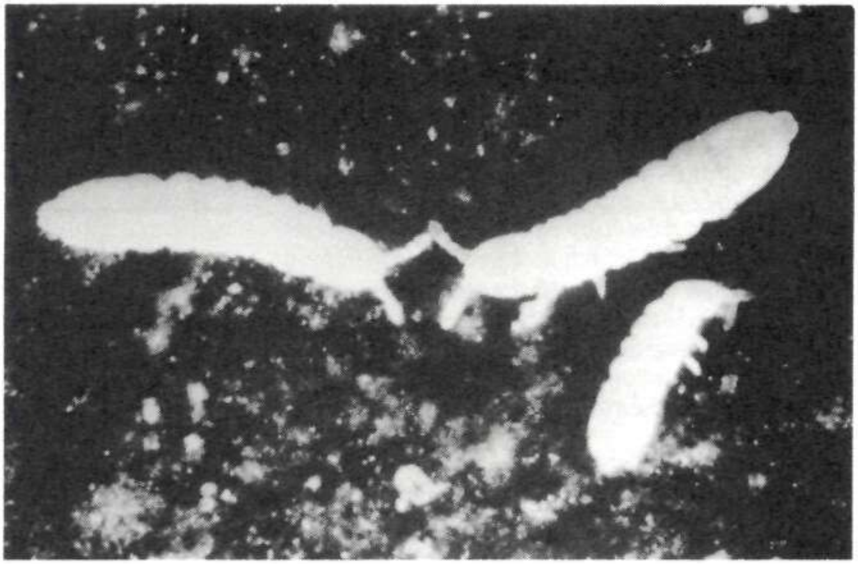
The soil is a medium that teems with life, both animal and plant, most of it microscopic; a population so varied and so well balanced that it is difficult to imagine. This population of soil micro-organisms performs a number of functions, most significant among which is the total destruction of all dead organic matter. This matter is finally resolved into simple gases and soil minerals, in the course of which process all the plant nutrients such as nitrogen, phosphorus and potassium are re-cycled for use by subsequent generations of plants.

Among this vast multifarious soil population it is not surprising to find a few out-and-out rogues and some others normally law-abiding but in circumstances of great temptation liable to undesirable conduct. The former are called plant parasites and the latter facultative parasites. While the term 'parasite' is familiar enough, that of 'facultative parasite' needs explaining. They are organisms which normally live on dead organic matter but possess the ability in certain circumstances to attack living plants.

In normal circumstances all the species of soil micro-organisms are in such a state of competition for available resources that their numbers remain in a state of reasonable balance. As soon as a glasshouse is placed over the soil, conditions cease to be normal. To begin with, the temperature becomes higher; a crop such as tomatoes will be planted to the exclusion of all else giving a high density of a single kind of root; the addition of optimum quantities of fertilisers and manure and regular watering will all provide conditions which encourage a high rate of activity on the part of the soil micro-organisms. The high density of tomato roots encourages any parasites of their roots to multiply and the increased rate of activity may encourage the facultative parasites to turn from their normal harmless state to being harmful. We are mainly talking about root-attacking fungi, although the same applies to various animal foes such as certain eelworms, insects and slugs. The second year in which the same crop is grown the process is repeated, and the effect is cumulative, so after a few years the plant's roots are destroyed faster than they can be produced and it has difficulty in surviving. Although the problem was first

A symphilid (magnification ×100) — a soil pest of heated greenhouses, which is controlled by soil sterilisation. Symphilids may be present in compost made from unsterilised loam.





These almost microscopic pests are known as springtails or *Collembola*. They can be present in vast numbers and cause serious damage to plants growing in the soil or in soil-based compost. They are readily destroyed by soil-sterilising procedures, but when these are not available chemical methods may be used.

encountered with tomatoes it applies to any plant repeatedly grown as a crop on the same site; the technical term is 'monocropping'.

The tomato grower originally overcame the problem by removing all the soil in the greenhouse to a depth of a foot and replacing it with fresh. This tedious and expensive expedient was ultimately replaced by a process known as partial steam sterilisation. To accomplish this, steam is injected into the soil so that the top 380 mm (*15 in*) is heated to a temperature of 100°C (*212°F*), then allowed to cool down. This drastic treatment has a remarkable effect on soil fertility which leaps back to a level even higher than it was originally. The effect of heat is to kill the entire population of soil animals, most of the soil fungi and bacteria and all weed seeds. Certain soil bacteria do survive, and prominent among these are the ammonifying bacteria which play a vital role in the nitrogen cycle because they are the agents responsible for converting the nitrogen in organic matter into inorganic ammonia. Unfortunately, after steaming re-infection causes soil sickness to return quite rapidly, necessitating annual repetition of the treatment if high yields are to be maintained. As the cost of fuel and labour rose the tomato grower became desperate to devise techniques whereby he could abandon the soil totally as a medium in which to grow his plants, as the cucumber grower had done from the very beginning, although for different reasons. The answer eventually came with the peat bag on the one hand, and with sophisticated hydroponic techniques, such as 'nutrient film technique' and 'rockwool beds', on the other. On the way to reaching this recent answer chemical sterilisation was often used as an alternative to steaming, but always had the disadvantage that it took a greenhouse out of commission for longer than the commercial grower liked. Methyl bromide clears rapidly from the soil but it is so dangerous that it can be used only by qualified contractors.

Where in all this does the amateur gardener stand? He wants to use his greenhouse for growing tomatoes and lettuces, or anything else normally grown in the soil as distinct from a container. There is little doubt that he can start off in the soil, but after a couple of years, if he does not want to change the soil or move the greenhouse to a fresh site, the peat bag is his answer and at the present time it is difficult to see how a better or more convenient method could arise. Chemical treatment is one answer he might wish to keep in mind; the only substance which he can use being one called 'dazomet' which is sold under a number of proprietary names. Household disinfectant has many adherents among an older generation of gardeners but has a very limited range of troubles against which it is effective.

Moisture content

Soil sickness, though mainly a response to monocropping, can be compounded by two other problems which though distinct are related. The first is soil moisture content. The driest parts of the British Isles enjoy an annual rainfall of about 560 mm of rain per year (*22 in*) of which about half percolates down through the soil to drainage. In most of the rest of the UK the quantity is greater. This percolating water not only charges the soil with water to a considerable depth but also removes soluble materials from its surface levels to lower ones and perhaps out of it altogether into the drainage system. In the greenhouse rainfall does not occur, so in order to recharge the soil with water to the depth which roots will inhabit, it is necessary to apply substantial amounts of water when preparing it for planting, to ensure that this occurs. For rough and ready reckoning it can be assumed that 25 mm of water (*1 in*) is sufficient to wet the soil to a depth of 255 mm (*10 in*) and that five times this amount should be applied, which is about 125 litres per square metre (*24 gall per sq yd*); a surprisingly large amount when it comes to applying it. It is, of course, most easily done by means of an irrigation system or at least a hosepipe with a sprinkler. The flow rate of the hosepipe should be checked first by noting the time taken for the sprinkler to fill a bucket and then calculating the time it will take to deliver the required amount of water. Use the formula:

$$\frac{\text{Time taken to fill bucket (in minutes)} \times \text{amount of water required}}{\text{capacity of bucket}}$$

which will give the answer in minutes.

Soluble salts

The second and related problem is that of the concentration of soluble salts in the soil moisture. Although its significance was not realised until the early 1950s it had undoubtedly been responsible for many previously unexplained crop failures. It simply means that the quantity of nitrates which has accumulated in the top spit of the soil is such that the plants' uptake of water and nutrients other than nitrogen is impeded and certain unmistakable symptoms of ill health become apparent. The concentration of salts was first measured on a scale known as the pC scale ('p' indicates that it is logarithmic and 'C' stands for conductivity) and later by one known as the CF scale ('C' = conductivity and 'F' = factor) and ever since greenhouse growers have referred to the pC problem or the CF problem.

Amateurs are just as likely to encounter the problem as professionals but they can avoid it completely if they practise flooding, as described above, before planting a crop, and do not apply fertilisers at a rate greater than that recommended. Incidentally, lettuces, tomatoes and cucumbers are very sensitive to high soluble-salt concentrations (see Appendix V).

Chapter 7

Seed and potting composts

Gardeners have been growing plants in pots and boxes for a long time and they soon learned that garden soil was not satisfactory for the purpose unless it was considerably modified. To begin with, ordinary garden soil is not sufficiently open to allow water to percolate through it at the required rate. This meant that some gritty material like sand had to be added. Next, when wetted its water-holding capacity (container capacity) is insufficient and this has to be increased by adding some spongy material of an organic nature, like leafmould, decomposed manure or peat. Even with these additions the mixture, or compost as gardeners call it, is not satisfactory unless the soil selected has certain characteristics: it has to be one in which none of its mineral component parts, i.e. sand, silt and clay, are present in such quantities that one or the other stamps its presence too strongly; soils of this equable type are described as loams and so the soil component of a compost is always referred to as loam. When loam, sand and peat are mixed together the compost is still unlikely to have a sufficient reserve of plant nutrients and these must finally be added. If the compost, now complete, is put in a container and watered it will produce a crop of weeds which will compete and interfere with the germinating seeds or whatever has been planted so carefully, while at the same time soil-borne pests and diseases will be attacking everything that grows. This state of affairs can only be avoided by sterilising the loam in which these troubles are located.

This was the case in the 1930s when little or no scientific work had been undertaken to establish the optimum quantities of compost ingredients and the most suitable forms of each of the disinfecting procedures that should be undertaken. The task was tackled for the first time by Messrs Lawrence and Newall at the John Innes Horticultural Institution which was situated in Merton, England. After some years of painstaking work they were able to make recommendations for the preparation of standardised composts, which still hold good forty years later. Although details of these composts are readily available no apology is given for repeating them here. There are two composts, one for small and medium seeds, and one for large seeds and plants.

Seed Compost
Sterilised loam 2 parts by volume
Horticultural peat 1 part by volume
Sand (Sharp 3 mm grist) 1 part by volume
To each 100 litres (*bushel*) is added 117 g (*1½ oz*) of superphosphate and 58 g (*¾ oz*) of ground limestone.

NB: These metric and imperial quantities are not equivalent.

Potting Compost
Sterilised loam 7 parts by volume
Horticultural peat 3 parts by volume
Sand (Sharp 3 mm grist) 2 parts by volume
To each 100 litres (*bushel*) of the potting compost is added 310 g (*4 oz*) of John Innes base and 58 g (*¾ oz*) of ground limestone to make what is called JIP 1.
If the quantities of base and chalk are doubled the compost is called JIP 2 and if trebled JIP 3.
The point of having three strengths, so to speak, is to allow for varying types of plant and seasons, e.g. JIP 1 is for slow growing plants at any time of the year and for other plants in the winter, JIP 2 is for spring and summer use for more vigorous plants, and JIP 3 for vigorous plants in the summer.

When amateurs read that the loam has to be sterilised they may feel that making 'John Innes' lies beyond their ability. This is not the case, however, because it is a relatively simple matter to make a steriliser that will sterilise small quantities of loam quickly and effectively (see Fig. 16). The greatest difficulty is likely to be that of obtaining suitable loam and, in many parts of the country, coarse sand, free from lime. Fine sand beloved of old time gardeners is not suitable for John Innes. John Innes base is a mixture which consists of:

Hoof and horn meal (14% N) 3 mm grist	2 parts by weight
Superphosphate (18% soluble phosphoric acid)	2 parts by weight
Potassium sulphate (48% K_2O)	1 part by weight

It is widely available as a ready-mixed commodity.

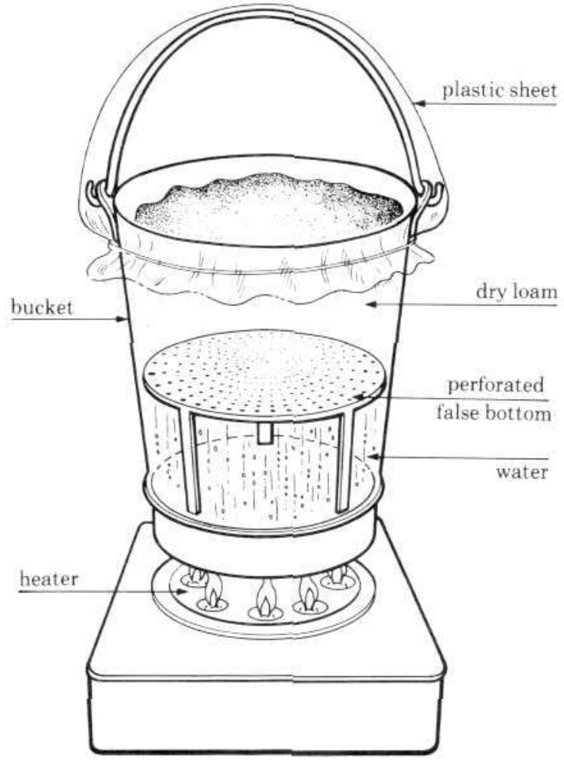


Fig. 16: a simple soil steriliser can be made by placing a perforated false bottom about one-third up inside the bucket. Sufficient water is added — one litre per nine litres of dry loam — and the bucket is placed over a gas ring or similar heater. A *plastic sheet is tied over* the top, and when this balloons out with steam the soil is sterilised.

If the soil in your garden is neither sandy nor contains too much clay, it will probably make a reasonable compost. If this is not the case the amateur must fall back on loamless composts. The traditional test for gauging the suitability of loam for compost purposes is to squeeze a quantity of it in the hand when it is moist, but not wet. When the pressure of the hand is released it should hold together but shatter if dropped. When in a lump it should, if stroked with a wet thumb, show a 'greased' track, but not a 'polished' one. These rough and ready tests help to assess the clay content to establish that it is neither excessive nor deficient. Gardeners of an earlier generation would cut and stack for at least six months turf from old pastures, such soil usually having excellent 'crumb structure'. The period of six months provided an opportunity for all the roots and herbage to decompose. Apart from the physical properties of a loam sample, it must not have too high a lime content or this may cause complications later with certain plants. A slightly acid loam is to be preferred.

Although for most purposes loam-based John Innes composts cannot be beaten, especially for amateur gardeners, a vast number of plants are now grown in loamless composts. These were developed in the USA and have been widely adopted in Britain by growers who had difficulty in obtaining suitable loam for John Innes and who wanted to avoid the chore of steam sterilising. In Britain loamless composts usually consist of peat or mixtures of peat and fine sand to which have been added a range of fertilisers. In the United States and Australia composts made of shredded bark or sawdust are in common use and give excellent results, but where good peat is easily obtained they have not made much impact.

Peat composts are now marketed by many firms under their own brand names and their compositions are not known precisely, because the manufacturers do not divulge them. Suffice it to say that they are usually peat or peat/sand mixes to which the appropriate range of fertilisers has been added. For those who want to do it themselves the Glasshouse Crop Research Institute has investigated the composition of peat-based composts and has stated that a well-designed one will produce plants as good as in John Innes, but that the management of plants in them is more exacting. The mixtures they recommend, which are known as GCRI composts, are as follows:

Seed Compost
Granular horticultural peat 1 part by volume
Lime-free fine sand (0.05–0.5 mm particles) 1 part by volume
To each 100 litres (*bushel*) is added: 40 g (½ *oz*) ammonium sulphate
80 g (*1 oz*) 18% superphosphate
40 g (½ *oz*) potassium sulphate
310 g (*4 oz*) ground limestone (calcium carbonate)

Potting Compost
Granular horticultural peat 3 parts by volume
Lime-free fine sand (0.05–0.5 mm particles) 1 part by volume
To each 100 litres (*bushel*) is added: 155 g (*2 oz*) 18% superphosphate
235 g (*3 oz*) ground limestone
235 g (*3 oz*) dolomitic limestone (calcium magnesium carbonate)
40 g (½ *oz*) Frit No. 253A

If the compost is to be used immediately, or within a short time, the following must be added:

20 g (¼ oz) ammonium nitrate
40 g (½ *oz*) urea-formaldehyde
80 g (*1 oz*) potassium sulphate

If, on the other hand, it cannot be used fairly quickly then instead the following are added:

40 g (½ *oz*) ammonium nitrate
80 g (*1 oz*) potassium nitrate

The list of additives looks frightening but, in fact, they are all common fertiliser materials easily purchased either as individual materials or proprietory mixtures. The Frit No 253A is absolutely vital as it contains all the trace elements (boron, zinc, manganese, iron, copper and molybdenum) which are needed in minute quantities and are difficult and dangerous to supply in any other way.

When plants are grown in containers they soon exhaust the nutrient reserves of the compost, a fact demonstrated by the slowing down of growth, a hardening of their tissues and a paling of their foliage. Before these symptoms of starvation are observed steps should have been taken to avoid it, either by liquid feeding or by moving the plant into a larger pot or planting it out. Liquid feeding is generally the most convenient method and will be discussed later when dealing with the various crops.

All 'growing media' as composts are frequently called must provide the correct physical conditions for root growth. If these are not correct no amount of fertiliser treatment can compensate. Experiments have shown that in a compost with a sub-standard physical condition, the difference in plant growth between a low standard of nutrition and a high one is no more than 12 per cent whereas with a compost of good physical condition, the difference rises to 91 per cent.

Good physical condition mainly refers to what is termed the air-filled porosity of a compost. This is the amount of air it contains after it has been saturated and drained back to 'container capacity', which is holding all the water it can against the pull of gravity, all drainage having ceased.

If the air-filled porosity drops below 10–15 per cent growth is affected and root-death occurs at the lower levels of the container. Above 15 per cent, roots can grow and function properly. Composts made from coarse sphagnum peat alone have an air-filled porosity of 30–40 per cent and made from the finer grades an air-filled porosity of 12–15 per cent.

Air-filled porosity is a function of the larger pore spaces within the compost, i.e. those greater than 60 microns (1 micron = 0.001 mm).

It has already been stressed that with loam compost coarse sand of 3 mm grist is used to increase air-filled porosity and sand of this size can be relied upon always to do this, whereas finer sands reduce it. In the case of the GCRI loamless composts the grade of sand recommended is much finer. Although its function is to make the compost heavier in weight (which it does by about 400 per cent) it will inevitably reduce the air-filled porosity of the peat, though not below the critical level if the correct grade of granular peat has been selected.

Whenever there is doubt about air-filled porosity of a compost a simple test can be conducted as follows:

1 Weigh a container and fill with compost consolidated as though it contained a plant.

2 Place the container in water (weighed down if necessary) until the compost is saturated.
3 Remove the container rapidly from the water and place in an empty bucket of known weight and weigh.
4 Immediately stand the container on a sand-base and allow to stand for twelve hours, then weigh again.
5 *Mark the position inside the container reached by the compost, empty* the container and line it with a thin polythene bag.
6 Fill the lined container with water to the level formerly reached by the compost and weigh.
7 Subtract the weight of the container from all three measurements.
8 Calculate the percentage of air-filled porosity using the formula:

$$\frac{\text{(weight of saturated compost} - \text{weight of drained compost)} \times 100}{\text{weight of water equal to the volume of the compost}}$$

If the calculation gives a value lower than 15 per cent suspicion must fall on the coarseness of the sand.

Specifications for compost ingredients always state that sands should be non-calcareous (lime-free). This is to prevent the use of materials which would cause the pH of the compost to rise. The pH scale describes the acidity or alkalinity of solutions. The letter 'p' indicates that the scale is logarithmic, meaning that each point on the scale represents an increase or decrease by a factor of 10. Loam composts are designed to have a pH of about 6.5, and as little as 0.5 per cent of calcium carbonate (lime) in a sand used for the GCRI composts can raise the alkalinity of the compost by pH 0.7, i.e. five times. This is quite critical because the neutral point of the pH scale is pH 7 and an increase of 0.7 takes the original pH of the compost from 6.5 to 7.2 which is well within the danger zone for many plants.

Chapter 8

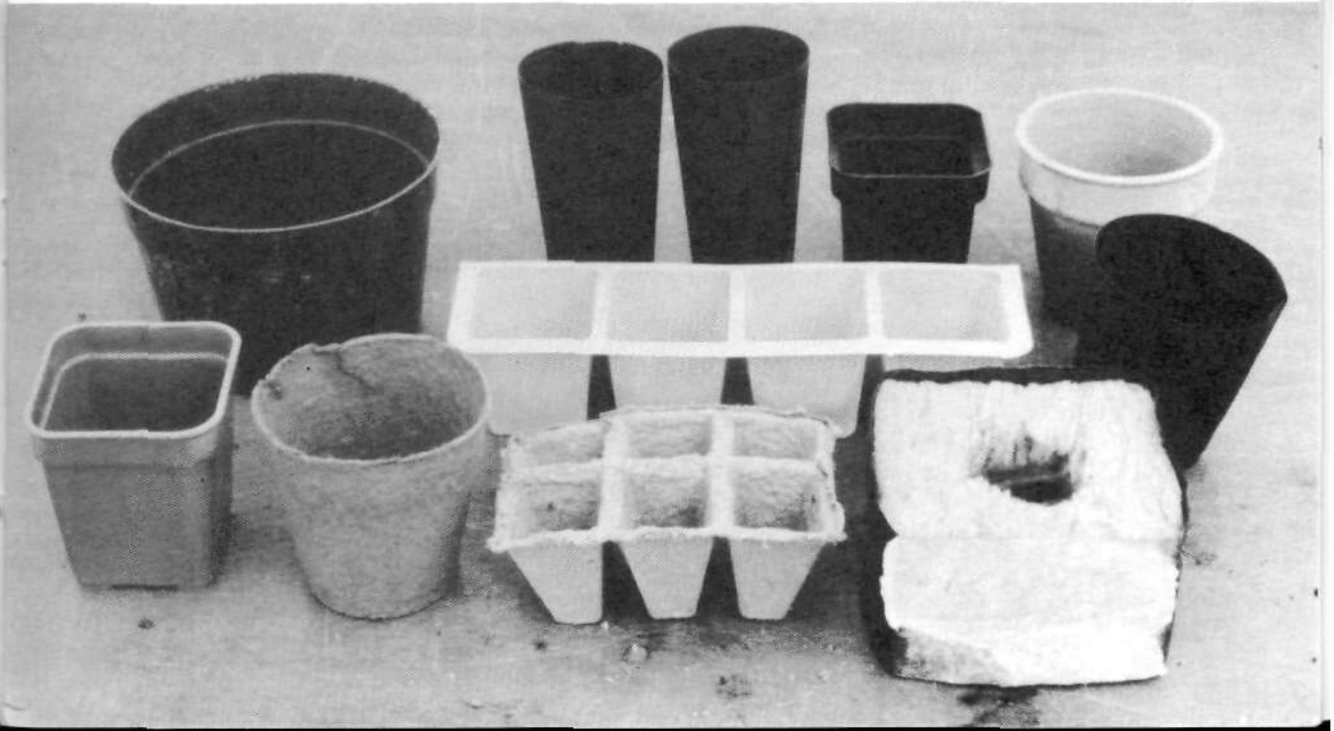
Plants in containers

It is not so many years ago that to say 'plants in pots or boxes' would have sufficed. Today the range of 'things' in which plants are grown is so varied that the more general term 'container' now has to be used to cover all possibilities.

The traditional flower pot, made of baked unglazed clay, has virtually disappeared, having been superseded by the plastic pot. Plastic pots are usually rigid and made of polypropylene; they are not long lived because after a while they become hard and brittle, but being light, cheap and easily transported they have displaced the heavy and now very expensive clay pot.

The clay pot, being porous, has water evaporating from all of its surface which causes the compost in it to be slightly cooler than in a plastic pot of equivalent size; differences of 1.1C° (*2F°*) at night and 3.3C° (*6F°*) in the daytime having been recorded. Thus with higher temperatures and a slower moisture loss an overall gain in growth in plastic pots can occur.

Traditional practice was to 'crock' clay pots, i.e. broken pieces of pot were placed in the bottom over the drainage hole (see Fig 17). It was always difficult to find out from gardeners why this was done but one was usually told that it aided drainage, aided aeration and prevented earthworms getting into the compost. All these reasons have been shown to be fallacious and the practice has now died out almost totally.



A range of plant containers, both durable and biodegradable. On the right of the front row is a rockwool block for hydroponic growing methods.

Conversely, it is now known that crocks not only fail to assist drainage, they actually impede it, to say nothing of taking up space better occupied by compost.

Another traditional practice was the firming of the compost. The degree of consolidation varied with the subject being grown but for all pots over 130 mm (*5 in*) diameter the compost was forced down with a 'rammer' and good gardeners had a set of rammers for different sizes of pots. It has now been shown that consolidation of the compost is unnecessary and can usually be brought about to the extent required by the subsequent overhead watering of the plant.

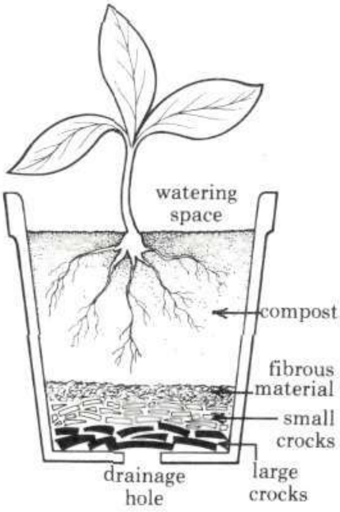
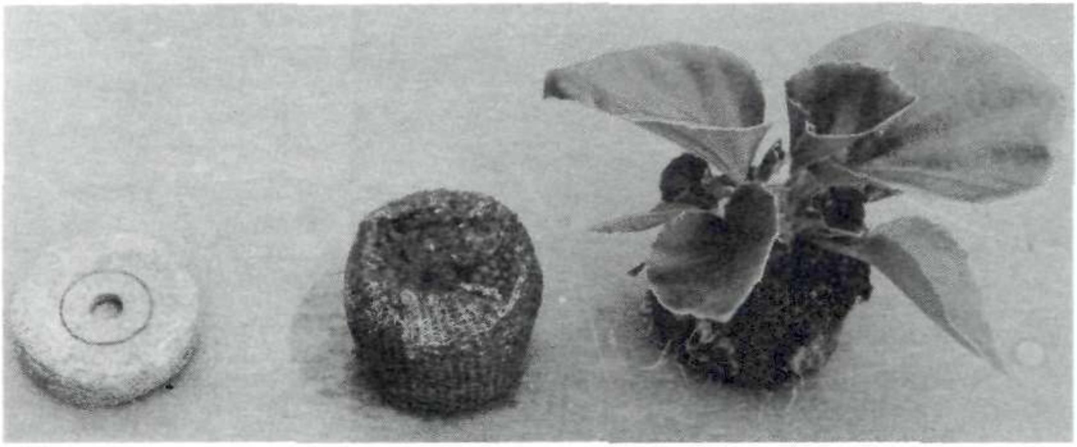


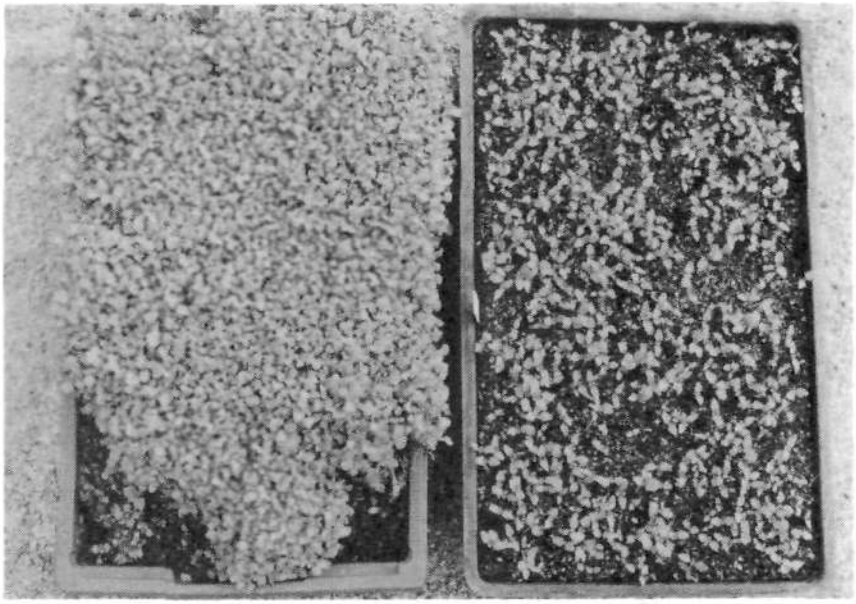
Fig. 17: this traditional method of crocking a flower-pot is now known to impede drainage rather than to assist it, and is thus no longer used by modern gardeners.

Old-fashioned gardening practice also required the use of a large range of pot sizes. The range started with thumbs and thimbles and proceeded by way of small 60s, middle 60s, large 60s, 48s and 32s up to 200 mm (*8 in*), 225 mm (*9 in*) and 250 mm (*10 in*) pots. Plants raised from seed were sown in trays or pans, pricked-out (or pricked-off) into trays and then, according to their vigour, potted (potted-off was the term) into one of the 60s range, i.e. 63 mm (*2½ in*), 75 mm (*3 in*) or 90 mm (*3½ in*) diameter. From this size of pot they might be planted out in the soil or 'potted-on' into larger pots. Potting-on normally required leap-frogging over one size of pot, e.g. from a 75 mm (*3 in*) pot to a 113 mm (*4½ in*) one, or from a 90 mm (*3½ in*) to a 125 mm (*5 in*) one, and so on. Gardeners liked to pot-on at the moment when the plant was beginning to exhaust the nutrient reserves of the compost. When plants were in their 'final' pot they might have to be 'top-dressed' in order to sustain them until ready for sale or display. Top-dressing usually meant scraping away the accumulation of liverwort and moss growing on the surface of the compost, pulling out any weeds and, if their presence was detected, removing any earthworms. This done, fresh compost was put on the surface together with a teaspoonful of an evil-smelling fertiliser containing, among other things, dried blood and steamed bone flour. Liquid feeding was rarely attempted, but when it was, consisted of watering with an infusion made from manure of one kind or another.

All these methods represented a craftsmanship that had been built up over a couple of centuries or more by methods of trial and error, coupled in some cases with beliefs, never questioned, built on misunderstandings. Today economic necessity, coupled with scientific investigation has led to a greatly simplified procedure, outlined here.



The Jiffy pot, made from peat enclosed within a mesh. It is bought in the dehydrated form,the disc on the left; after immersion in water it swells to form the container depicted in the middle of the photograph; and on the right a young begonia is seen well established in one of these. Peat modules in a similar dehydrated condition, convenient to handle and store, are now available.



Two boxes of seedlings: the one on the right is sown at an acceptable density, and the seedlings are at the correct stage for pricking-off; the box on the left has been sown too thickly, and the seedlings have long since passed the stage at which they should have been pricked-off.

Seed sowing

It is convenient to think of seeds in three simple categories: the small and dust-like, e.g. *Rhododendron, Lobelia*; medium-sized, i.e. seeds which can be seen easily with the naked eye like *Primula* and *Antirrhinum* up to lettuce, *Cyclamen* and tomato, some of which are large enough to be sown singly; and large seeds such as cucumber, melon, sweet pea and so on.

The fine seeds are sown on a compost which has been sieved fairly finely, but not so fine that only the finest particles of the compost go through the sieve producing a material of a silty nature which will set hard on watering. The surface of the compost in the containers must be flat, for which a 'presser' is needed to firm the surface lightly. The seed is then scattered as thinly as possible. Various techniques are used by different people to achieve the fine scattering required, but there is no foolproof method that can be recommended above all others. The scientific approach with fine seeds is to assume that ideally each seedling needs about 1 sq cm in which to expand its cotyledons. Then, allowing for the fact that many of the seeds will not germinate, it is possible to calculate what the sowing rate should be. With dust-like seeds trial and error is all that is possible. Fine seeds do not need to be covered; they must be sown onto a previously watered compost which has drained back to container capacity. Evaporation from the surface, which would hinder germination, is prevented by covering the container with a sheet of glass or polythene and shading with newspaper or cloth to prevent it being overheated by the sunlight.

Medium-sized seeds are sown at rates which seek to provide each with about 3–4 sq cm in which to expand their cotyledons. These are rates which are much easier to calculate and to achieve in practice than those for fine seeds. It is usual to cover them with a scattering of compost sufficient to bury the seed completely to a depth equal to approximately its own diameter. The normal reason for covering a seed is to keep it in an environment uniformly moist, and often to aid the emerging seedling in leaving its seed coat stuck in the compost and in contact with moisture. Glass or plastic covering is still needed to prevent drying out.

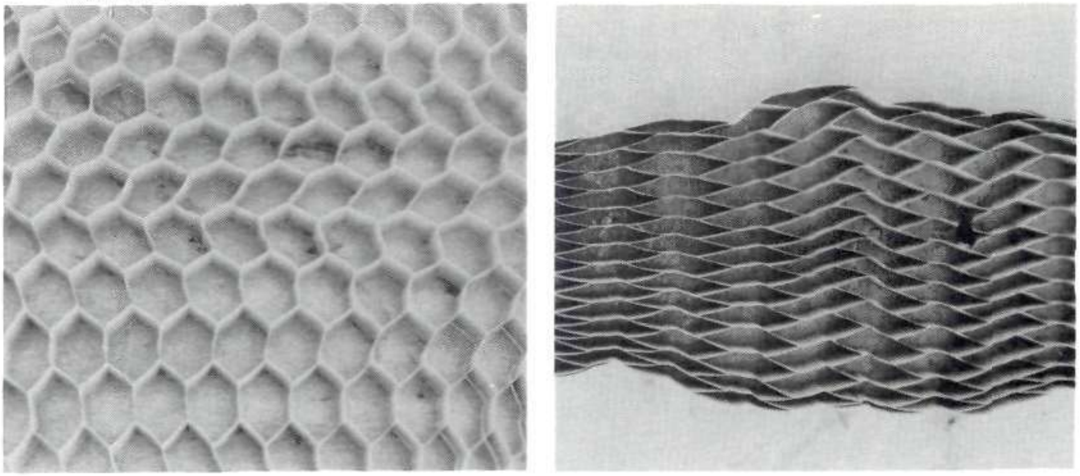
Large seeds can be sown in a coarsely sieved compost, say 10 mm (*0.4 in*), and may be best placed in individual containers. This is to some extent a matter of judgement but where germination is fairly reliable individual sowing is usually highly advantageous as it avoids pricking-out, always a serious check to growth. Large seeds in containers can safely be watered from overhead without being dislodged so the practice of covering them with glass or plastic film becomes optional.

Germinating temperatures vary considerably with the subject but 15°C (*60°F*) is suitable for a wide range of hardy and half-hardy plants; 18°C (*65°F*) suits most temperate and sub-tropical plants and 21°C (*70°F*) is required for tropical plants. Maintaining these higher temperatures is difficult without automatic controls, but small propagating cases known as 'propagators' can be used by amateurs to advantage, although they are rather expensive.

Pricking-out is the act of moving a seedling into an individual container or several seedlings into a tray. The time to do it is at the *earliest* possible moment, when the seedling is large enough to be handled, which usually coincides with the expansion of the cotyledons, but before the appearance of true leaves. Careful observation has shown that early pricking-out causes the plant to receive the least amount of check. The older the seedling the greater the amount of root it has, and the more this is damaged in the process the longer the seedling takes to recover from the move.

The container into which the seedling goes depends upon the purpose for which it is to be grown. If it is intended to be a flowering pot-plant it may be pricked-out into a small pot or an intermediate size of container, such as a 'Jiffy' pot. This is a proprietory product which is bought in a dehydrated compressed condition, but after soaking expands into a peat container. For economy of greenhouse space an intermediate size of pot is still necessary while the plant is relatively small; starvation, which was the problem of the gardener of yesterday, can be completely avoided by liquid feeding; but once the plants require more space, and are too large for their containers (top heavy), they are then moved into their final pot.

When plants were transferred to larger pots it was not formerly permitted for them to be watered until several days had elapsed. The theory behind this was that it would give the roots an opportunity to find



Left: paper pots which are glued together in a honeycomb arrangement. Sometimes referred to as Japanese pots from their country of origin, they are extremely useful for raising batches of plants under protection which are intended for subsequent planting out in the garden. *Right:* the paper pots before they have been stretched out to their normal hexagonal shape.

their way into the new compost, which they would not be encouraged to do if they were watered. This strange logic may have had something to do with the excessive firming of the compost which reduced its air-filled porosity. If it was kept on the dry side for a few days it gave the roots an opportunity to grow into it, whereas, if it were watered, such air spaces as it had would be filled with water and new root-growth discouraged. In modern practice, the use of composts with the correct physical conditions and the avoidance of undue compaction should enable watering to be done immediately after potting-on with advantage to the plant.

Seedlings intended ultimately for planting out in the soil may be planted into any of a whole host of biodegradable containers including 'whalehide' pots which are made of special paper, peat pots, fibre pots and possibly best of all peat blocks. For young shrubs, black plastic bags are popular, and old fruit cans once had considerable vogue, so much so that in American nurseries large plastic pots now in general use are still referred to as cans.

In container cultivation, as mentioned elsewhere, a positive choice has to be made between growing plants by the slow-release fertiliser method or by the liquid feeding techniques. Both methods have their advantages and disadvantages but the slow-release fertiliser method wins on the score of simplicity and convenience. Slow-release fertilisers, provided they are used in strict accordance with the makers' recommendations, contain all that the plant requires to sustain it for a period of time. They are all proprietory compounds and it is not possible to give detailed information about them. The compound is mixed thoroughly with the compost before potting takes place. It does not, of course, last for ever and plants which are destined to spend a long life in pots will require ultimately to be liquid-fed.

Liquid feeding will be described specifically in relation to tomatoes and cucumbers, but for general use with pot plants in loam composts the feed is as follows:

Potassium nitrate	72 gram	*11½ oz*
Ammonium nitrate	164 gram	*26 oz*
Water	1 litre	*1 gallon*

This is diluted 200 times (5 ml spoonful/litre; *0.8 fl oz/gallon*) and is given to vigorous plants throughout the year with every watering. Plants which grow more slowly can either have the dilution rate increased to 1 in 400 (5 ml spoonful/2 litres) or alternatively receive the feed at normal strength every other watering.

In loamless composts different factors operate, particularly in hard water areas where the lime content of the compost tends to increase and may cause some plants to suffer from a deficiency of iron and manganese; a condition called lime-induced chlorosis. A recommended mixture is:

Ammonium nitrate	120 gram	*19 oz*
Potassium sulphate	88 gram	*14 oz*
Mono-ammonium phosphate	13 gram	*2 oz*
Water	1 litre	*1 gallon*

The dilution rate, as usual, is 1 : 200 and the recommendations for application are the same as those given for plants in loam composts.

As the range of plants which can be grown in pots is so great and their rates of growth vary so considerably, e.g. a chrysanthemum grows four times as fast as a cyclamen, the amateur has plenty of scope to establish for himself by experience what rate and strength of feeding best suits a particular plant.

When plants are watered from above, the practice is to give sufficient water to fill the space at the top of the pot. The surplus then drains away until the compost is left at container capacity. The faster and more efficiently this happens the better for the healthy functioning of the roots.

Provided the compost has the correct physical properties its air-filled porosity can still be improved if the base-material on which the container is standing has pores of a similar size and range to those of the compost, and sufficient depth to exert drainage pull. There must be no discontinuity between the compost and the base-material and the two must be able to make good contact. Ideally a container should have 25 per cent of its base consisting of holes in order to provide maximum contact between compost and base-material. Many pots and most seed-trays will be seen to be lacking in this respect.

The best material for exerting a drainage pull on the compost is fine sand, the deeper the better, though in practice a depth of 150 mm (*6 in*) is adequate. Coarse sand and gravel drain freely themselves but cannot exert a drainage pull on finer grained materials, the laws of surface tension acting in such a manner as to cause coarse materials to drain freely into less coarse ones and so on, but not the other way round.

Pea-gravel, coarse sand and 6 mm (*¼ in*) granite chippings are frequently used as materials for standing-down beds but are not as effective as is really necessary. A further word of explanation about container capacity might be helpful. When soil in the garden has ceased to drain, i.e. when the force of gravity has pulled down to the water table all the water which the soil could not hold back by surface tension, the soil is said to be at field capacity. This term will not do for containers because the compost they contain is not part of a column of indefinite depth (as is the case with soil) and is not subject to the same drainage pull. This means that container capacity is not only affected by the physical properties of the compost, but also by the height of the container and the drainage properties of the material on which it is standing. The greater the height of the container the better will be its drainage and thus its air-filled porosity. Seed trays, therefore, will be poorly drained compared with 250 mm (*10 in*) pots. This explains why gardeners of an earlier generation insisted on using deep pots called 'long Toms' for plants known to grow in natural soil environments where the air-filled porosity is very high.

Chapter 9

Watering and irrigation systems

This subject is referred to elsewhere in connection with the cultivation of various plants, with the general management of plants in containers and with the management of greenhouses themselves. The subject under discussion here is the actual equipment used.

Horticulturists were very slow to come to the process of watering plants by using sophisticated equipment, preferring for decades to use watering cans and spending countless hours carrying these cans up and down greenhouses. For years the favoured method was to have a tank of water in the house, preferably sunk to ground level, from which cans could be filled rapidly by dipping them into the water. Invariably the water became contaminated with disease and led to endless problems. Watering with hosepipes was regarded with suspicion and was only resorted to for permanently planted crops such as tomatoes and cucumbers or plants in very large pots such as chrysanthemums.

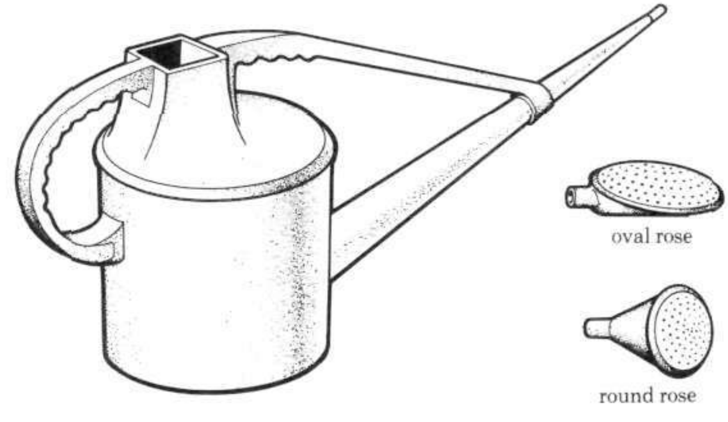


Fig. 18: Haw's pattern watering can of the modern plastic type.

The type of watering can preferred was that known as the 'Haw's Pattern' (it is still available), which is relatively comfortable to carry and comes in many sizes. Larger cans holding two gallons were preferred because they meant less travelling up and down. In general, watering was most often done without a rose on the can so that an individual stream of water could be directed to each plant that was thought to need it.

Watering cans may be fitted with any one of a variety of roses to enable a shower to be delivered instead of a jet: oval roses with small holes are for 'damping down' and for watering seed trays and small pots; oval roses with coarse holes are for watering batches of plants in frames and on staging; round roses are convenient for directing the spray towards one particular pot. An oval rose can be turned around so that the spray is directed

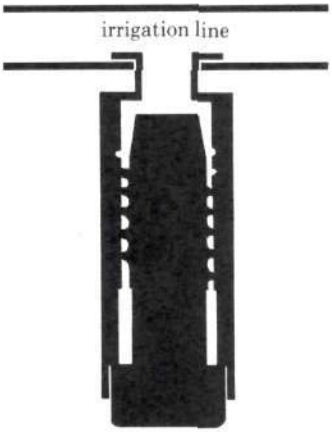


Fig. 19: trickle-irrigation *nozzle of the Cameron* type. The thread of the barrel is truncated, thus providing a spiral passage for the water.

downwards with its spread reduced or turned upwards to deliver a cascade.

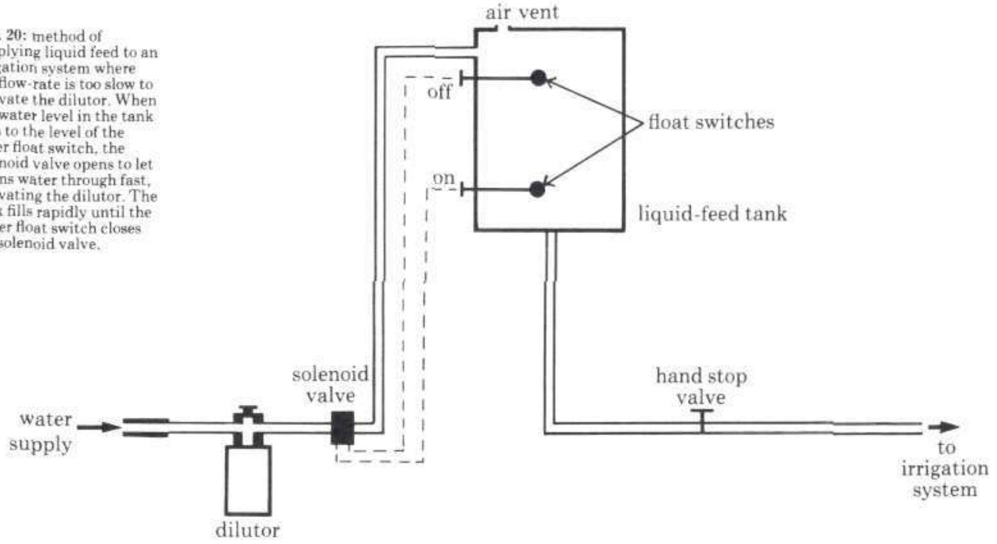
In the world of the commercial grower most of this watering art has gone. The hosepipe with or without a choke, or with a rose fitted to it, has almost replaced the can and whenever possible irrigation systems have replaced both.

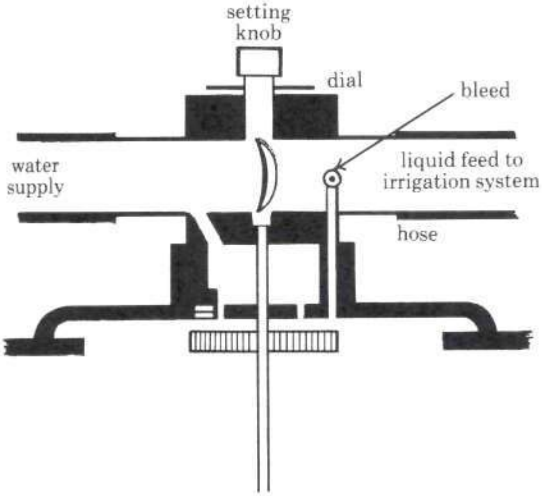
Irrigation systems are of three kinds: capillary systems (dealt with elsewhere), trickle systems and spray lines. Trickle systems first appeared in the early 1950s, for watering tomatoes. One of the first was a proprietory system invented by the late Dr Blass and marketed by the then Cameron Irrigation Company. It consisted of lines of thin rubber pipe with nozzles inserted at intervals corresponding with each tomato plant station. The nozzle was most ingenious and consisted of a metal barrel with a truncated thread. Into this was screwed a small bolt, and water escaped along the spiral created by the flattened thread onto the soil surface at rates as slow as one litre (*0.2 gallon*) per hour. The water pressure had to be matched to the number of nozzles and this was achieved by the simple device of fitting a vertical transparent tube to one of the nozzles and adjusting the tap pressure until a column of water rose in the tube to a height of say two metres (*six feet*) which meant the whole system was pressurised to about 23 kN/m^2 (*3 psi*).

With the advent of plastic materials of every sort, trickle irrigation systems are now made by a whole range of manufacturers and the customer can choose whichever seems to suit his purpose best. They are made primarily for watering individual plants, the range now extending from tomatoes in greenhouses through apples and oranges to date palms in the tropics. They can be modified by replacing nozzles with capillary tubes, each of which can supply water to a plant in a pot (the point-watering system); they can be used for irrigating capillary benches; and, finally, they may be so designed that, instead of having nozzles, they seep water along their length, thus moistening bands of soil between rows of plants.

Frequently, displacement-type liquid-feed dilutors (see Fig. 21) are fitted in-line with a trickle irrigation system so that continual liquid

Fig. 20: method of supplying liquid feed to an irrigation system where the flow-rate is too slow to activate the dilutor. When the water level in the tank falls to the level of the lower float switch, the solenoid valve opens to let mains water through fast, activating the dilutor. The tank fills rapidly until the upper float switch closes the solenoid valve.





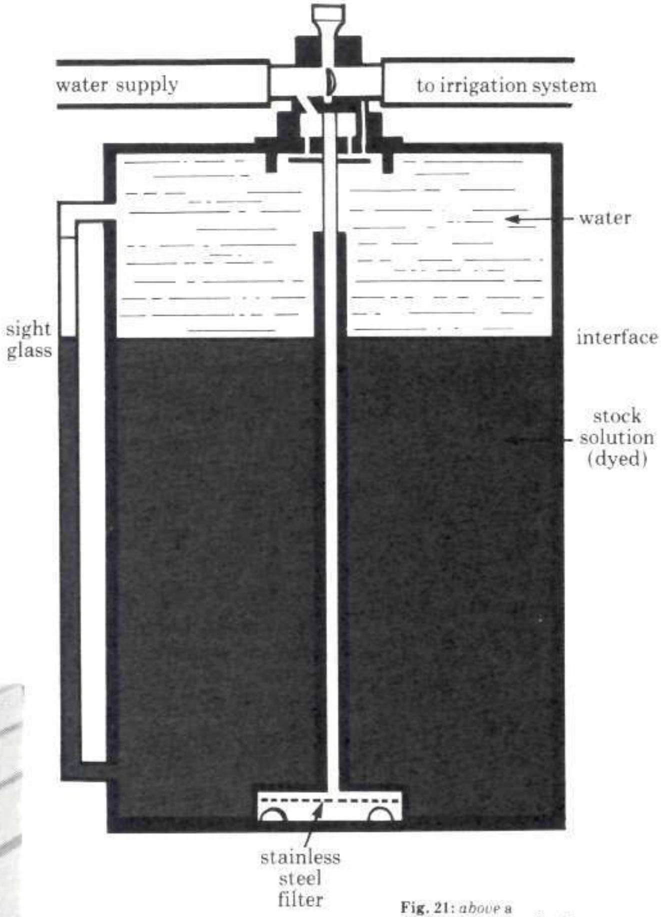
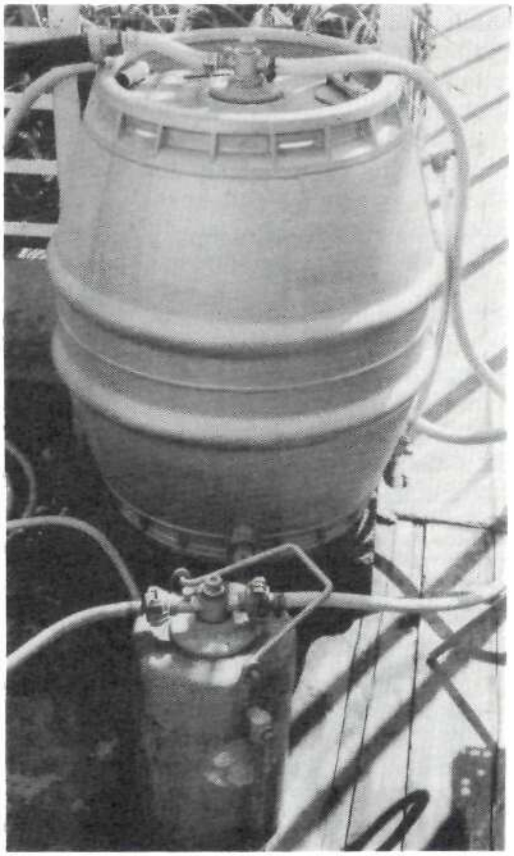


Fig. 21: *above* a displacement-type liquid-feed dilutor; *above left* the head of the dilutor in more detail.



Two liquid-feed dilutors. The one in the background is a large model for commercial growers, but the one in the foreground holds about nine litres (*two gallons*) of stock solution, which provides about 1800 litres (*400 gallons*) of liquid feed to an amateur greenhouse irrigation system.

feeding can take place. For the amateur snags arise here. The first is that the small system he is likely to require will not have a flow-rate sufficient to activate the dilutor, and so he will be forced, if sufficiently enthusiastic, into using a certain amount of gadgetry. This consists of a tank in which two float switches are fixed, one near the top and one near the bottom. From the bottom of the tank a hose connects directly to the irrigation system. This tank must be mounted about 1½ m (*5 ft*) high so that it provides sufficient pressure to activate the system. (See Fig. 20.) As the tank discharges into the irrigation system by gravity the lower float switch will eventually drop and open a solenoid valve. This will allow the tank to be refilled with the water which has passed through the dilutor and so it will, in fact, be liquid feed. When the tank has refilled, the upper float switch will be lifted, and will close the solenoid valve. No garden-scale production could justify this expense, but enthusiasm does not necessarily have to be justified in commercial terms!

The second drawback is that many water authorities will not permit liquid-feed dilutors to be connected directly to the mains water supply.

It is important to understand that when trickle irrigation is used on plants in the soil the water moistens the soil beneath the trickle in the form *of an ever-broadening cone. Within this cone of wet soil the roots of the* plant will be confined. The more rapidly the cone broadens out, the greater will be the volume of soil available for the roots of that plant. In light sandy soil narrow cones often result, and on such soils it is advisable to spread a 50 mm (*2 in*) thick layer of peat around the plant so that the trickle of water spreads before it percolates downwards. (See Fig. 22.)

If the amateur is unable to incorporate liquid feeding into a trickle-irrigation system, he must rely on the use of slow-release fertilisers for plants in containers, even though this may not give him the precise degree of control of nutrition that might otherwise be desirable.

Spray-lines are normally used for overhead watering and in large houses are suitable for such crops as lettuces. The amateur can use them in the summer for overall watering and for flooding in winter, and if they are of the type which is mounted at low level, they will send sprays of water out horizontally for watering cucumbers and tomatoes. Spray-lines were once very popular in greenhouses but have to some extent been superseded by trickle systems. As they are relatively inexpensive, however, amateurs who use the soil for growing their plants will find them invaluable for winter flooding.

Spray-lines these days are made of rigid plastic pipes and are usually suspended in the house from wire slings. In sunny weather they soften and sag unless supported by a number of slings at one metre (*3 ft*) intervals.

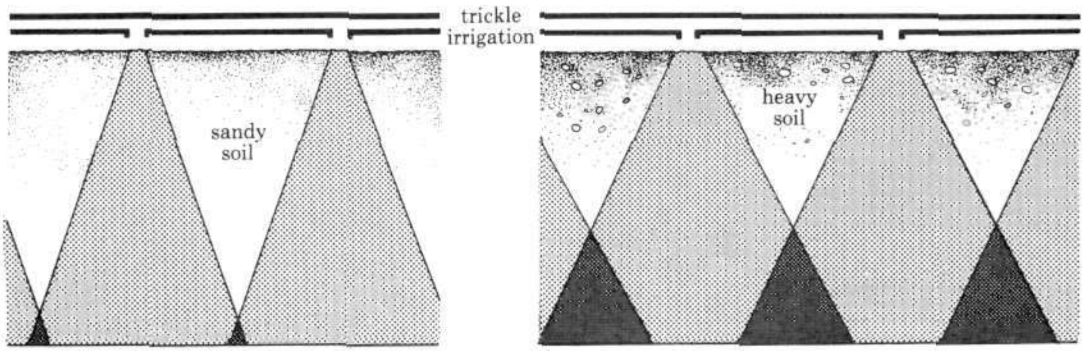


Fig 22: water forms cones of wetted soil below trickle-irrigation nozzles. The relatively narrow *cones formed in sandy soils* can be broadened if a layer of peat is spread below the nozzle.

Chapter 10

Greenhouse staging and bench watering

Solid and open staging

It would seem a simple matter to decide that if you wanted to grow pot plants in a greenhouse and have them at a height at which it was convenient both to see and work with them, you could construct an elevated platform on which to stand them. Like many other things in horticulture it is not as simple as it might appear.

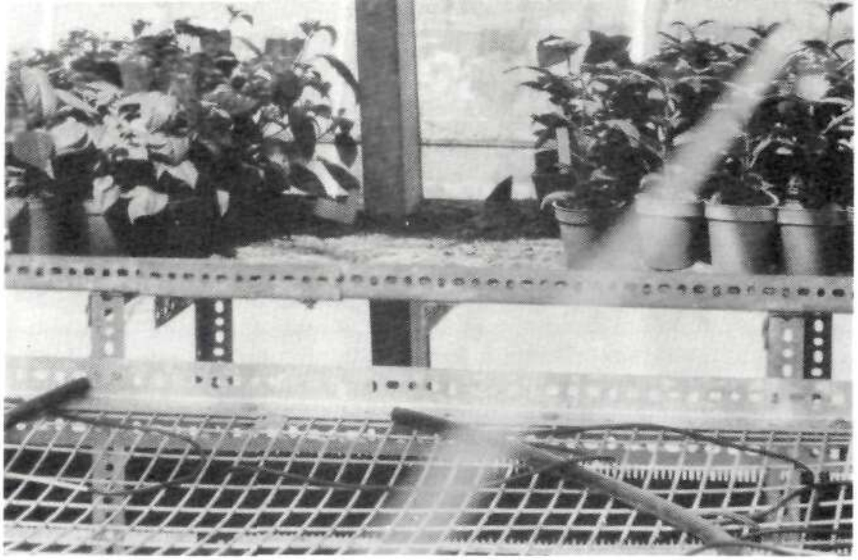
To begin with, the position of the bench, or staging as it is properly called, is very important because of the flow of convection currents in the house. In general the warm air from the heating pipes or heater rises up to the ridge of the house, and as it loses heat it sinks alongside the under surface of the roof. Should the staging go right to the wall of the house and be joined to it the cooled air will spread across the staging thus bringing about a temperature lower than the average for the house. The mean temperature of the greenhouse atmosphere is usually referred to as the *ambient temperature*. This name is important because it distinguishes it from the temperature of any surface within the house which is receiving radiant heat from the sun and which may well have a temperature above the ambient.

To return to the staging: it should always be fixed so that a gap of at least 150 mm (*6 in*) is left between it and the wall of the house through which the heavier cool air can flow downwards to be reheated.

By the same token it follows that if the staging consists of welded mesh wire or wooden slats, cooled air will also sink through it to be rewarmed by the pipes below. This will ensure that the temperature on the bench is closer to the ambient. For all winter work and when a warm temperature around the plants in the staging is required it is always recommended that 'open staging' be provided. In summer, on the other hand, open benches can lead to arid conditions around the pots, to the extent that some growers actually install overhead spray-lines so that they can spray the plants from time to time in order to make them moister and thus cooler.

It has been traditional for gardeners to construct solid benches with a floor of flat asbestos sheeting, or for greater strength, corrugated asbestos or galvanised iron. The staging has then been covered with one of a variety of materials such as sand, pea gravel, granulated peat, or sifted clinker. It is only recently, as mentioned earlier, that the advantages of fine sand have become apparent.

Solid staging, whether bare or covered with one of the materials mentioned is, if dry, hot in the day because of the radiation it receives from the sun, and conversely very cool at night because of the radiation it emits. If the covering material is wet a cool environment is provided around the pots and containers standing on it because of evaporative cooling. When water evaporates from a surface, the heat required to change it from liquid to vapour is taken from the surface concerned. On a solid staging covered with a water-retaining medium like those mentioned above, evaporation



Two kinds of staging. In the foreground is open staging made from galvanised mild steel welded mesh, and in the background solid staging on which corrugated asbestos has been covered with a coarse grit sand (fine sand would have been better).

takes place all the time, also from the surface of the compost in the pots and other containers, and finally from the leaves of the plants themselves by means of the evaporative process botanists call transpiration. The cumulative effect of all this, plus the fact that the cooled air has to flow over the side of the staging instead of through it, explains why the solid stage can be a much cooler place than the open one. In winter it may be very disadvantageous, but in summer it is quite the reverse for many plants.

The height and width of staging is a subject to which pot-plant growers have devoted a lot of attention, but the amateur usually has little room for manoeuvre. He has really only two alternatives: the first, to build a central stage to be reached from either side, an arrangement likely to provide considerable access problems in a small greenhouse; the second, to construct a stage on one or both sides of the central path. A double stage should not exceed about 1800 mm (*6 ft*) in width and a single stage should not exceed 900 mm (*3 ft*). These widths should allow all parts of the bench to be reached easily by anybody of average height. The lower the bench the greater the reach permitted but the more the back has to be bent; and the higher it is the more it will be reduced by the slope of the roof. A height of 835–900 mm (*33–36 in*) is thought to be the most comfortable and convenient for most people. In a small greenhouse height is often determined by the height of the side walls, because if the staging comes above the wall, space will be lost due to the incline of the roof. It is also best for even circulation of heat if the heating pipes can be mounted on the walls of the house rather than under the staging. When staging is properly installed the plants on it tend to dry evenly because the temperature across it is even.

Bench watering

As methods of irrigating plants in pots in the greenhouse are affected by the type of staging, the two should be considered together. Irrigation methods are of two kinds: first, the capillary bench where water rises up into the pot through the force of capillary attraction; second, the point-watering system where a main supply pipe has small capillary tubes conducting water from it to the surface of the compost in each pot. This is sometimes referred to as the 'spaghetti system'. The narrowness of the internal diameter of the tubes causes the water flow to be reduced to a trickle.

Open staging on which a multi-point watering system is installed for watering individual pots such as the dwarf chrysanthemums depicted.

Capillary systems, though all working on the same principle, are many and varied. First to be developed were the sand benches, which divide into two types. In the more simple type the bench is covered with a sheet of plastic film and then 50 mm (*2 in*) of fairly fine sand. A trickle irrigation system is then laid over the sand which is wetted until water is dripping out from the edges of the sand. The sand has to be wetted frequently enough to keep it fully charged with water at all times and thus to prevent it drying sufficiently for the roots of the plants to grow out of the pots and root through into the sand. When the pots are removed such plants suffer a check in growth, possibly a severe one. This correct irrigation is very difficult to bring about in practice, and it is only recently that a device has been made available which monitors the wetness of the sand and is able to activate a circuit which will open a valve to let water into the irrigation system.

Not only is sand heavy, but it tends to become covered with algae, and is now often replaced by mats made of plastic fibres which are lightweight

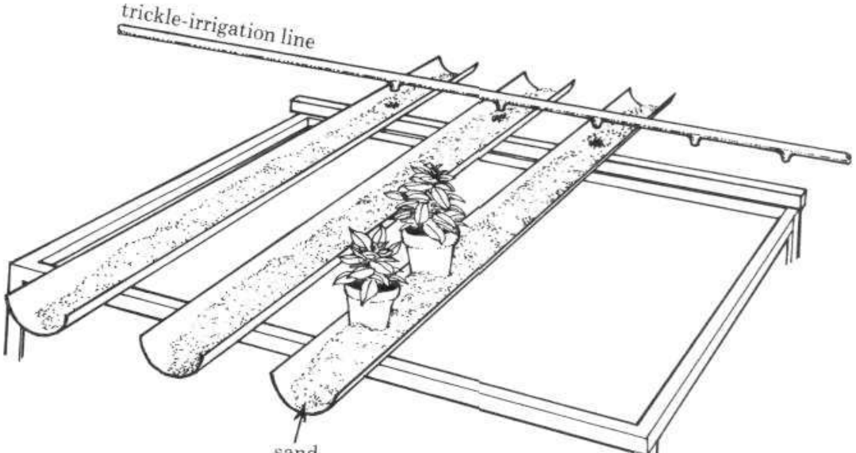


Fig. 23: a staging consisting of lengths of guttering filled with sand, between which cold air can sink. The lengths of guttering slope slightly down from the trickle-irrigation line, which can be left on all the time.

and more convenient. There are different kinds available, but none has the *capillary properties of fine sand, which is twice as good as the best of them*.

Another development of the sand capillary bed was to make it fully automatic by waterproofing the staging completely with plastic film and then introducing water into the sand by means of a plastic pipe running along the centre of the bench below the sand. Perforations in the pipe every few centimetres allow water to seep into the sand to saturate it to a level just below its surface. This is carefully controlled by a float valve in a header tank which receives the water supply. A proprietory version of this 'do-it-yourself system' has the water level controlled by a device similar to a carburettor float chamber. The fully automatic sand bench (now adaptable to capillary matting) offers many attractions to the amateur, particularly in the summer time.

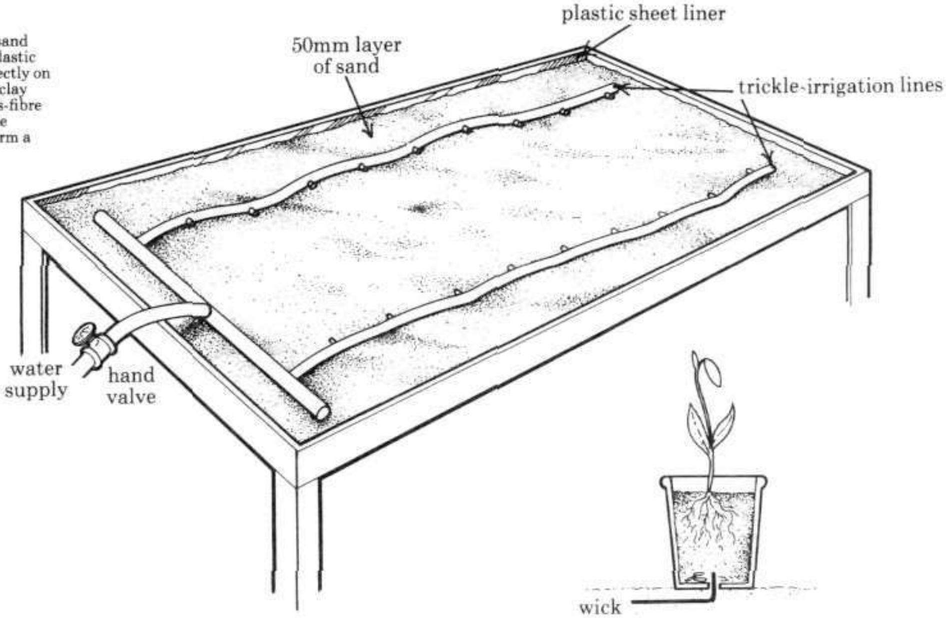


Fig. 24: irrigated sand capillary bench. Plastic pots can stand directly on the sand, whereas clay pots require a glass-fibre wick inserted in the drainage hole to form a capillary bridge.

Another variation which attempts to combine the advantages of the capillary bench with those of the open bench is to construct a framework which supports parallel lengths of asbestos cement guttering filled with fine sand. The sand is wetted by a trickle irrigation system and the spaces between the lengths of gutter allow cool air to sink past the plants.

One notable disadvantage with capillary bench irrigation systems is the difficulty of liquid feeding the pot plants without introducing a liquid-feed dilutor into the irrigation system, which would be expensive for the amateur. With fully automatic sand capillary benches, the flow of water to the bench is insufficient to activate a liquid-feed dilutor and complicated arrangements are needed to overcome this drawback.

When we turn to point-watering systems we find that we are confined to using them for larger pots, because there are not sufficient capillary tubes available on a harness for a batch of small pots standing close together. Another limitation is that if the pots on a staging are of different sizes they will all require different amounts of water to bring them to container capacity. This may necessitate taking two capillary tubes to a larger pot so that it receives, in the same time, twice as much water as a smaller one.

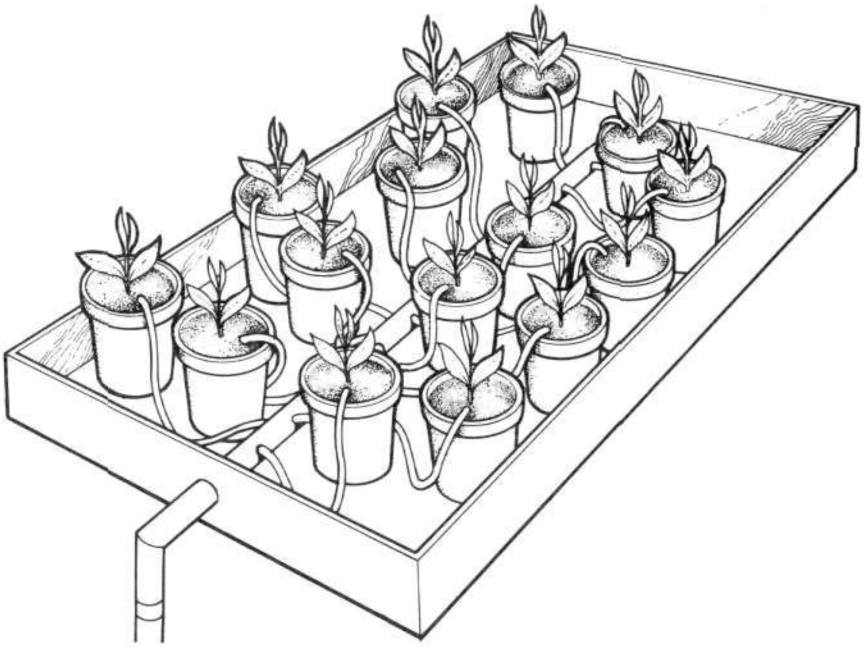


Fig. 25: multi-point watering system.

Unfortunately this simple expedient does not stop smaller pots drying more rapidly than larger ones. Watering may have to be done so that the larger pots get enough and the smaller ones get too much; not a matter for concern in the summer, but undesirable in the winter.

It is difficult to reconcile all the conflicting facts about staging in greenhouses, related systems of irrigation, and the materials with which staging is covered. The facts are:

1 Staging must be so arranged that it does not collect cold air.
2 Open staging provides a warmer and drier environment than solid staging – good in winter but perhaps too dry in the summer. It can be combined only with point-watering systems. It does not provide any assistance in draining pots and therefore militates against good air-filled porosity. This does not matter greatly if composts have excellent physical condition with air-filled porosity over 15 per cent, or in summer when evaporation is rapid.
3 Solid staging, provided it is covered with fine sand which is kept wet, gives a cool and moist environment. It can be exploited for capillary irrigation in the summer if it is given a water-table just below its surface. In winter if the sand is 150 mm (*6 in*) deep it will effectively drain containers and assist in maintaining good air-filled porosity at a time when evaporation rates are low.
4 All other materials which are used for covering staging have poor drainage pulling qualities in comparison with fine sand.
5 Benches carrying a 150 mm (*6 in*) depth of sand need to be very robust and are expensive to construct and equip.
6 Fine sand, if kept moist, rapidly becomes colonised by green algae. This can be controlled by the use of algicides.
7 To overcome the cooler environment of a solid bench the greenhouse heating-system thermostat should be installed just a little above the bench.

Chapter 11

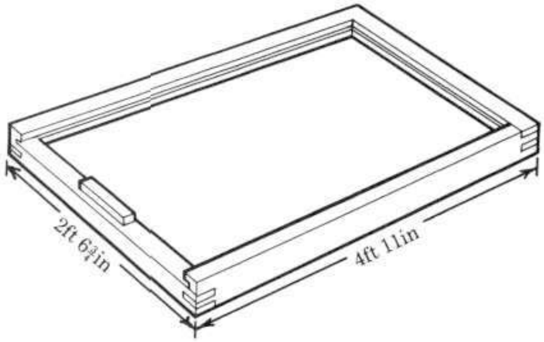
Cold frames

Frames have been in use for as long as greenhouses, providing for them a most important ancillary function. In fact it is difficult properly to utilise a greenhouse, heated or cold, without the back-up a frame provides. Some qualification is required because cold-frames are used for a number of purposes such as producing early vegetables, raising the seeds of vegetables and flowers, and striking cuttings of shrubs and herbaceous perennials.

The cold-frame associated with the greenhouse is used for holding plants in containers until they are either moved out into the open or returned back to the greenhouse. Traditionally the greenhouse cold-frame has always had an ash base over clinker, but modern studies of water movements in pots and other containers require a re-appraisal of this practice. The cold-frame is being discussed for the simple reason that heated frames are an expensive luxury which few can afford, although they do add a further dimension to greenhouse growing.

Frames can be constructed from various materials, of which brick is best, but timber the more common. Whatever the material, the frame, these days, is best covered with Dutch lights: first because they are the cheapest, and second, because they admit more light into the frame than any other kind. The Dutch light consists of a wooden frame measuring 1500 mm × 780 mm (*4 ft 11 in × 31 in*) (some manufacturers make a Dutch light 810 mm wide (*32 in*)) into which a single sheet of glass 1420 mm × 730 mm (*56 in × 29 in*) is slid and is secured top and bottom by wooden cleats fixed with galvanised nails. The standard reversible Dutch light is butt-jointed and nailed, but, at slightly more cost, versions are available with comb and feather joints, glued together with waterproof glue, and with the top rail grooved so that the glass is supported in grooves along three of its sides. The standard reversible light is adequate for most purposes.

Fig. 26: non-reversible Dutch light. The dimensions shown are the precise British standard.



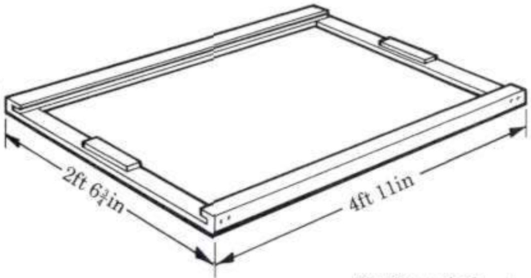


Fig. 27: standard reversible Dutch light, butt-jointed and nailed.

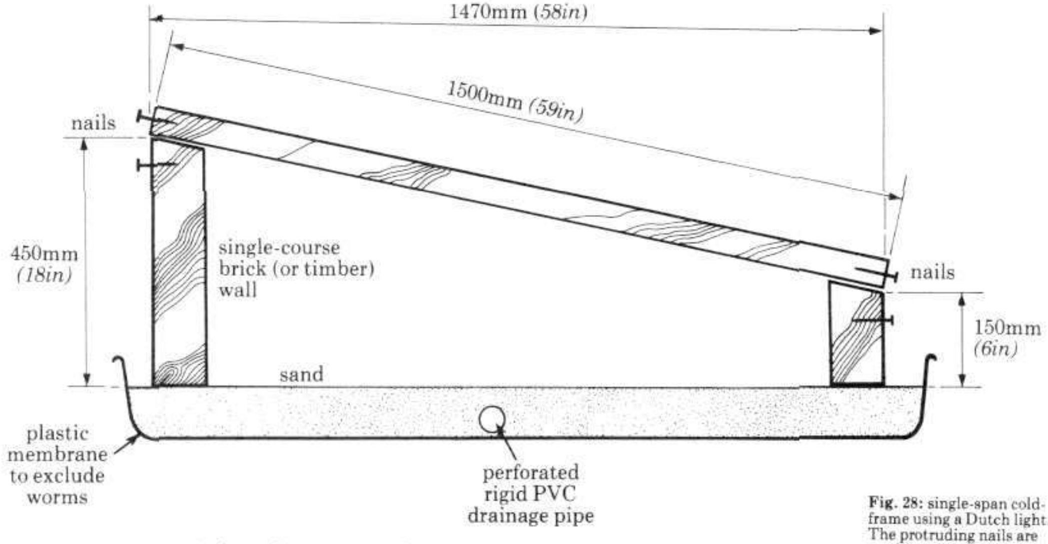


Fig. 28: single-span cold-frame using a Dutch light. The protruding nails are used for securing the light against wind.

Whatever version is bought, it must be pressure-treated to preserve the wood (see page 18).

When using Dutch lights it is possible to construct either a single frame or a span frame. A single frame consists of a high back wall and a lower front one. The exact height of each is a matter of convenience related to the size of plant to be accommodated. One reasonable arrangement is a back wall 450 mm (*18 in*) high and a front one 150 mm (*6 in*) high giving a fall of 300 mm (*12 in*). Such a frame would have an overall width of 1470 mm (*58 in*) (see Fig. 28).

A span frame is more economical and convenient with regard to utilisation of space. It is also cheaper to construct per area covered; but cannot, of course, be built as a lean-to structure against the greenhouse. It consists of a ridge board 100 mm (*4 in*) wide and 25 mm (*1 in*) thick supported on uprights driven into the ground at one metre (*3 ft*) intervals. Nailed along the centre of the ridge board and on its upper face is a ridge-fin 25 mm × 25 mm (*1 in × 1 in*). The two side walls should not be less than 150 mm (*6 in*) high with the ridge 550 mm (*22 in*) high. Such a frame would be 2700 mm (*9 ft*) wide overall. If the side walls are required to be higher the ridge should be raised by an equal amount. If timber is used for construction it should, for preference, be pressure-treated, otherwise painted liberally with a copper preservative such as Cuprinol. (See Fig. 29.)

The frame, single or span, obviously can be of any length, but if it can be about the same as that of the greenhouse it accompanies, it will normally be adequate.

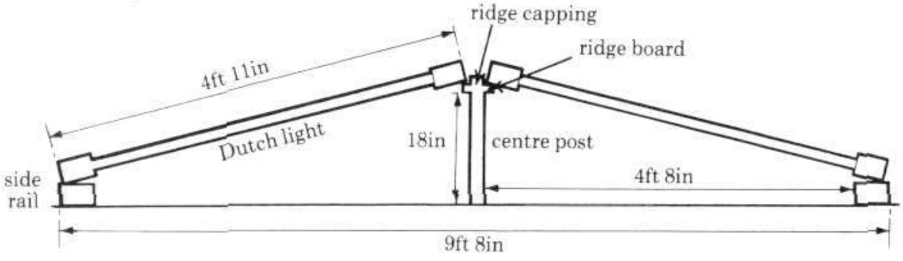


Fig. 29: double Dutch-light span frame.

A careful experiment at Stockbridge House Experimental Horticulture Station, Cawood, Yorkshire, in the early 1950s, showed surprisingly little difference in the winter growth of lettuces in span frames orientated in various directions. This being the case, a frame can be placed in the garden in the most convenient position, provided, of course, that it is not in the shadow of buildings or screens. A popular idea in the past was to construct a frame as a lean-to on either side of a north–south greenhouse or on the south side of an east–west one. This is a satisfactory arrangement with houses that have base walls of sufficient height.

Frames made from Dutch lights are not elaborate structures and the methods for securing the lights against wind are simple. Lights on single frames have a nail driven halfway into the middle of each end rail and two others similarly into each wall in a position directly below those in the light. Galvanised wire wrapped around each pair of nails will hold the light down. With span frames, nails are driven halfway into the upper surface of one end rail of each light and halfway into the edge of the other end rail of each. When the lights are placed on the frame each pair is hinged together with wire wrapped around the nails protruding upwards from the end rails and across the ridge. (See Fig. 30.) They are secured at their lower ends to the side walls in exactly the same way as with single frames.

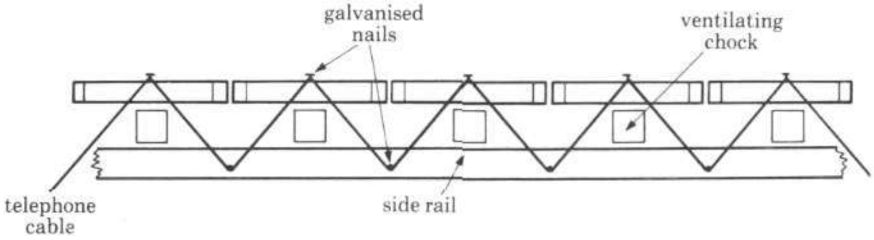
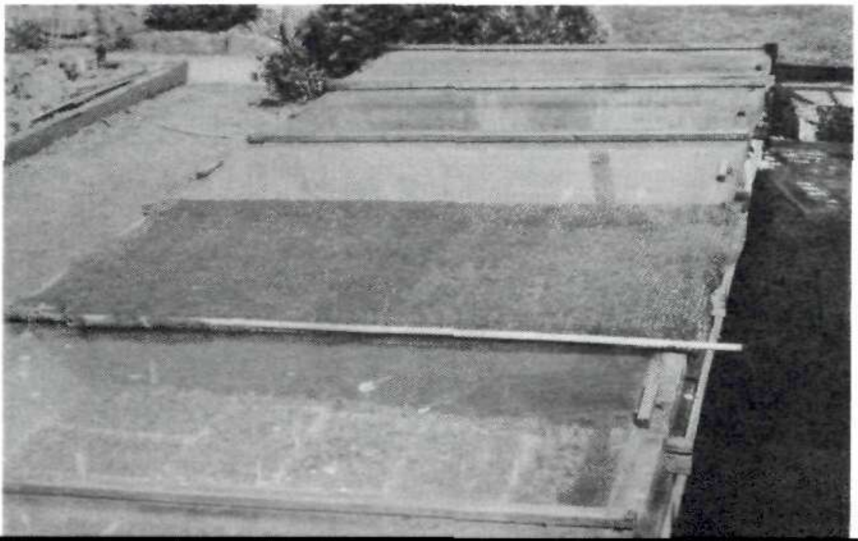
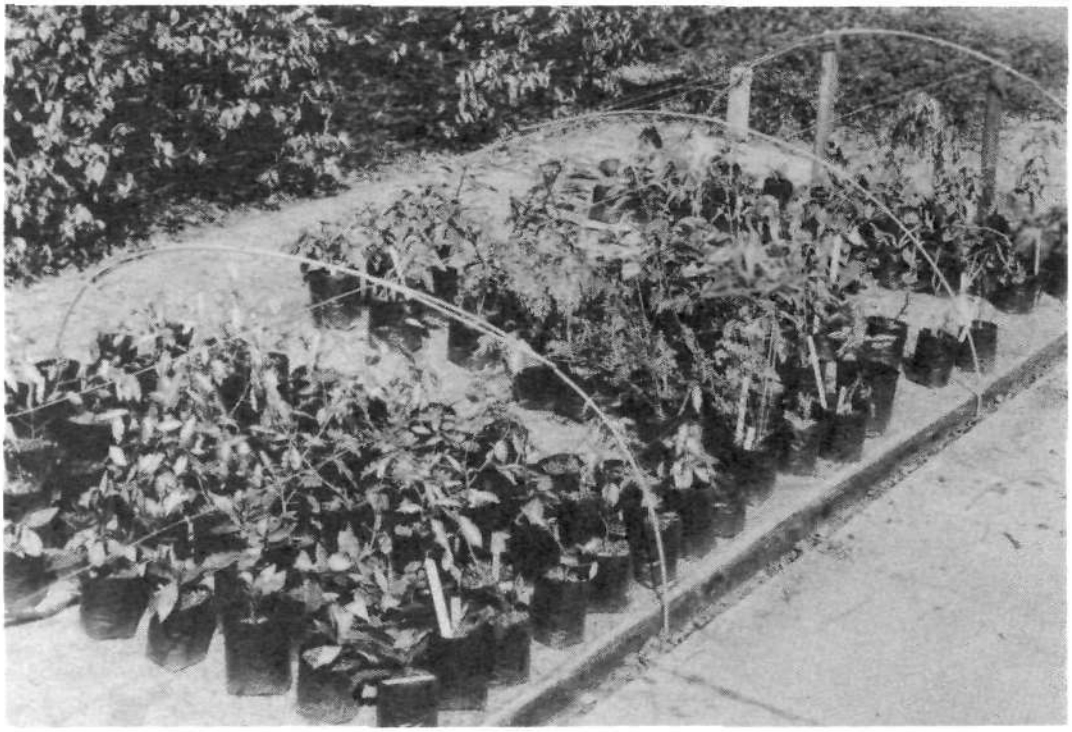


Fig. 30: fixing Dutch lights on frames to secure them against wind.

One of the great advantages of cold-frames is the facility they provide for giving plants increasing ventilation until they can withstand full exposure to the normal climate – the process known as hardening-off. Lights are propped up with wooden chocks to provide ventilation: a piece of wood measuring 50 mm × 100 mm × 150 mm (*2 in × 4 in × 6 in*) will provide three positions. If greater ventilation is required than this chock provides, then the time has come when the light can be removed altogether during the daytime. Dutch lights can easily be lifted by one person and when removed must be carefully stacked and secured.



A single-span Dutch-light frame being used for hardening-off bedding plants in an amateur's garden. The frame in the middle is covered with a plastic-mesh shading material which can also be used in frosty weather to provide further protection.



Plants in containers standing on a base material which is provided with a capillary watering system. The wire hoops are for placing polythene film over the area, either for protection from weather or to provide a propagation environment.

In winter time, protection extra to that provided by the glass may be *needed, for which purpose the frame is covered with heavy-grade hessian* fabric. At one time reed mats were made specifically for the purpose of covering frames. These, like hessian, are now difficult to obtain. The plastic fabrics used for thermal screens might provide a modern substitute.

Plants being hardened-off in frames are sometimes in danger of being scorched during periods of bright spring and early summer sunshine. To prevent this the glass of the light is sprayed with a shading material. This must be washed off before the lights are brought back into service in the autumn.

As previously stated, it was the practice to remove the soil to a depth of 150 mm (*6 in*) or so, put down a bed of clinker and cover this with ash to form a base on which the various containers could stand. The 'standing-base' for containers, as it is now called, has been shown to be almost as important as the compost in which the plants are growing. It has the function in summer of supplying water to the containers by capillarity and distributing it evenly over the whole standing area. In winter it has the function of draining the compost in the containers to maintain its air-filled porosity.

Nurserymen are being recommended to construct special standing-bases or standing-down beds for their container-grown plants. This bed was designed at the Experimental Horticulture Station of the Ministry of Agriculture, Fisheries and Food at Efford in Hampshire.

The bed is made of fine lime-free sand at least 50 mm (*2 in*) deep, and preferably 150 mm (*6 in*). It is lined with 500 gauge black polythene which is brought over the retaining walls and ends. A perforated 25 mm (*1 in*) alkathene pipe runs along the bed, under the sand, to act as a drainage channel to remove all surplus water to a soak-away.

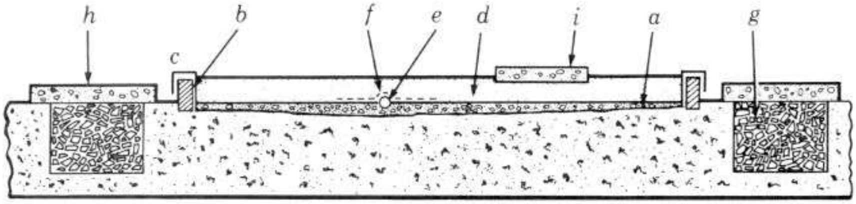


Fig. 31: a drained sand bed adapted to form a standing-base for a cold-frame.

a levelling sand or shingle
b timber side boards
c 500g black polythene enclosing bed
d firmed, clean, sharp sand (50mm depth)
e 25mm plastic pipe with 5mm drainage holes
f porous material to prevent pipe silting up
g soakaway trench
h outer pathway slab
i access pathway (if required)

There is no reason why such a bed could not be adapted to provide the base for a cold frame. (See Fig. 31.) A frame is, after all, no more than a standing-down bed, with removable glass cover.

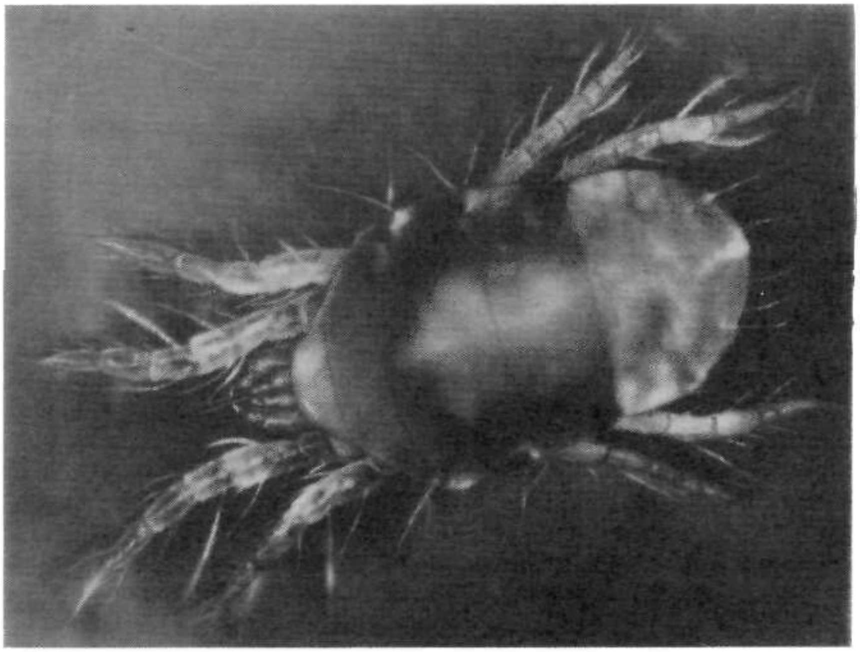
Hardening-off has already been described as a process of acclimatisation from one environment to another, for which the cold-frame is particularly suitable, but it may be helpful to enlarge a little more upon it. If plants are suddenly subjected to a change of environment which involves a lowering of temperature and exposure to a much more turbulent atmosphere, the soft tissue they will have developed previously will suffer considerable damage before their natural powers of adaptability have had time to bring about the necessary changes. Plants can often survive within quite a wide temperature band, but grow at different rates at either end of it, producing softer tissues at the higher end and harder ones at the lower end. The hardening-off process in frames is a procedure for bringing about these temperature-induced changes gradually in a situation sheltered from atmospheric turbulence, where protection from sudden extremes of temperature is also available. Meanwhile the environment outside the frame is gradually improving. After a few weeks the adaptation of the plant and the improvement in its intended environment have reached the point of coincidence, where acclimatisation has been achieved.

Chapter 12

Pests and diseases

Green plants directly and indirectly provide the food for most other living things including, of course, man. When other living things are in direct competition with man for a particular plant or crop they are referred to as pests, diseases, parasites and the like. Technically any life form attacking a plant is, in plain language, a pest and in scientific language a pathogen, and causes the plant to be diseased. For convenience horticulturists categorise pathogens into *pests* which are invertebrate animals, mostly insects and mites, and *diseases*, which are caused by fungi, bacteria and viruses. In addition plants may be in a state of ill-health without any pathogen being responsible. Such conditions are referred to as physiological disorders, and are caused by an abnormality in the environment, e.g. waterlogging, nutrient deficiency, chemical damage etc. Finally, vermin such as mice, squirrels and rabbits may cause havoc. No one would hesitate to call them pests, though strictly speaking they are vertebrate animals as opposed to the more common invertebrates.

Plants under glass may be diseased through any of the preceding causes, some of which attack anything whereas others are more selective in their choice of host. The subject of pests and diseases and their control is the source of an abundant literature, some of which is very academic. In Great Britain the Ministry of Agriculture, Fisheries and Food (MAFF) produces



The red spider mite, which is a serious and common pest of plants in greenhouses, particularly heated greenhouses. It is almost impossible to avoid attacks from this pest sooner or later, and pesticides have to be used to control it. (The biological control by means of a parasite used by commercial growers is impracticable for amateurs.)

annually a book entitled *Approved Products for Farmers and Growers* which is regarded as a standard work of reference and which lists all the products approved for general use in agriculture and horticulture; it gives the name of each pesticide by which it is internationally known; the purposes for which it may be effectively used; the limitations to its use, e.g. plants which are damaged by it, if any; pests which may develop resistance to it and any hazards attendant upon its use together with the precautions which should be adopted; it then lists the manufacturers and the proprietory names under which they sell it. In another section it gives information on the pests and diseases of various important plants and the chemicals which control them. It is well worth the cost, and in spite of the new products which continue to come onto the market, one edition remains sufficiently up-to-date for two or three years.

Should the gardener use the above book he can find which chemicals are available for use for a specific problem, but he will not know whether the product is available in suitable small packs. To guide him through this difficulty the MAFF produces another very useful publication entitled *Chemicals for the Gardener*. This lists the chemicals available for the amateur and gives brief but accurate information on the identification of the more common pests and diseases. Lastly the MAFF also produces a series of *Advisory Leaflets*, each on a specific pest or disease; they are continually updated and give the best advice available on the subject at a very modest cost. A catalogue is published annually by Her Majesty's Stationery Office listing, with their prices, all the publications available. Another source of information is to be found in the booklets produced by the pesticide firms, which often contain a vast amount of technical information in condensed and tabulated form.

Application of pesticides

Pesticide chemicals can be applied in greenhouses in a number of different ways. The most familiar method is high-volume spraying which is where the chemical is dissolved in a large amount of water and then applied as a drenching spray all over the crop. Next and equally familiar is fumigation which is when a chemical is vaporised in the greenhouse, usually by heat. Fumigation has to some extent been superseded by the use of smokes

A plastic walk-in tunnel being fumigated by means of a smoke.

which are pyrotechnic devices on which a fuse is lit to produce dense smoke which carries particles of the chemical to all parts of the house. Aerosols work on a similar principle. It is now possible to purchase electric devices whereby a very low-volume spray is distributed so that minute droplets of the fluid reach all parts of the plant. The last method, and the least popular, is dusting.

It is difficult to say which is the best method of application because it depends on the problem that is being dealt with, the size of the house and so on, but a light plastic pneumatic sprayer or similar hand-operated knapsack sprayer is really indispensable for the application of high-volume sprays. If the substance to be applied can be obtained as a smoke or aerosol, so much the better, and if an electric atomiser can be afforded then the armoury will be quite formidable.

Pesticides

All parts of the plant are susceptible to attack by pathogens, the roots as much as the aerial parts. Soil-borne pathogens have already been mentioned in Chapter 6 as well as their eradication by heat sterilisation by means of steam. This remains an extremely effective way of dealing with them and, although it cannot penetrate deeply enough to deal completely with tomato mosaic virus or certain wilt-causing fungi, nothing has superseded it. Notwithstanding this, in the last few years effective chemical sterilants have been developed for disinfecting the greenhouse soil, the compost for containers and even the soil round individual plants in the greenhouse. The more important of these are:

Metham-sodium. This can be purchased as a liquid preparation under the names of 'Vapam' or 'Sistan' or as a solid prilled* material under the name of 'Dazomet'. It is used as a chemical sterilant for the greenhouse soil or for sterilising compost loam. After application the soil has to be covered with a plastic sheet to stop the methyl isothiocyanate vapour it gives off escaping. After three weeks of fumigation the soil is uncovered and cultivated three times at fortnightly intervals to rid it of residual fumes which are phytotoxic (injurious to plant tissues).

* see Glossary

Drazoxolon. This is a fungicide sold under the name of 'Milcol' and is used against the damping-off disease of seedlings (*Pythium debarryanum*). Containers ready for sowing can be treated before the seed is sown (or afterwards if there is no danger of the seed being washed away) and also when the seedlings have been pricked-off.

Etridiazole. This is available under the trade names 'Truban', 'Terrazole' and 'Aaterra'. It is effective against the damping-off disease of seedlings and footrot *(Phytophthora* species) and is now very widely used for this purpose.

Cheshunt Compound. This mixture has been in use for over fifty years and is very effective against the damping-off disease of seedlings.

New materials or mixtures of existing ones with a broader spectrum of activity are being developed or are under trial.

The common pests of greenhouse crops, the appearance of which sooner or later is inevitable, are aphids, known as greenfly (although they may be all sorts of other colours), red spider and whitefly. All are very difficult to control because of their ability to develop resistant strains to new pesticides. As it is impossible to give specific recommendations for the control of the first two, you should purchase two or three different pesticides recommended for the control of each of these pests and use them in turn. For red spider and whitefly commercial growers of tomatoes and cucumbers use 'integrated control', which is a careful blend of chemical and biological control. Unfortunately it is quite beyond the resources of the amateur.

Biological control means the introduction of a parasite which will reduce the population of the pest to a point where its effect can be tolerated. It was thought at one time that it would prove the answer to the problem for amateur and professional alike, but in the event it proved impossible to maintain the parasite population in small greenhouses.

A fairly recently developed group of pesticides (e.g. Resmethrin) is that known as the synthetic pyrethroids. These are proving very successful against whitefly, and are now available in small packs for amateur gardeners.

Since the advent of peat composts and capillary beds, sciarid fly or fungus gnat has become a serious pest of plants in containers. The small flies are seen on the surface of the compost but the damage is caused by the maggots which feed on the roots of the plants. A sharp look out should be kept for this pest and if it is seen Diazinon should be used as a drench.

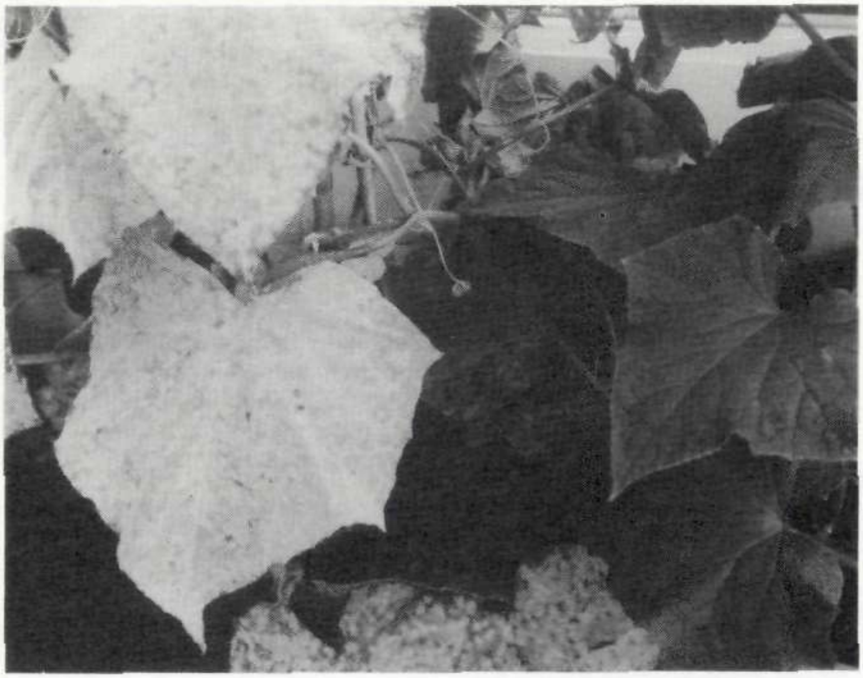
Another general pest of pot plants is the tarsonemid mite, sometimes called the cyclamen mite. It is waxy white or light brown in colour and hardly visible to the naked eye. The leaves of pot plants are attacked and become brittle and curled. Their surfaces may become purple and dark with a cracked appearance. An effective control is to spray the plants with dicofol (sold under the trade name of Kelthane).

Fungicides

Turning to fungal diseases, we have as general troublemakers the powdery mildews. There are many different species concerned, but the symptoms of their damage are white spores which look like powder and which cover the leaves and stems of the host plant. Benomyl (sold as Benlate) has proved very effective against the powdery mildews. It is a systemic fungicide and can be used as a root drench as well as a spray. It has prophylactic effects as well as curative ones. It is effective against many other fungal diseases in addition to the powdery mildews. Incidentally, powdery mildews are active in dry conditions whereas the downy mildews as a general rule require very damp and moist environments. The dreaded tomato leaf mould (*Cladosporium fulvum*) is similar to the powdery mildews, but brown in colour, and is also controlled by Benlate.

The downy mildews which attack grapes, lettuce and some pot plants have to be controlled by protective sprays based on copper compounds, sold under such trade names as Colloidox, Fungex, Cuprokylt and Perenox. Such sprays are most effective if applied before the disease appears and in anticipation that it will do so. Do not delay until symptoms appear. The dithiocarbarmate group, of which zineb is most readily available to the amateur, is effective against downy mildews as well as other diseases.

Perhaps the most common fungus seen under glass is the grey mould fungus (*Botrytis cinerea*). Normally it does not attack healthy tissues but confines itself to dead plant tissue on which it forms the common, ever present, grey fluff of decay. It can, however, pass from dead or dying tissue into living tissue; if, for example, tomatoes are de-leafed so that stumps are left on the stem to die, *Botrytis* can establish itself on them and then pass into the stem and kill the plant. If this is seen to be happening and can



Cucumber leaves which have been badly affected by powdery mildew.

be taken in time, a dab of creosote on the lesion will save the plant. A dab means a very small amount – if the creosote is put all round the stem the plant will die. *Botrytis* attacks tomato fruits where they are attached to the stalk causing them to fall to the ground. In cold greenhouses it also causes spots to form on the fruits. Strawberry fruits are sometimes attacked, but spraying with Benomyl or Captan will give good control.

Virus diseases

Virus diseases attack most plants grown under glass. The two most common viruses are tomato mosaic virus (TMV), originally called tobacco mosaic virus, and cucumber yellow mottle mosaic. The latter has a very wide range of hosts. A number of viruses attack chrysanthemums and carnations, and, in fact, it is difficult to find any plant of importance which does not have some virus enemy. Viruses are spread mainly by sap-sucking insects, among which winged aphids are by far the most important, so that aphid control is an indirect method of virus control. Viruses rarely kill their host, but they weaken it and may make it unsightly and perhaps unusable. The most common symptom is mosaicing of the leaves, sometimes distortion of the leaf or flower, and a characteristic spotting called Ringspot. Virus diseases can be eradicated from stocks of plants by special propagation techniques known as meristem culture or micropropagation (see Appendix VII). The principle underlying this practice is to propagate the plant from a few cells excised from the growing tip of a stem before the virus particles have had time to enter them. This method has provided us with virus-free stocks of many plants, particularly carnations and chrysanthemums.

Physiological disorders

The tomato provides a number of examples of physiological disorders. Blossom end rot is one that plagues amateur gardeners. It is characterised by a dark brown hard sunken lesion at the point of the fruit where the petals were originally attached. It is thought to be caused by the plant having undergone water stress coupled with calcium deficiency at some time. Plants in peat modules are very susceptible if the modules are not watered frequently enough. Blotchy ripening and greenback of the fruits are other physiological disorders with rather more complicated causes; magnesium deficiency is due to potassium levels in the soil being too high in relation to magnesium. Shanking of grapes (see page 100) is a physiological disorder, probably connected with moisture stress in the plant, and so probably is tipburn of lettuces which is a constant anxiety to the commercial grower.

The avoidance of physiological disorders is simple in theory, because all that is required is to ensure that there are no imbalancing factors in the plant's environment. In practice every experienced grower knows that the more sophisticated the cultivation of a crop the greater becomes the risk of physiological disorders occurring.

For further information on pesticides see Appendix III.

Appendix I

Heat requirement for greenhouses

In order to maintain a given temperature in a greenhouse the heat input must at all times equal the rate at which the house is losing heat. Heat loss is constantly changing, the determinants being windspeed, the clearness of the night sky, and whether the glass overlaps are sealed by moisture. Any estimate of heat loss must allow for the most extreme conditions which could occur, and then strike some compromise between them and what is probable.

This is done by dividing the country into regions with similar climatic patterns and deciding upon an outside base temperature. This is the lowest outdoor temperature in that particular region likely to persist for a protracted period of time, rather than for only two or three hours. In England, for example:

	°C	*°F*
Southern England	−4.5	*24*
London and the East	−5.5	*22*
South-west	−1	*30*
Yorkshire and North-east	−6.5	*20*
North-west	−5.5	*22*

Check for your own locality by consulting the local horticultural advisor of the Agricultural Development and Advisory Service (ADAS) of the Ministry of Agriculture and Fisheries, in Great Britain, or similar advisory bodies in other countries.

Once the outside base temperature has been determined it must then be decided what is the lowest temperature required to be maintained in the greenhouse. This is best referred to as the minimum night temperature, because if it can be maintained at night, when there is no assistance whatever from the sun, it can easily be maintained during the day. If the outside base temperature is subtracted from the greenhouse minimum night temperature, we have what is called the temperature lift.

The heat loss through the surface of a greenhouse is estimated as being

8 watts per metre squared per C° difference between inside and outside temperatures
(1.4 British thermal units per hour per square foot per F° difference between inside and outside temperatures)

To obtain the total heat loss per hour it is necessary to calculate the surface area of the greenhouse. As this includes the brick wall on which the house may stand the area of the wall is divided by half to allow for its lower thermal transmission. The total figure is called the equivalent glass area. Calculate it as follows:

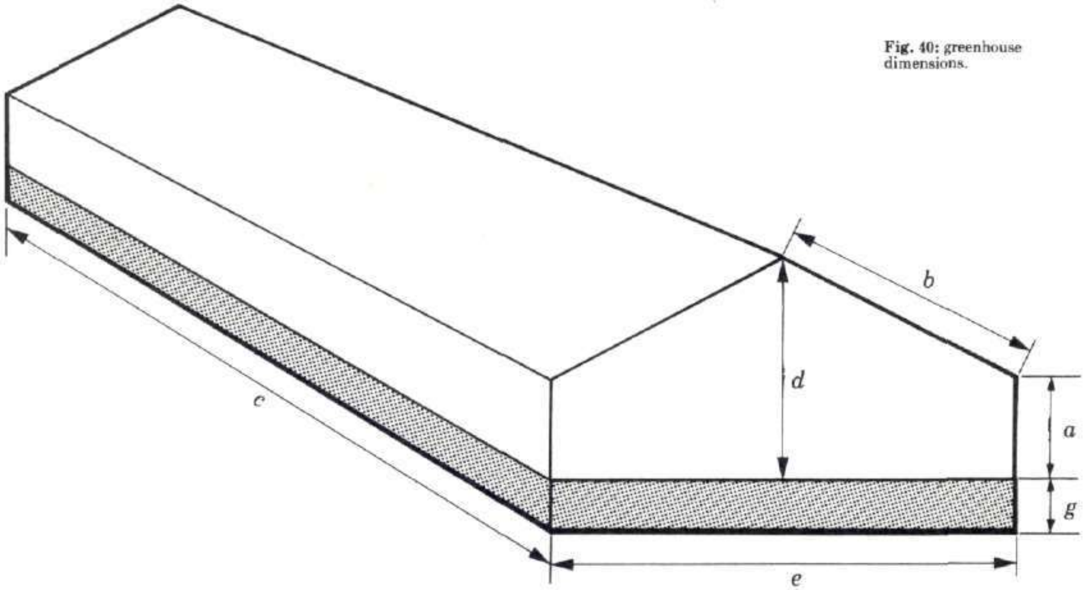


Fig. 40: greenhouse dimensions.

area of roof plus glass walls = 2 × (height of glass walls (*a*) + roof slope (*b*)) × length (*c*) =	*x*
area of gable ends plus end glass walls = (height of glass to ridge (*d*) + height of glass wall (*a*)) × width (*e*) =	*y*
half area of brick walls = height of brick walls (*g*) × (length (*c*) + width (*e*)) =	*z*
	x + *y* + *z*

If we give values to the dimensions, e.g.

a =	1 m	*3½ ft*
b =	5 m	*17 ft*
c =	30 m	*100 ft*
d =	3.5 m	*11½ ft*
e =	9 m	*30 ft*
g =	0.5 m	*1½ ft*

then the equivalent glass area of the house in Fig. 40 would be:

Area of roof and glass walls		
= 2 × (1 + 5) × 30	= 360 m²	
or *2 × (3½ + 17) × 100*	=	*4100 sq ft*
Area of gable ends + end glass walls		
= (3.5 + 1) × 9	= 40.5 m²	
or *(11½ + 3½) × 30*	=	*450 sq ft*
Half area of brick walls		
= 0.5 × (30 + 9)	= 19.5 m²	
or *1½ × (100 + 30)*	=	*195 sq ft*
	420 m²	*4745 sq ft*

The heat requirement of the house is

equivalent glass area in m² (*sq ft*) × temperature lift in C° (*F°*) × *F*

where *F*, the conversion factor, is 8×10^{-3} kW/m²/C° (*1.4 Btu/sq ft/F°/hr*). The metric calculation gives the answer in kilowatts, and the imperial calculation gives the answer in British thermal units per hour.

Suppose that the greenhouse used as our example is in Yorkshire, where the outside base temperature is −6.5°C (*20°F*). If it is to have a heating system which will maintain a minimum night temperature of 15.5°C (*60°F*), we can calculate that the temperature lift required will be:

15.5° + 6.5° = 22C° (*60° − 20° = 40F°*)

and its heat requirement will be

$420 \times 22 \times 8 \times 10^{-3} = 74$ kW (*4745 × 40 × 1.4 = 265,720 Btu/hr*).

If this amount of heat is to be provided by a solid-fuel boiler it is usually necessary to have a boiler with a heat capacity one-third greater than the heat requirement of the greenhouse. This allows for the various unavoidable losses of heat normally referred to as boiler inefficiency.

For further details see MAFF Bulletin No. 115, *Commercial Glasshouses*.

Thus the boiler capacity required would be

74 × 1.33 = 99 kW (*265,720 × 1.33 = 354,293 Btu/hr*)

Boilers are, of course, made in discrete sizes, and the one suitable would have a capacity not less than that required – say 400,000 Btu/hr or 120 kW. If oil or gas boilers are used the efficiency may be higher. Professional advice is required before purchase is made.

The next step in installing a heating system is knowing how much pipe of any particular diameter is needed to deliver the amount of heat required into the house. The thermal transmission of metal pipes depends upon their diameter, the temperature of the water or steam inside them and the temperature at which the house is kept. In a hot water system it is usual for the heat to leave the boiler, when the system is working to the full, at a temperature of 82°C (*180°F*) and return at one of 71°C (*160°F*) giving an average temperature of 76.5°C (*170°F*). At this temperature the thermal emission of various pipes is as follows:

100 mm (*4 in*) cast iron	277 watts/metre	*288 Btu/ft/hr*
50 mm (*2 in*) mild steel	174 watts/metre	*180 Btu/ft/hr*
37 mm (*1½ in*) mild steel	129 watts/metre	*134 Btu/ft/hr*
31 mm (*1¼ in*) mild steel	104 watts/metre	*107 Btu/ft/hr*
25 mm (*1 in*) mild steel	93 watts/metre	*96 Btu/ft/hr*

These figures have to be adjusted up or down slightly if it is intended to maintain higher or lower temperatures in a greenhouse, but the difference in the amount of pipe required in a small greenhouse is neither here nor there.

The amount of pipe required is the heat requirement of the house divided by the thermal emission of the pipe. Thus in the example chosen the amount of pipe required would be:

	metres	**feet**
100 mm (*4 in*) cast iron	267	*923*
50 mm (*2 in*) mild steel	425	*1476*
37 mm (*1½ in*) mild steel	574	*1983*
31 mm (*1¼ in*) mild steel	712	*2483*
25 mm (*1 in*) mild steel	796	*2768*

As can be seen, for smaller diameters of pipe a considerable length has to be accommodated within the house, e.g. 31 mm (*1¼ in*) pipe would have at least twelve flows up the house and twelve returns. To reduce the amount of such pipe, gilled pipe, which has a much greater thermal emission per unit length, is often used.

Fuel required to maintain a minimum temperature of 7 °C (*45 °F*) throughout the year in small greenhouses

Size	**Coal** (kg) (70% efficiency)	**Oil** (litres) (80% efficiency)	**Electricity** (kW-hr) (100% efficiency)	**Natural gas** (therms) (100% efficiency)	**Bottled gas (propane)** (cu ft) (100% efficiency)
1.8 × 2.4 m *6 × 8 ft*	158	103	860	30	1174
2.4 × 3.7 m *8 × 12 ft*	226	146	1227	42	1675
2.4 × 4.6 m *8 × 15 ft*	330	213	1796	62	2452
3 × 3.8 m *10 × 12½ ft*	308	199	1674	58	2284
3 × 4.6 m *10 × 15 ft*	399	260	2162	74	2951
3 × 5.3 m *10 × 17½ ft*	448	291	2426	83	3312
3 × 6.1 m *10 × 20 ft*	495	323	2689	92	3670
3 × 7.6 m *10 × 25 ft*	599	383	3218	110	4392
3 × 9.1 m *10 × 30 ft*	690	446	3746	128	5113
3.7 × 6.1 m *12 × 20 ft*	559	360	3037	104	4145
3.7 × 7.6 m *12 × 25 ft*	666	432	3615	124	4934
3.7 × 9.1 m *12 × 30 ft*	773	496	4193	144	5727
4.6 × 9.1 m *15 × 30 ft*	869	560	4713	161	6433

Fuel required to maintain a minimum temperature of 15°C (*60°F*) during March, April, May and June in small greenhouses

Size	Coal (kg)	Oil (litres)	Electricity (kW-hr)	Natural gas (therms)	Bottled gas (propane) (cu ft)
1.8 × 2.4 m *6 × 8 ft*	312	202	1693	58	2311
2.4 × 3.7 m *8 × 12 ft*	446	288	2416	83	3298
2.4 × 4.6 m *8 × 15 ft*	689	444	3733	128	5095
3 × 3.8 m *10 × 12½ ft*	653	421	3541	121	4832
3 × 4.6 m *10 × 15 ft*	785	507	4257	146	5810
8 × 5.3 m *10 × 17½ ft*	882	568	4777	163	6520
3 × 6.1 m *10 × 20 ft*	977	630	5295	181	7227
3 × 7.6 m *10 × 25 ft*	1169	754	6336	217	8648
3 × 9.1 m *10 × 30 ft*	1361	877	7376	252	10067
3.7 × 6.1 m *12 × 20 ft*	1103	711	5986	205	8170
3.7 × 7.6 m *12 × 25 ft*	1313	847	7118	243	9715
3.7 × 9.1 m *12 × 30 ft*	1523	982	8257	282	11270
4.6 × 9.1 m *15 × 30 ft*	1712	1105	9282	317	12669

The cost ratio is, very approximately,

coal	18
oil	38
electricity	100
natural gas	21
propane	54

(based on UK fuel costs at November 1981).

Fuel required to maintain a minimum temperature of 18°C (*65°F*) throughout the year in small greenhouses

Size	Coal (kg)	Oil (litres)	Electricity (kW-hr)	Natural gas (therms)	Bottled gas (propane) (cu ft)
1.8 × 2.4 m *6 × 8 ft*	1825	1178	9904	338	13517
2.4 × 3.7 m *8 × 12 ft*	2604	1680	14132	483	19288
2.4 × 4.6 m *8 × 15 ft*	3075	1985	16686	570	22774
3 × 3.8 m *10 × 12½ ft*	2908	1876	15780	539	21537
3 × 4.6 m *10 × 15 ft*	4589	2960	24719	844	33737
3 × 5.3 m *10 × 17½ ft*	5149	3323	27944	954	38138
3 × 6.1 m *10 × 20 ft*	5707	3683	30974	1057	42274
3 × 7.6 m *10 × 25 ft*	6830	4408	37066	1265	50588
3 × 9.1 m *10 × 30 ft*	7950	5131	43147	1473	58888
3.7 × 6.1 m *12 × 20 ft*	6446	4160	34981	1194	47743
3.7 × 7.6 m *12 × 25 ft*	7673	6302	41641	1421	56832
3.7 × 9.1 m *12 × 30 ft*	8900	7309	48302	1649	65923
4.6 × 9.1 m *15 × 30 ft*	10004	8717	54296	1853	74104

Appendix II

The preparation of liquid feeds

1. The preparation of liquid feeds, as opposed to the purchase of ready-mixed preparations either as powders or solutions, offers three advantages:

a. It is considerably cheaper.
b. Any nutrient ratio can be achieved.
c. Any concentration of feed can be obtained from a standard dilution rate.

2. In the past, various dilution rates for stock solutions have been used, but the Glasshouse Crops Research Institute has long advised a standard dilution rate of 1 in 200, varying the concentration of the stock solution accordingly. All the calculations that follow are based on this procedure.

3. The concentration of liquid feeds is expressed in terms of parts per million of nutrient (ppm). To give an immediate impression of the concentration of a particular feed, the total nutrient concentration is frequently stated together with the nutrient ratio. For example:

A widely used feed for vigorous pot plants contains
500 ppm of nutrient with N and K_2O in the ratio of 2 : 1
ppm of $N = 500 \times \frac{2}{3} = 333$
ppm of $K_2O = 500 \times \frac{1}{3} = 166$
N = Nitrogen K_2O = Potash $K_2O \times 0.83$ = Potassium.

4. The fertilisers used for liquid feeding must be soluble and free from insoluble impurities. It may be necessary occasionally to strain stock solutions through fine gauze to remove any insoluble impurities. Those in normal use are as follows:

a. Potassium nitrate (KNO_3) 13%N : 46% K_2O – the most widely used potassium source and one which will not affect the pH of the compost.
b. Potassium sulphate (K_2SO_4) 48% K_2O. This is a single source of potassium. Its sulphate ions will lock up calcium as calcium sulphate, and reduce the amount of exchangeable bases in a compost, so preventing its pH rising under the influence of hard water. It is the preferred form for loamless composts.
c. Ammonium nitrate (NH_4NO_3) 35%N. This is the normal substance used for increasing the nitrogen content of a feed without adding any but ammonium and nitrate ions. The nitrification of its ammonium ions leads to the removal of two calcium ions.
d. Urea ($CO(NH_2)_2$) 46%N. This may be regarded as a straight alternative to ammonium nitrate in all respects. It must be guaranteed free from the phytotoxic impurity biuret. It is less readily obtainable, and now has been more or less superseded by ammonium nitrate.
e. Ammonium sulphate ($(NH_4)_2SO_4$) 21%N. This is generally used for feeds for tomatoes, whose flavour it is said to improve. Its nitrification can immobilise four calcium ions, and its use may be advisable for increasing the nitrogen content of feeds for use on loamless composts and where hard water may cause the pH to rise.
f. Mono-ammonium phosphate ($NH_4H_2PO_4$) 11%N: 48% soluble P_2O_5. This is used for providing phosphate to a feed on the comparatively rare occasions when it is needed.
NB The ammonium metallic phosphates such as Magamp have no real use in the preparation of liquid feeds.
g. Magnesium sulphate ($MgSO_4$) 20% Mg. This may be needed to prevent magnesium deficiency, particularly for sensitive crops such as those of the family Solanaceae, e.g. tomato, pepper etc.
h. Aluminium sulphate $Al_2(SO_4)_3$. Used for the 'blueing' of hydrangeas.

5. In order to prepare a stock solution, the quantities of the various fertilisers that must be dissolved in one litre (*one gallon*) of water must be calculated.

a. In grams for preparing stock solutions in litres using the formula

$$\frac{\text{ppm of nutrient required} \times 20}{\text{percentage of nutrient in fertiliser}}$$

to prepare a stock solution for a liquid feed containing 166 ppm of potash (K_2O) using potassium nitrate

$$\frac{166 \times 20}{46} = 72 \text{ grams (to nearest gram) are required per litre}$$

b. In ounces for preparing stock solutions in gallons using the formula

$$\frac{\text{ppm of nutrient required} \times 16}{5 \times \text{percentage of nutrient in fertiliser}}$$

$\frac{166 \times 16}{5 \times 46} = 11\frac{1}{2}$ oz of potassium nitrate (to nearest $\frac{1}{2}$ oz) are required per gallon

c. When it is necessary to use fertilisers like potassium nitrate which contain two nutrients, i.e. in this case nitrogen and potassium (K_2O), it is necessary to calculate first the amount of potassium nitrate needed to provide the correct amount of potash as in (a) or (b) above and then to calculate the ppm of nitrogen this will provide. This amount of nitrogen must then be subtracted from the total amount of nitrogen required in ppm if this is greater than the amount already provided by the potassium nitrate.

For grams use the formula:

$$\frac{\text{percentage of nutrient in fertiliser} \times \text{amount of fertiliser}}{20}$$

from example (a) above

$\frac{13 \times 72}{20} = 47$ ppm of nitrogen (to nearest ppm)

are provided by 72 grams of potassium nitrate

For ounces use the formula:

$$\frac{\text{percentage of nutrient in fertiliser} \times 5 \times \text{amount of fertiliser}}{16}$$

from example (b) above

$\frac{13 \times 5 \times 11\frac{1}{2}}{16} = 47$ ppm of nitrogen (to nearest ppm)

are provided by $11\frac{1}{2}$ oz of potassium nitrate.

6. A worked example illustrates the method of calculation:

Using potassium nitrate and ammonium nitrate, calculate to the nearest gram (*$\frac{1}{2}$ oz*) the quantities of each to be dissolved in one litre (*one gallon*) of water to make a stock solution which when diluted 200 times will contain 333 ppm of nitrogen and 166 ppm of potash (K_2O)

Amount of potassium nitrate required =

$\frac{166 \times 20}{46} = 72$ grams *or* $\frac{166 \times 16}{5 \times 46} = 11\frac{1}{2}$ *oz*

This will provide

$\frac{13 \times 72}{20} = 47$ ppm nitrogen $\frac{13 \times 5 \times 23}{16 \times 2} = 47$ *ppm nitrogen*

ppm of nitrogen still required = 333 − 47 = 286

Amount of ammonium nitrate required =

$\frac{286 \times 20}{35} = 164$ grams *or* $\frac{286 \times 16}{5 \times 35} = 26$ *oz*

So the quantities required are:

Potassium nitrate	72 grams	*11½ oz*
Ammonium nitrate	164 grams	*26 oz*
Water	1 litre	*1 gallon*

7. The same method may be used where three nutrients are required, as in the following example:

Calculate in grams per litre (*ounces per gallon*) the quantities of ammonium nitrate, potassium nitrate and mono-ammonium phosphate required to make a stock solution which when diluted 200 times will provide a feed containing 600 ppm of total nutrient with N: soluble P_2O_5: K_2O in the ratio 2:1:1.

ppm of N $= 600 \times \frac{1}{2} \times 300$

ppm of soluble $P_2O_5 = 600 \times \frac{1}{4} = 150$

ppm of $K_2O = 600 \times \frac{1}{4} = 150$

Amount of potassium nitrate required =

$\frac{150 \times 20}{46} = 65$ grams   or $\frac{150 \times 16}{5 \times 46} = 10\frac{1}{2}$ *oz*

This will provide

$\frac{13 \times 65}{20} = 43$ ppm nitrogen $\frac{13 \times 5 \times 10\frac{1}{2}}{16} = 43$ *ppm nitrogen*

Amount of mono-ammonium phosphate =

$\frac{150 \times 20}{48} = 63$ grams   or $\frac{150 \times 16}{5 \times 48} = 10\frac{1}{2}$ *oz*

This will provide

$\frac{11 \times 63}{20} = 35$ ppm nitrogen   or $\frac{11 \times 5 \times 10\frac{1}{2}}{16} = 36$ *ppm nitrogen*

ppm of nitrogen still required =

$300 - (43 + 35) = 222$ or $300 - (43 + 36) = 221$

Amount of ammonium nitrate required =

$\frac{222 \times 20}{35} = 127$ grams   or $\frac{221 \times 16}{5 \times 36} = 20$ *oz*

So the quantities required are:

Ammonium nitrate	127 grams	*20 oz*
Potassium nitrate	65 grams	*10½ oz*
Mono-ammonium phosphate	63 grams	*10½ oz*
Water	1 litre	*1 gallon*

8. With the concentrations normally used for stock solutions, solubility problems are rarely encountered. If they do occur the quantities of fertilisers required should be dissolved into two litres (*2 gallons*) of water and the dilution rate set at 100 times. Potassium nitrate is soluble to the extent of about 0.22 kg per litre (*2¼ lb per gallon*) in cold water. The other chemicals have greater solubility.

9. Nutrient ratios in common use range in simple proportions from $1N{:}3K_2O$ to $2N{:}1K_2O$. Feeds applied to crops in soil usually range from $1N{:}3K_2O$ to $1N{:}1K_2O$, while for plants in containers ratios with N in excess of K_2O, e.g. $2N{:}1K_2O$, are common. This may be explained by the fact that in soil large amounts of NO_3^- (nitrates) would lead quickly to high conductivity (high soluble salt concentration) resulting in restriction of plant growth, whereas in a container leaching of nitrates prevents high conductivity.

10. Total nutrient concentrations may be as low as 300 ppm for slow-growing plants in winter, and as high as 800 ppm for container-grown shrubs in summer.

11. Liquid feeding when growth is fast (at the nutrient concentrations mentioned in (9) above) should be continual, i.e. with *every* watering.

12. Investigation of the nutrient needs of plants in soil or containers have been thorough for all the crops covered by the Agricultural Development and Advisory Service (ADAS) 'Blueprints', but for others, gardeners need to be guided by experience and only general recommendations can be given, e.g. vigorous pot plants in summer $N2{:}K_2O1$ total nutrient 300 ppm; these concentrations possibly reduced in winter, although as watering is then less frequent care to avoid malnutrition is necessary.

13. With loamless composts in hard water areas pH values tend to rise and result in lime-induced chlorosis and to counteract this liquid feeds which lock up calcium as calcium sulphate or cause it to be leached as calcium bicarbonate are necessary. Potassium sulphate and ammonium sulphate are used for this purpose.

14. Trace elements are included in many proprietory feeds, but are superfluous if a micro-nutrient frit has been added to the compost.

Some common liquid feeds (dilution always 1 in 200)

1.

Potassium nitrate	150 grams	*1½ lb*
Water	1 litre	*1 gallon*

Nutrient content = 105 ppm nitrogen, 335 ppm potash K_2O.
Nutrient ratio = $1N:3K_2O$
Used for newly planted tomatoes in soil.

2.

Potassium nitrate	150 grams	*1½ lb*
Ammonium nitrate	38 grams	*6 oz*
Water	1 litre	*1 gallon*

Nutrient content = 170 ppm nitrogen, 335 ppm potash K_2O
Nutrient ratio = $1N:2K_2O$
Used for tomatoes and other plants in soil through the main part of the growing season.

3.

Potassium nitrate	150 grams	*1½ lb*
Ammonium nitrate	70 grams	*11 oz*
Water	1 litre	*1 gallon*

Nutrient content = 225 ppm nitrogen, 335 ppm potash K_2O
Nutrient ratio = $1N:1\frac{1}{2}K_2O$

4.

Ammonium nitrate	62 grams	*10 oz*
Water	1 litre	*1 gallon*

Nutrient content = 110 ppm nitrogen
Used on cucumber on straw bales for first three weeks after planting.

5.

Ammonium nitrate	132 grams	*21 oz*
Water	1 litre	*1 gallon*

Nutrient content = 230 ppm nitrogen
Used on cucumbers on straw bales for second three weeks after planting.

6.

Potassium nitrate	25 grams	*4 oz*
Ammonium nitrate	100 grams	*16 oz*
Magnesium sulphate	25 grams	*4 oz*
Water	1 litre	*1 gallon*

Nutrient content = 191 ppm nitrogen: 58 ppm potash K_2O:25 ppm magnesium
Nutrient ratio = $7.5N:2.5K_2O:1Mg$
Used on cucumber on straw bales from six weeks after planting to end of season.

7.

Potassium nitrate	72 grams	*11½ oz*
Ammonium nitrate	164 grams	*26 oz*
Water	1 litre	*1 gallon*

Nutrient content = 333 ppm nitrogen:166 ppm potash K_2O
Nutrient ratio = $2N:1K_2O$
Used as a liquid feed for vigorous pot plants with every watering. Used at half strength for slow-growing plants.

8.

Ammonium sulphate	120 grams	*19 oz*
Potassium sulphate	88 grams	*14 oz*
Mono-ammonium phosphate	13 grams	*2 oz*
Water	1 litre	*1 gallon*

Nutrient content = 271 ppm nitrogen:30 ppm phosphate P_2O_5:203 ppm potash K_2O
Nutrient ratio = $1.3N:0.15P_2O_5:1K_2O$
Used for pot plants in peat-based loamless composts. 44 g (*7 oz*) of magnesium sulphate may be added.

Appendix III

Pesticides

1. 'Pesticide' is a general term which describes all chemicals used for the control of pests and diseases and for the destruction of weeds. Pesticides can be categorised according to their principal use, though relatively few have only one specific purpose. The following terms are in common use and in most cases their meaning is obvious:

Name	**Pest controlled**
acaricide	spider mites
aphicide	greenflies
bactericide	bacteria
fungicide	fungi
herbicide	weeds (herbicides have a sub-classification of their own)
insecticide	insects (including aphids)
moluscicide	slugs and snails
nematocide	nematodes (eelworms)
ovicide	eggs of insects and mites

2. It is usual to speak of controlling pests and diseases rather than curing or eradicating them. Control means limiting the incidence of the pathogen to an acceptable level. Nevertheless, it is often possible to prevent an attack from occurring, and sometimes possible to eradicate a pest from a crop for an extended period of time.

3. Almost all pesticides are freely available, but, for many, special precautions in their use must by law be observed under the appropriate regulations. Some compounds require full protective clothing to be worn by those using them, and others require a lesser but still high degree of protection for the user. These substances are taken out of effective reach of the amateur by the simple fact that they are not marketed in small enough packs to reach the garden centre and retail shop outlets. Some pesticides are scheduled as poisons and are, therefore, only obtainable on signature.

Although the amateur gardener will not normally be concerned with these regulations, you should, nevertheless, regard all pesticides with caution, and ensure that the instructions on the pack are observed to the letter. Manufacturers always give directions as to use, and the dilution rates they recommend have been established by intensive trial and investigation and must be adhered to. It is always dangerous to 'exceed the stated dose'.

4. Many pesticide chemicals fall into groups of related substances which tend to control the same categories of pests. The most important of these groups are:

The dithiocarbamate group These are fungicides used to control a wide range of fungal diseases including both downy and powdery mildews. Zineb, Maneb and Thiram are the best known and are used as protectant sprays. Thiram is also a valuable seed-dressing substance.

Copper fungicides These include the oldest effective fungicides we have, such as Bordeaux mixture (copper sulphate and calcium hydroxide), Burgundy mixture (copper sulphate and sodium carbonate), and Cheshunt compound (copper sulphate and ammonium carbonate). The two former are still used, although colloidal copper sprays have to some extent superseded them. Copper sprays are particularly useful against downy mildews and are used as protectants.

Sulphur and organo-sulphur compounds Sulphur on its own is no longer much used except for fumigating empty greenhouses. This is done by burning sulphur candles. Lime–sulphur has been used for many decades as a fungicide by the fruit grower. It is not, however, used under glass. The organo-sulphur materials are very useful modern safe fungicides. Captan is one of the better known.

Mercury compounds Mercuric oxide and mercurous chloride have been in use for a long time for seed dressing and for clubroot control in the cabbage family. Under glass, organo-mercury compounds were used for tomato mildew control and for other fungicidal purposes, but they have been superseded by new materials and will not be used by the amateur.

Systemic fungicides New fungicides within the last decade have been increasingly successful and further developments are likely. These are the systemic fungicides, of which benomyl is the best known. A systemic substance is one which is absorbed by the foliage or taken up by the roots of a plant and spreads throughout the whole organism.

The organo-chlorine group These were formerly called chlorinated hydrocarbons and include such well-known substances as DDT, BHC, aldrin and dieldrin. Because many are persistent chemicals and get into the food chains of birds and animals, their widespread field use is now restricted. Under glass the hazards to wildlife do not apply and smokes based on DDT and gamma BHC (Lindane) are still valuable insecticides and acaricides.

The organo-phosphorus group A very large number of these substances have been developed, mainly as acaricides and aphicides. They are mostly very poisonous. They include several systemic materials and are, unfortunately, substances to which aphids, red spider mites and white flies seem to develop resistance. Few are available to the amateur, but malathion is very valuable as an aphicide, acaricide and general insecticide under glass.

Carbamates These are mostly persistent chemicals used as wormkillers, nematocides and moluscicides but also as general insecticides. The only one likely to come the way of the amateur is the moluscicide draza; it is an excellent defence against slugs and snails.

Derris and pyrethrum These are plant derivatives which have for long been safe and reliable insecticides, particularly for the amateur. Active research and development is now directed towards the production of chemicals which have many of the properties of pyrethrum; these are called synthetic pyrethroids. They are expected to increase in number and to be approved for wide use as insecticides, particularly under glass. Resmethrin is the best known at the present time.

Appendix IV

Ventilation

1. Natural ventilation

Ventilation is the process whereby warm air within a greenhouse, because of its lower density, floats upwards and escapes into the external atmosphere through the overlaps of the glass and any other aperture.

In new, well-designed greenhouses, when the doors and ventilators are closed, this leakage of air brings about total replacement of the atmosphere within about two hours. In general, and especially in older houses, the rate will be about twice as fast, i.e. one complete change in one hour.

By providing ventilators along the ridge of the house the rate of air-change can be greatly increased, and if low-level side and end ventilators are provided also, the entry of external cooler air can be greatly facilitated by increasing what is called the 'chimney effect'.

2. Measurement of ventilation

The easiest way to think of ventilation is in terms of the number of air changes per hour (ac/h), but a more precise determination is to think in terms of air-flow.

If it is imagined that a fan, at one end of a greenhouse, were extracting air from within it, it is quite easy to picture the air flowing along and agree that this could be measured as the volume of air passing over a square metre (*square foot*) of floor-surface. It also follows that the taller the greenhouse, the greater the volume of air it would enclose and the faster this air would have to flow to bring about an air-change within the same compass of time as would be the case were it a lower house, enclosing less air.

The ventilation rate is thus stated as cubic metres of air per square metre of base area per hour (*cubic feet air/square foot/hour*).

3. Ventilation requirement

This cannot be stated precisely but there is general agreement that to provide efficient cooling in hot and still summer weather, air-flow rates of from 140–180m^3/m^2 of base area/hour are needed (*450–600 cu ft/sq ft of base area/hour*).

The lower rate is appropriate for large houses, i.e. with an average height greater than 3 m

(*10 ft*), and the higher rate for small ones, i.e. with an average height less than 3 m (*10 ft*).

Flow-rates can be converted to air-changes per hour, by dividing flow-rate by average height. Thus for a garden greenhouse with an average height of 2.05 m (*6 ft 9 in*) the air-change rate would be (180/2.05) = 88 ac/h.

4. Ventilation provision

There is no formula for calculating ventilator provision from air-change rate.

Experience indicates that in larger houses, with side and end ventilators, effective cooling can be obtained with ridge ventilators providing an opening equal to 15 per cent of the base area of the house. Where there is no side or end ventilation the provision has to be doubled to 30 per cent of base area.

For garden-size greenhouses there is no stated recommendation but 30 per cent of base area with side and end ventilation is assumed to be adequate.

In practical terms this would mean that a garden greenhouse measuring 2.4 m × 3.7 m (*8 ft × 12 ft*) requires on both sides of its ridge 1.3 m^2 (*14½ sq ft*) of ventilator opening, which could be provided by ventilators on each side of the ridge, running its whole length and 0.36 m (*15 in*) wide (or deep).

To be effective these ventilators would need to open through 60° so that the opening provided is equal to the area of the ventilator.

5. Forced-draught or fan-ventilation

Positive ventilation can be provided by means of extractor-fans installed at one end, or side, of a greenhouse, with louvres at the other end, or side, which open, proportionately with the speed of the fan, to admit the replacement air. Fans and louvres are controlled by thermostats. The systems work effectively but are not really appropriate for amateur gardeners. The fans are noisy and the systems are dependent on an electricity supply which must be backed up by standby generators in case of power failure.

For further details see MAFF Bulletin No. 115, Commercial Glasshouses.

Appendix V

Soil sterilisation

1. As the temperature of the soil is raised there is a progressively more lethal effect upon its teeming population.

Thermal death points of soil organisms

Temperature		**Organisms killed or inactivated**
°C	°*F*	
55	*130*	All soft-bodied animals, e.g. earthworms, eelworms, slugs, protozoa; most weed seeds; nitrifying bacteria, and most plant viruses
63	*145*	Most of the fungi causing plant diseases, particularly root rots; all weed seeds
82	*180*	Fungal wilt diseases of plants, particularly *Verticillium* and *Fusarium*
88	*190*	Tomato mosaic virus (TMV) is inactivated.
100	*212*	Ammonifying bacteria form resistant spores and can survive quite long exposures
127	*261*	All living organisms

Lower temperatures for longer periods can have the same effect as higher ones for short periods, e.g. 43°C (*110°F*) for 10 minutes has the same effect as 63°C (*145°F*) for seconds.

2. The soil can only be heated effectively by causing steam to condense within it.

(a) It takes 112–118 g of steam to raise the temperature of 1 litre of dry soil to 100°C (*7–8 lb of steam per cu ft*).

(b) Dry soil can absorb steam at the rate of about 345 grams per litre per hour (*21 lb/cu ft/hr*); thus at this rate of injection, it takes about 20 minutes to bring the soil to 100°C (*212°F*).

3. The normal procedure of heat-sterilisation with steam is to raise the temperature of the soil to boiling point (100°C/*212°F*) which is indicated by steam issuing from the soil surface. The soil being steamed is covered with a plastic sheet, which is weighed down around its edges. When this balloons-out with steam, the desired temperature will have been reached.

4. Amateurs sterilising small quantities of soil in steamers made from buckets or oil drums (see diagram) must allow one litre of water to about 7 litres of dry soil (*1 pint of water to 7 pints of soil*) and always add 25% more water to prevent the container boiling dry. A small sheet of plastic film must be tied over the top of the container. When this balloons, the container is removed from the heat source, or this is switched off and unplugged if an electric kettle or immersion heater is used to boil the water.

5. As heat 'sterilisation' does not bring about complete sterilisation, but allows the ammonifying bacteria to survive, the process is only one of partial sterilisation or 'pasteurisation'.

6. Chemical effects of heat sterilisation
a. The survival of the ammonifying bacteria and their subsequent rapid increase leads to higher levels of ammonia and ammonium compounds. These do not decrease until re-infection with nitrifying bacteria enables the ammonia to be converted to nitrate. The accumulation of ammonia is highest in soils containing a high level of organic matter, or those that are too moist, before steaming.
b. There is an increased availability of the major nutrients, phosphorus and potassium.
c. There is an increased availability of many minor and trace elements, but manganese is the only one likely to cause trouble. This is most likely if the pH of the loam was too low.

7. Physical effects of heat sterilisation
After heat sterilisation, loams have a somewhat higher field capacity (and thus container capacity).

8. After heat sterilisation to 100°C (*212°F*) soils and composts are very vulnerable to re-infection by pathogens, particularly fungal ones, because of their reduced biological competition. To compensate for this commercial horticulturists use lower temperatures – 66–71°C (*150–160°F*) – to pasteurise soil. This is accomplished by using mixtures of air and steam. The apparatus is sophisticated and beyond the reach of the amateur. This lower temperature is applied for 80 minutes and succeeds in destroying most fungal pathogens, but leaving many of their competitors alive. Re-infection is much slower in soils so treated.

9. Amateurs steaming their own loam for making composts should ensure that:
It is dry.
It has a pH in the range 6–6.5.
Whenever a sample comes from a different source, it should be tested by sowing some antirrhinums which are highly sensitive to any toxic levels of ammonia or manganese.

Appendix VI

Soil conductivity

1. It is all too easy for excessive amounts of soluble salts to accumulate in greenhouse soils and growing-media. Originally chlorides, sulphates and nitrates were all thought to be involved, but now only nitrates are considered to be responsible in most cases.

2. As the concentration of soluble salts in a solution increases, its electrical resistance decreases, and thus provides a straightforward means of measuring this concentration.

3. For convenience the resistance of a standard soil solution is given as its arithmetic reciprocal, or conductance, which is 1/resistance (in ohms). The reciprocal of an ohm was formerly called a mho, but is now known as a siemens, and the conductance of a standard soil solution is expressed in micro-siemens. The standard solution is made by shaking air-dried sifted soil (below 2 mm grain size) with two-and-a-half times its own weight of a saturated solution of calcium sulphate, and its conductivity is measured with a Mullard conductivity bridge.

4. The Agricultural Development and Advisory Service of the MAFF has now produced a scale as follows:

Conductivity (micro-siemens)	ADAS Index
1900–2200	0
2210–2400	1
2410–2500	2
2510–2600	3
2610–2700	4
2710–2800	5
2810–3000	6
3010–3500	7
3510–4000	8
over 4010	9

5. Interpretation of ADAS Index

Light soils	Other soils (or light soils with high levels of organic matter)	
0	0	Normal range for outdoor soils.
0	1	Greenhouse soils with low nutrient levels.
1	2	Safe level for lettuces and flower crops.
2	3	Safe level for tomatoes.
3	4	Danger level for lettuces and chrysanthemums which will show restricted growth.
4	5	All crops likely to show some restriction of growth; and sensitive crops, seriously so.
5	6	Root damage and growth restriction on all crops.
6	7	Cropping impossible.

Drenching the soil with water will always lower the conductivity.

6. Earlier literature expresses conductivity on the pC scale, which was logarithmic and where a low numerical figure represented a high concentration, or on the CF scale where high figures represented high concentrations. Both are superseded by the ADAS Index.

Appendix VII

Micro-propagation

1. Micro-propagation has been developed from the long-established technique of botanical research called tissue culture. Some prefer to call it *in-vitro* propagation, and in view of the fact that it is a laboratory process and the propagules are kept in glass flasks, this is probably the best term. Micro-propagation, however, is the term which seems to be most popular.

2. Tissue culture was developed before the First World War by botanists, not with thoughts of propagation in mind, but for studying plant nutrition and many related processes. Small pieces of plant tissue are excised from the plant and usually placed on agar jelly, previously impregnated with a solution containing all the nutrients required by the tissue to continue its existence and to multiply. Kept thus, in completely sterile conditions, and provided the nutrients supplied are the right ones and in the right concentrations, the tissue can be kept alive almost indefinitely.

3. *Micro-propagation developed from tissue culture when it was discovered that introducing* hormones into the nutrient jelly could, in a reasonably controlled manner, cause excised meristems to multiply and form roots and thus new plants, which can be established in a normal environment.

4. As micro-propagation has developed it can now be seen to have three distinct functions to fulfil:

a. to provide a means of propagating plants vegetatively which are difficult to propagate by other means. Epiphytic orchids, e.g. *Cymbidium*, provide a good example.

b. to provide a rapid multiplication method for plants otherwise intolerably slow, e.g. a new *Narcissus* cultivar would take, by natural multiplication, 16 years to provide 1000 bulbs, 6 to 7 years by the relatively new horticultural technique of twin-scales, but only 12 to 18 months by micro-propagation.

c. to establish new stocks of virus-free cultivars in plants normally propagated vegetatively and having severe virus problems, e.g. potato, strawberry, apple.

5. Micro-propagation is a sophisticated technique, requiring sterile laboratory facilities. It lies beyond the normal resources of amateurs and most nurserymen, though not necessarily all; but in view of its probable far-reaching consequences for the future, no apology is required for this brief description.

6. The tissue used as a source of propagules for micro-propagation may be:

a. Axillary meristems: These are the growth points found normally in plants in the axils of leaves (in buds) or at a more developed stage at the tips of shoots. The meristem is stripped of all its surrounding leaves until only the flat dome of the growing tip with two or three leaf primordia remain. This tip is then excised, probably under a dissecting microscope, to form the propagule, known in this case as an explant. The explant is sterilised and placed on a sterile nutrient base within a flask, where in due course it increases in size to form a small shoot. The hormone cytokinin is then introduced and causes the shoot to branch and form a cluster of shoots. If rooting hormone is then introduced, the shoots form roots and in due course the young plants can be established in a normal environment. Explants prepared in this fashion are known as meristem tips and are the kind used for attempting to raise virus-free stock, because whilst virus diseases are systemic and pervade the whole of the plant, the newly forming cells at the tip of the meristem are frequently not affected.

Shoots of *Callistemon citrinus* 'Splendens' (Crimson bottlebrush) in a sterile flask. The apical meristem has proliferated on a medium rich in cytokinin. It will soon be forming roots and will then be broken into single plants and carefully rehabilitated into a normal atmosphere.

Well-rooted shoots of *Callistemon citrinus* 'Splendens' after growth on a medium rich in auxins.

Shoot-tip culture differs only from meristem-tip culture in that the growing point is not stripped of its leaves to quite the same extent and may be a few millimetres in length, even a centimetre, compared with the meristem tip which is only about 0.5 mm in length.

In the early days of micro-propagation shoot tips were often obtained from plants which had undergone 'heat therapy'. This was a process whereby the stock plant was placed in a very high temperature for several days before the shoot tips were excised. It was believed that the high temperature slowed down virus activity, but speeded the growth of the plant so that the shoot tips were growing faster than the virus could reach them. Little is now heard of heat therapy as this belief has proved to be almost certainly fallacious.

b. Adventitious shoots. Some plants do not produce axillary shoots at all, e.g. many palms, or else too few, e.g. *Narcissus* bulbs. In such cases it may be possible to use parts of plant organs, other than axillary meristems, in the hope that adventitious meristems will develop *in vitro* This is the case with the bases of the scale leaves of *Narcissus* bulbs, the leaf tips of orchids and small leaf sections of *Begonia* and *Streptocarpus*, all of which form explants capable of giving rise to adventitious meristems.

c. Callus. When pieces of plant organ are subjected to tissue culture, they often, if hormone levels are increased, give rise to masses of the undifferentiated tissues called callus. Callus can be multiplied and sub-cultured quite extensively and, in some cases, hormones can cause it to produce plantlets reliably. This is the case with *Freesia* and *Citrus*.

The possibility exists that callus when dispersed into minute, single-cell pieces to form a suspension in a liquid could be induced regularly to form thousands of plantlets.

7. Adventitious meristems to some extent and callus to a greater extent give rise to mutated plants or sports, most of which are aberrant and not worth keeping. However, this raises the possibility of a fourth function for micro-propagation; that of producing new cultivars.

8. Micro-propagation is a relatively new technique which will become more precise and certain as time goes by, and holds out exciting and far-reaching possibilities in many fields of horticulture and agriculture.