The Co-composting of Domestic Solid and Human Wastes

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Integrated Resource Recovery

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NUMBER 7

This is the seventh in a series of reports being prepared by the Resource Recovery Project as part of a global effort to realize the goal of the United Nations International Drinking Water Supply and Sanitation Decade, which is to extend domestic and community water supply and sanitation services throughout the developing world during 1981 to 1990. The project objective is to encourage resource recovery as a means of offsetting some of the costs of community sanitation.

Other volumes published to date include:

1. Recycling from Municipal Refuse: A State-of-the Art Review and Annotated Bibliography (Technical Paper No. 30) by S. Cointreau et al.
2. Remanufacturing: The Experience of the United States and Implications for Developing Countries (Technical Paper No. 31) by R. T. Lund.
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6. Wastewater Irrigation in Developing Countries: Health Effects and Technical Solutions (Technical Paper No. 51) by H. Shuval et al.

Photographs (from top to bottom, left to right): Workers show how compost can be used to improve the quality of soil for agricultural purposes. A range of different waste materials can be efficiently composted if the right mix of carbon and nitrogen is provided in the materials. Here garbage is placed on a conveyer belt for sorting out noncompostible matter, and sludge from a septic tank is mixed with paper wastes and wood chips for co-composting. Aeration of composting materials can be carried out in a variety of ways. These include by hand-turning, provided proper protective clothing is worn; by using windrow machines or tractors to turn windrows of composting materials, here made up of garbage and sludge; and by forced aeration in which air is blown or drawn through a static pile by a small horsepower motor. The large amount of heat generated destroys disease-causing organisms.

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ABSTRACT

This report is part of a joint global research, development, and demonstration effort of the United Nations Development Programme and the World Bank. It reviews current literature and practices on the co-composting of human waste (fresh nightsoil or sewage sludge) together with the organic fraction of domestic solid waste (as well as with other wastes).

The report describes the composting process, reviews various co-composting systems, and discusses health aspects such as pathogen destruction. The uses of compost as a soil conditioner, mulch, fertilizer or for land reclamation are also described.

The report also develops several cost/benefit models for economic analysis of co-composting operations and outlines the economics of the process as a whole. The focus of the analytical methodology is on developing countries. The computer models are written for use on widely available microcomputers and are designed so that they can be adapted to site-specific economic conditions. A copy of the computer models is available on request.

Key issues for consideration in planning for composting are also discussed. Decision makers and planners will find this report a valuable reference on co-composting when addressing waste management and resource recovery issues in the developing countries.

FOREWORD

This is the seventh of a series of generic reports produced by the joint UNDP/World Bank Global Research and Development Project on Integrated Resource Recovery (GLO/84/007, GLO/80/004). The primary project goal is to achieve economic and social benefits through sustainable resource recovery activities in the developing countries by recycling and reusing solid and liquid wastes from municipal and commercial sources within the context of appropriate waste management.

Increasing recognition of the need for technical and economic efficiency in allocating and utilizing resources and the role that appropriate resource recovery can play in the water and sanitation sector have led this project to be included in the formal activities of the United Nations International Drinking Water Supply and Sanitation Decade.

Urban areas are finding it increasingly difficult to safely dispose of human wastes and domestic solid wastes. It is also becoming increasingly important worldwide to improve the nutrient and physical qualities of agricultural soils. This is especially true in the food production areas surrounding growing urban centers in developing countries. This report presents a review and analysis framework of co-composting, which is a process that can convert more than one waste, such as human and domestic solid wastes, into a useful resource.

The report describes composting and examines ways of co-composting of human waste (fresh nightsoil or sewage sludge) together with the organic fraction of domestic solid waste. It discusses the procedures entailed, the health aspects, and the uses of compost based on a literature review. Furthermore, an economic analysis methodology is developed using computer models that perform cost-benefit calculations of co-composting operations. These models are suitable for analysis of specific co-composting investments when modified to reflect local conditions. Copies of the LOTUS-123 1/ template are available on request.

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Your comments on this report would be welcome, and we would be grateful to receive any case study information from which future editions of the resource recovery series could benefit. Please send your comments to WUDAT, The World Bank, 1818 H Street, N.W., Washington, D.C. 20433, USA.

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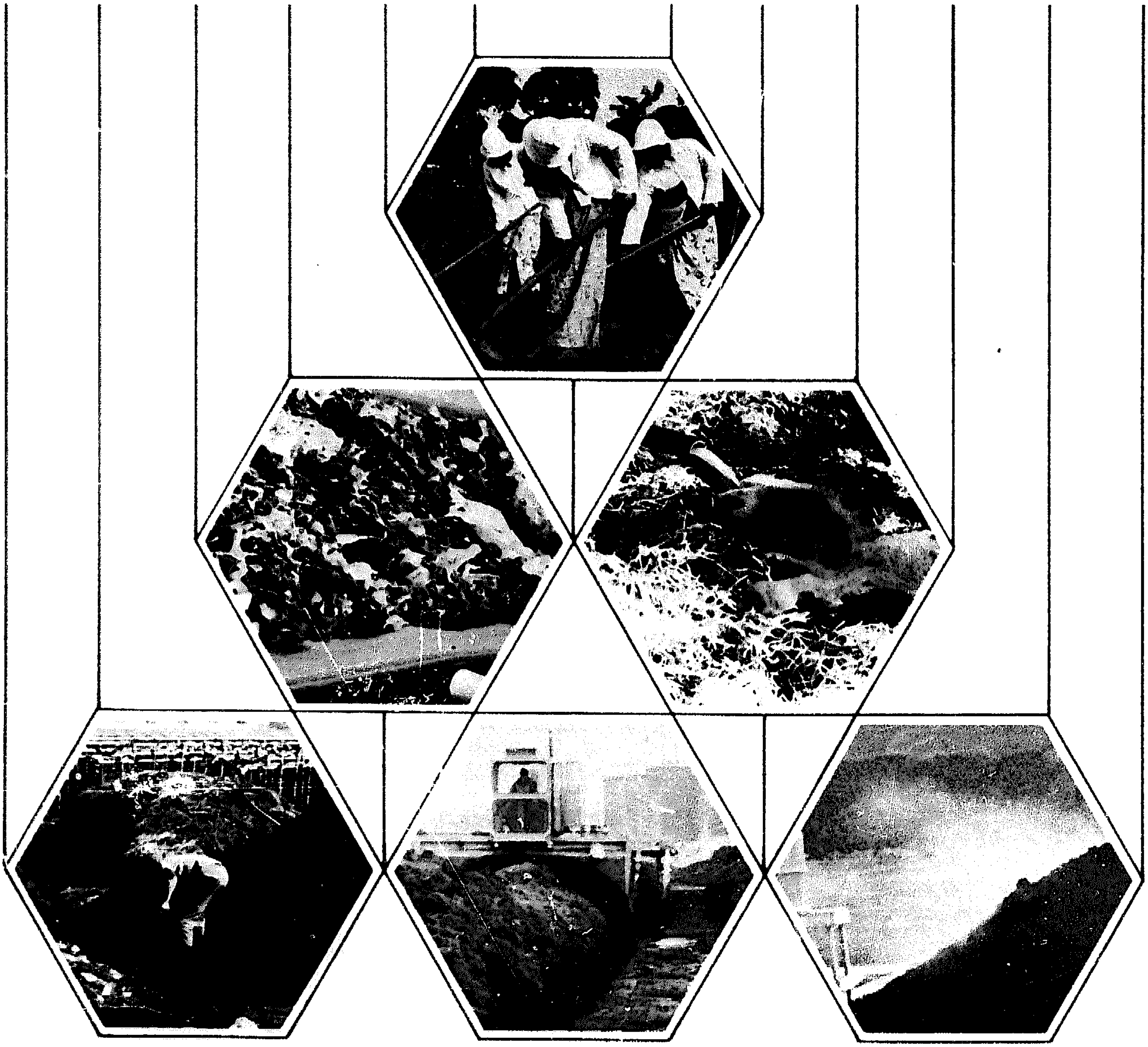

CONTENTS

LIST OF TABLES AND FIGURES

TABLES

FIGURES

CHAPTER 1

INTRODUCTION

The recycling of human waste has been an accepted practice throughout the world for many years. One method of reusing human waste is composting, which means converting it into a material that is safe to use, usually on land.

AIM

The purpose of this report is to describe methods of co-composting garbage with human waste in various places (using selected literature) and some of the health aspects, uses, and the economics of composting. The report also suggests ways in which planners and operators in developing countries can co-compost these two wastes (garbage and human) to best suit their needs and requirements.

NIGHT SOIL

Human waste may be deposited into buckets, pits, vaults, or flush toilet basins. When it is deposited into buckets, pits, or vaults, it is referred to as night soil. If the night soil is deposited into buckets or vaults, it has to be removed and treated away from the site of collection. If the night soil is deposited into pits or vaults, these have to be emptied when they become full. Emptying of these pits is often hazardous because full pits contain fresh excreta. If twin or double pits are in use, the night soil in one pit is usually stored for at least one year (preferably two) before the pit is emptied. During this time, most of the disease-causing organisms are destroyed. However, hardy pathogens such as Ascaris eggs may survive.

The night soil that is removed from the pits (either fresh or stored) can be reused in agriculture, as it contains many nutrients. It can be mixed with other materials in a biogas plant or it can be used as a raw material in a compost plant. During the composting process, most disease-causing organisms that may be present in the night soil will be destroyed. The resulting compost is a humus-like material with good soil-conditioning properties as it contains many nutrients and minerals essential for plant growth.

SEWAGE SLUDGE

Waste that is flushed away into sewers is transported to sewage-treatment plants. The solid waste matter produced by this treatment is known as sludge. This material can be further treated by anaerobic digestion to produce digested sludge.

Many countries in Europe and in North America either use sewage sludge directly on the land or convert it into compost, which is put to many uses. The use of sewage sludge compost on land is restricted in some industrialized areas because it contains relatively high concentrations of heavy metals.

Sewage sludge and night soil are similar in their moisture and nutrient content. The advantage of night soil over sludge is that it does not contain heavy metals, but there has been little experience in night soil composting. Nevertheless, the experience with sewage sludge composting can provide some information that may be of use in night soil composting. This review focuses primarily on co-composting of garbage and human wastes, but there are also other ways of co-composting with sludge and night soil (see annex A). Any of these systems could be a useful guide to plant planners wishing to find a suitable method of composting human waste.

SOLID WASTE

In this report garbage refers to the organic material present in refuse or solid waste. Refuse also contains metals, glass, plastics, cloths, and other such materials. In most industrialized countries, solid waste consists primarily of non-compostable matter that has to be sorted out before the waste can be composted. Very often the main costs of refuse composting plants arise from these sorting activities. In many developing countries the sorting is done by scavengers before the refuse reaches the treatment plant. Diaz and Golueke (1985) discuss scavenging in relation to other aspects of solid waste management, including the social, political, and economic ones. In some countries the waste is mainly organic and does not need to be sorted, but in others sorting is required (see table 1). There is a wealth of information on the sorting of refuse, but that subject is beyond the scope of this report.

CO-COMPOSTING OF GARBAGE WITH HUMAN WASTE

The term co-composting means the composting of two or more raw materials together. Many examples of different materials being composted together are available. Some are cited in Annex A. In the case of human waste and garbage (the organic part of refuse), this kind of composting is advantageous because the two waste materials complement each other well. The human waste is high in nitrogen content and moisture and the garbage is high in organic (carbon) content and has good bulking quality. Furthermore, both these waste materials can be converted into a useful product.

Table 1. Refuse Content from Various Municipalities
(weight percent)

Constituents	Iraq	Algiers, Algeria	Hong Kong	Abu Dhabi, UAE	Accra, Ghana	Alexandria, Egypt	Cairo, Egypt	Sao Paolo, Brazil
Vegetables	68.6	72.0	46.2	22.5	87.1	65.0	43.8	46.9
Textiles	3.8	2.6	9.0	0.3	1.2	2.5	3.0	3.4
Paper/carton	10.2	16.0	25.7	42.4	5.7	23.0	9.2	25.9
Straw	1.0	0.1	-	0.4	-	-	7.7	-
Timber	1.1	1.0	2.5	2.9	-	-	2.5	1.9
Leather/rubber	1.8	1.2	0.3	-	-	-	0.9	1.5
Horn/bones	1.2	0.2	0.3	2.9	-	0.5	1.3	0.1
Plastics	2.1	2.5	8.1	6.3	1.3	0.25	2.0	4.3
Metals	2.3	2.5	1.9	14.0	2.6	1.75	3.0	4.2
Crockery	5.5	0.7	0.4	3.8	1.4	-	24.7	9.7
Glass	2.4	1.2	5.6	4.4	0.7	2.25	1.9	2.1
Organic fines	-	-	-	-	-	4.75	-	-
Total	100	100	100	100	100	100	100	100
Moisture of crude refuse	58.5	60.0	44.7	30.0	50.0	-	30-40	62.0
Compostable portion	87.7	90.0	77.9	73.5	94.9	-	87.3	84.6

\- = not measured

Sources: Weber (1983); Hughes (1986).

CHAPTER 2

THE COMPOSTING PROCESS

Composting can be defined as the biological decomposition of the organic constituents of wastes under controlled conditions. This process can take place in the presence or absence of oxygen. The former is called aerobic composting and the latter anaerobic. If efficiently carried out, aerobic composting can rapidly produce a pathogen-free product, as this review attempts to show. Anaerobic composting by contrast requires much longer decomposition times and is seldom free of pathogen and odor problems.

The material being composted decomposes as a result of the activity of the bacteria, fungi, actinomycetes, and protozoa present in the waste material and of those that are seeded from the atmosphere. The densities of the different organisms are a function of the nature of the waste in which they are found. Table 2 shows typical numbers of some organisms present in various stages of composting. The efficiency of the process depends to a large extent on temperature since microbial succession occurs with the temperature changes brought about by microbial activity. Figure 1 shows a typical temperature pattern in a compost pile over a period of 25 days. When a composting mixture is prepared, mesophilic microbial activity within the mass generates heat, which raises the temperature within the mixture. When the temperature reaches a certain level, the mesophilic activity begins to subside and thermophilic activity begins to increase. This process continues until the temperature conditions become limiting to the survival of the thermophils, and their population declines. Subsequently, the temperature declines. At this point mesophilic organisms (mainly fungi and actinomycetes) once again increase. As the process approaches completion, the concentration

Table 2. Microfloral Population during Aerobic Composting

	Numbers per gram wet compost			
	Mesophilic initial temperature - 40°C	Thermophilic 40°C-70°C	Mesophilic 70°C-initial temperatures	Numbers of microorganisms identified (species)
Bacteria				
Mesophilic	10^8	10^6	10^{11}	6
Thermopilic	10^4	10^9	10^7	1
Actinomycetes				
Thermophilic	10^4	10^8	10^5	14
Fungi[1]				
Mesophilic	10^6	10^3	10^5	18
Thermophilic	10^3	10^7	10^6	16

Source: adapted from Poincelot (1974).

[1] number less than or equal to number stated.

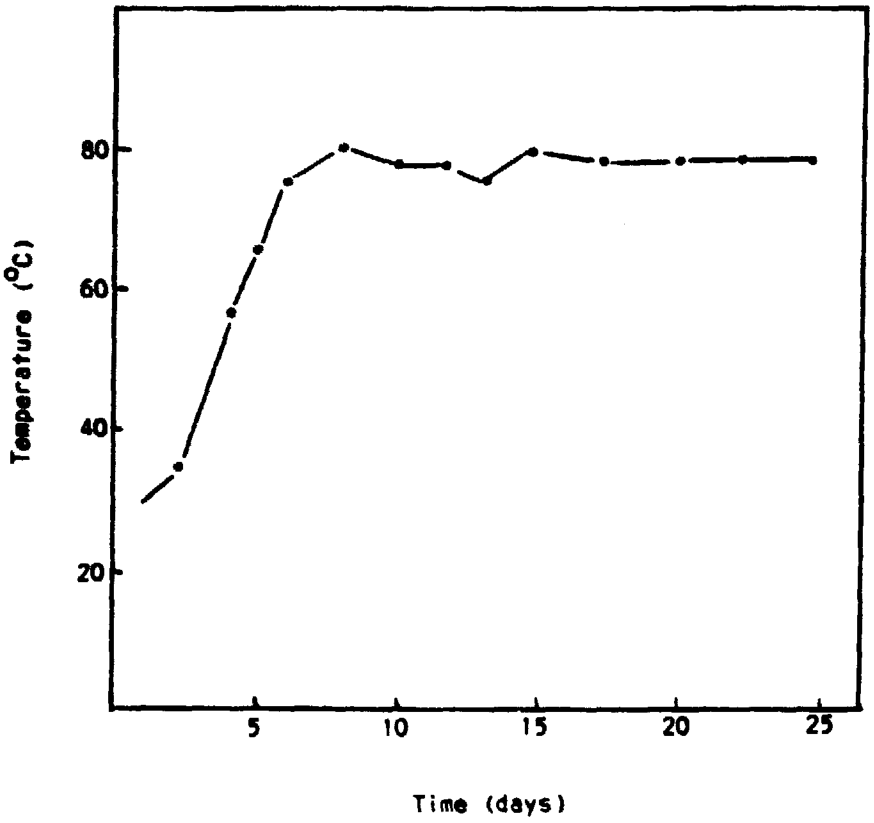

Figure 1. Typical time/temperature relationship using mode values of readings taken at 14 monitoring points within each of 12 static piles.
Source: Sikora et al. (1981).

of nutrients also becomes rate limiting and the temperature eventually returns to its ambient value. Table 3 indicates typical minimal, optimal, and maximal temperature ranges for mesophils and thermophils.

Table 3. Maximum, Optimum, and Minimum Temperature Ranges for Mesophils and Thermophils (°C)

	Minimum	Optimum	Maximum
Mesophils	10-25	25-35	35-45
Thermophils	25-45	50-55	75-80

Source: Glathe and Farkasdi (1966).

Excreted pathogens present in the raw waste material will be destroyed or inactivated during the thermophilic phase (see table 4). Since the composting process is aerobic, the raw materials must have sufficient structure and porosity for efficient decomposition to occur. In the case of sewage sludge and night soil composting, organic or inorganic materials normally have to be added so as to increase air spaces to allow for proper aeration, provide structural support, reduce the bulk weight of the composting mixture, and, in the case of organic additives, increase the quantity of degradable materials. The organic part of garbage or refuse is suitable for this purpose, as are other types of materials that can be added, such as wood chips, shredded tires, peanut shells, rocks, bark, rice hulls, peat, straw, sawdust, manure, and grass.

RATE-RELATED FACTORS

Various rate-related parameters or factors affect the efficiency of the composting process and the quality of the product. The most important ones are briefly described in this section. The optimal ranges given are not always found in practice as different operators may use conditions shown by experience to be the best suited to their particular raw materials and composting process.

Moisture Content

The moisture content of a composting mixture should be much greater than the lowest level at which bacterial activity will occur (which is about 12-15 percent). The optimum moisture content for efficient composting is usually in the range of 50-60 percent.

Sewage sludge and night soil contain a great deal of moisture (typically > 92 percent) in their untreated state. Even when dewatered, they may still be too wet to be composted on their own and amendments or bulking

Table 4. Feedback Loops in the Composting Ecosystem

Loop Components		Positive feedback (a)			Negative feedback (b)	
Microbiological factor	Physical factor	Temperature optimum for the population	Temperature level	Component interaction	Temperature level	Component interaction
Mesophilic population	Temperature	38° C (approx)	Ambient temperature at assembly of mixture	Mesophilis generate heat; temperature increases; mesophilis increase	Above 40° C, self-heating passes from mesophilic phase to thermophilic	Mesophilic temperature tolerance limit exceeded; populations collapse; accompanying heat outputs decline
Thermophilic population	Temperature	55° C (approx)	Above 40° C at start of thermophilic phase of self-heating	Thermophilis generate heat; temperature increases; thermophilis increase	Above 55° C	Thermophilic temperature tolerance limit approached; population and accompanying heat output declines

a. Positive. The microbial succession progresses.
b. Negative. The microbial succession is regressed.

Source: Finstein et al. (1980).

agents will then be required to reduce the moisture content and provide structural integrity as well as increase the carbon content. Typical amendments include sawdust, straw, garbage, grass, etc. Typical bulking agents include wood chips, shredded tires, rocks, peanut shells, etc. The moisture content of a composting mass will tend to decrease as decomposition proceeds, mainly because of evaporation losses during the thermophilic phase, and in some cases water may have to be added to maintain optimal conditions. Process performance can be evaluated during the drying out of a composting mixture since it is relatively simple to measure moisture and can easily be done even with poor laboratory facilities.

Temperature

Aerobic thermophilic composting has different temperature stages, including the important thermophilic one. Most microorganisms grow best between 20 and 35° C. Excreted pathogens thrive at body temperature (37° C). Temperatures above 50° C achieved during thermophilic composting should be high enough to destroy these pathogens if maintained for a sufficient period of time. This, however, is only possible if the temperature is maintained above 50° C throughout the composting mass and there are no pockets of low temperature during that time.

The temperature changes observed during the decomposition of organic matter can be used as an indication of the proper functioning (or malfunctioning) of the process. Temperature is perhaps a more reliable indicator than moisture, aeration, or nutrient concentrations, since it directly affects pathogen control, which is important to the production of good compost. Figure 2 shows typical time-temperature profiles for composting sewage sludge by the aerated pile method. Other methods use different time scales to attain thermophilic temperatures. In addition, the maximum temperatures achieved vary from system to system, depending on the raw materials used and operational and design factors. Many compost plant operators believe that it is important to maintain very high temperatures (>65° C), but this has been shown to be counterproductive because thermophilic microbial activity rapidly becomes limited at these temperatures.

Time

The quality of a product greatly depends on the length of time that a mixture is composted. If high composting temperatures (optimum 50-55° C) are not maintained throughout the material for a sufficient length of time (> 2 days), pathogen destruction will not reach the required level. (Some heat resistant pathogens may survive this temperature range.) Reactor retention times and curing times may vary from system to system.

Particle Size

Composting material that consists of small particles is more readily decomposed than material with larger particles as the surface area of contact is greater. At the same time, if particles are too fine, there will be less oxygen diffusion. Furthermore, very fine material tends to lose some of its

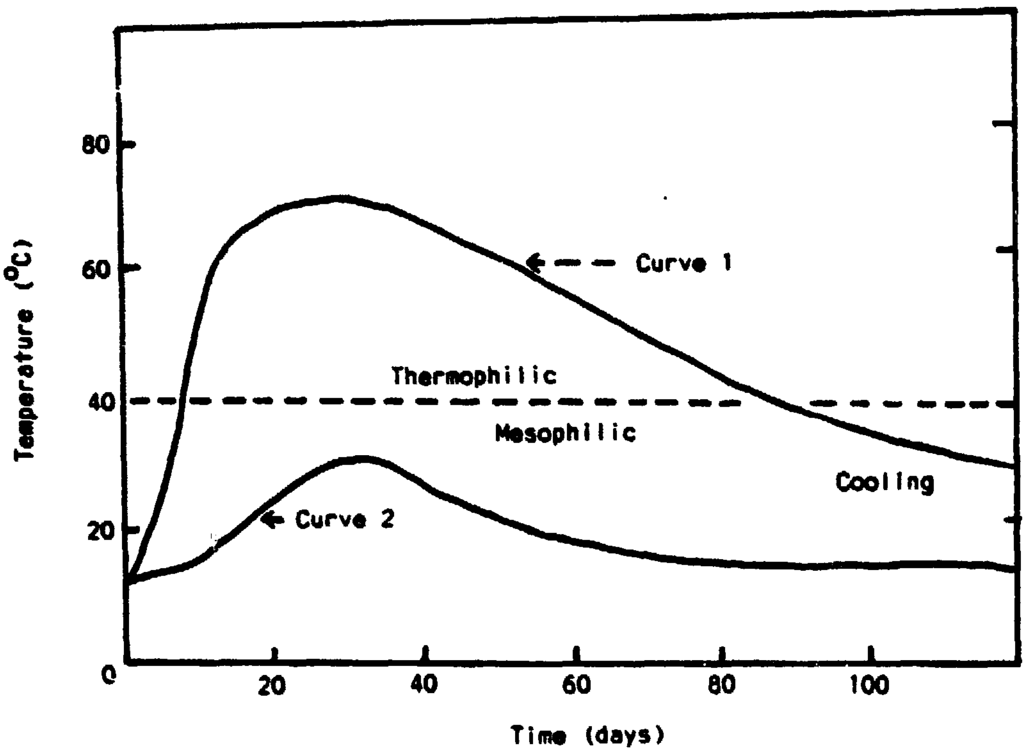

Figure 2. A typical time/temperature relationship for composting sewage sludge by the aerated pile method. Curve 1 depicts a situation where conditions of moisture, temperature, and aeration are at optimum levels for rapid transition from the mesophilic into the thermophilic stage. Curve 2 represents a condition where certain parameters are deficient or outside their optimum range, resulting in adverse effects on the growth and activity of the indigenous organisms.
Source: Parr, Epstein, and Willson (1978).

usefulness as a soil amendment. Typical particle sizes of material used for composting range from 10 to 50 millimeters, the lower value being appropriate for forced aeration or agitated systems and the upper one for static piles or windrows.

Oxygen Supply

The optimum levels of oxygen required for the growth of aerobic microorganisms range from 5 to 15 percent of the air, with 5 percent being the minimum essential for the growth of mesophils. The oxygen consumption in a composting mass depends on several factors: (a) the stage of the process; (b) the temperature; (c) the degree of agitation of the mass; (d) the composition of the composting mass; (e) the particle size of the mass; and (f) the moisture content. Oxygen consumption appears to increase and decrease logarithmically with changes in temperature, and the moisture content affects the air spaces within the composting mass. The rate at which the compost material is aerated also affects the process. If the aeration rate is high (33-78 cubic feet of air per day per pound of volatile solids) the excess flow of air causes the compost mixture to cool down. If this rate is low (4-6 cubic feet of air per day per pound of volatile solids), aerobic activity will decline and the process may become anaerobic.

Nutrients

Carbon and nitrogen are two elements required for microbial growth. The carbon-to-nitrogen (C/N) ratio provides a useful indication of the rate of decomposition of organic matter. Microorganisms generally require 30 parts of carbon to each part of nitrogen for their metabolism. This ratio is therefore commonly used in the composting process; the most frequently used value is between 25 and 30. Sewage sludge and night soil are both relatively high in nitrogenous compounds, and the C/N ratio is normally less than 15 for these wastes (see table 5 for the nitrogen content and C/N ratios of various wastes). The addition of amendments or bulking agents material that have a high C/N ratio compared with that of sewage sludge or night soil can be used to adjust the final ratio to one within the optimal range. If the C/N ratio is too high, however, the decomposition process slows down as nitrogen becomes growth limiting; if the ratio is too low, the large amount of nitrogen present is rapidly lost by volatilization as molecular ammonia. Since nitrogen is a valuable plant nutrient, its levels in mature compost need to be kept reasonably high; thus, maintaining an optimum C/N ratio is advantageous to the process.

pH Control

The optimal pH for the growth of bacteria and other composting organisms is in the range of 6.0 to 8.0. At a pH of 8-9, nitrogen may be lost through volatilization of molecular ammonia; if the pH is too acidic (< 5), microbial activity will cease. In some cases, pH may reflect process malfunction; if, for example, a composting mass begins to turn anaerobic, the pH may fall to about 4.5 owing to the accumulation of organic acids. Conversely, as the process approaches stability, the pH shifts toward neutrality (pH 7).

Table 5. Approximate Nitrogen Content and C/N Ratios for Some Compostable Materials

Material	Nitrogen % dry weight	C/N ratio
Urine	15-18	0.8
Mixed slaughterhouse wastes	7-10	2
Night soil	5.5-6.5	6-10
Digested sewage sludge	1.9	16
Activated sludge	5.0-6.0	6
Young grass clippings	4.0	12
Cabbage	3.6	12
Weeds	2.0	19
Grass clippings (average mixed)	2.4	19
Farmyard manure (average)	2.15	14
Seaweed	1.9	19
Potato haulms	1.5	25
Oat straw	1.05	48
Wheat straw	0.3	128
Fresh sawdust	0.11	511
Newspaper	nil	-
Food wastes	2.0-3.0	15
Fruit wastes	1.5	35
Refuse	0.5-1.4	30-80
Wood	0.07	700
Paper	0.2	170

Source: Gotaas (1956).

Odor

This indicator is not only an index of the efficiency of the process, but it also affects public acceptance of and support for composting plants, especially in areas of high population density. There are various methods of controlling or removing foul odors from composting materials. These usually are effective unless the process goes totally anaerobic, for example, and particularly foul odors are produced. In forced aeration systems a relatively simple and inexpensive method of deodorizing the exhaust air is to use some of the previously composted materials as a filter, since organisms present in the filter readily absorb and decompose the malodorous compounds present in the air. Simple filters consist of a small pile of compost through which the air is blown. (Some compost filters are described in table 6.)

Table 6. Methods of Odor Control Using Compost Filters

Filter type	Description	Source
Filter bed	A bed of perforated piping covered with compost	Composting plants at Duisburg and Heidelberg (Fed. Rep. of Germany) (Jäger and Jäger 1978)
Windrow filter	A windrow constructed over perforated pipe through which air from a reactor is blown	Beringen Composting Plant (Switzerland)
Filter pile	Cone-shaped pile of screened compost containing 1 cubic yard of dry material per 10 tons of wet sludge being composted	Beltsville Composting Plant United States (Willson et al. 1980)
Dano filter	16-inch diameter perforated asbestos cement pipes 8 feet apart are covered with 1-2 inches of gravel to a thickness of 16 inches and this is then covered with fresh compost to a depth of 5 feet	(Wesner 1978)

OTHER FACTORS

Increasing ammonia concentration and rising levels of carbon dioxide have been shown to correlate with different stages of the composting process (Japan Sewage Works Agency 1980). At composting installations with well-equipped laboratories, these parameters can be continuously monitored and thus be used as indicators of process operation.

CHAPTER 3

COMPOSTING SYSTEMS

The composting systems described in this report can be divided into two main categories: (a) reactor systems in which at least the initial composting occurs within a mechanical reactor and (b) nonreactor systems in which the entire composting process occurs outside a reactor. Most composting systems developed up to now have been used for composting refuse; however, since human wastes in the form of sludge and night soil are the main raw materials of interest in this report, systems that can be used to treat these wastes are described here as well as systems for their combined treatment with garbage.

REACTOR SYSTEMS

The different types of reactor systems used for composting are usually classified as vertical flow, inclined flow, and horizontal flow in which aeration occurs with or without agitation of the composting mass. There are many different reactor systems for composting. These systems can compost a combination of human waste (sludge or night soil) and garbage, provided the waste has been adequately prepared (presorted, pulverized, etc.). After a few days in the reactor, the waste material (raw compost) is put in piles or windrows to mature. A few of the more common reactor systems are described below.

A vertical flow system may have vertically stacked floors or decks in a silo or tower-type reactor. Aeration is effected by allowing the composting mass to drop from one level to the next over a period of days. The raw compost is then stored outside to mature.

The Dano system is a typical inclined flow type of system. It comprises a drum that is slightly inclined from the horizontal and can be rotated. Air is introduced into the drum by forced aeration. The composting mass stays in the drum for up to 5 days, after which it is placed in windrows to mature.

A typical horizontal flow reactor consists of a series of cells. A horizontal screw moves the waste from cell to cell. Air is introduced at the bottom of each cell. After a few days in the cells, the compost matures out in the open for several weeks.

NONREACTOR SYSTEMS

There are two types of nonreactor systems: (a) those in which the waste being composted is agitated or turned and (b) those in which the waste remains static during composting. The degree of mixing in the nonreactor system will vary considerably, depending on the technology used and the degree of control applied. In situations where the waste being composted is agitated or turned, this may be done by placing it in a windrow that is turned by a windrow-turning machine, by a front-end loader on a tractor, or manually by using shovels. The static pile system relies on two methods of aeration: forced aeration of the composting mass and natural ventilation (air diffusion). A comparison of different nonreactor systems by de Bertoldi et al. (1982) has shown that turning is a less efficient method of producing good compost than forced aeration of a static pile. This is mainly because of the difficulty of attaining thorough mixing by turning. A study conducted by Periero-Neto, Stentiford, and Mara (1986) in which windrows were compared with aerated static piles showed that a better quality compost (good pathogen removal) was produced by the forced aeration static piles. Table 7 describes briefly four different nonreactor systems. A typical forced aeration pile is shown in figure 3.

Table 7. Summary of Different Nonreactor Composting Systems

Item	General descriptions
1.	The waste material is placed in alternate layers in a trench or pile. It is turned frequently by shovel over a 3 to 6 month period.
2.	The waste material is formed into a windrow (triangular in cross section) using a front-end loader or windrower. This is then regularly turned by machine for 4 to 6 weeks.
3.	The waste material is extruded into pellets (each with a 1/cm diameter), pressed into briquettes or formed into bales, stacked in piles, and aerated by natural ventilation.
4.	The material is constructed into a pile (static aerated pile) through which air is either blown or drawn over a period of about 3 weeks.

CHOICE OF SYSTEM

The major differences between reactor and nonreactor systems are in the capital and operating costs of the two systems. This is of great importance if financial resources are a constraint in the choice of a composting system. Because of their complexity in hardware and their need for highly technically skilled operators, reactor systems have high construction, operation, and maintenance costs, whereas nonreactor systems that are less complex and can rely on fewer technically skilled staff tend to cost less. Reactor systems for composting have been popular in industrialized countries, where there has been increasing need to compost solid and human waste. In addition, complex equipment has been required to sort out the large amounts of noncompostable waste material in areas with limited space availability. In many developing countries, there is no need to opt for the reactor system on the basis of limited space availability. In addition, the waste often comprises more than 60 percent compostable material. Often this is because scavengers have removed most of the noncompostable material. Comparison is made of some of the management and operational differences between reactor and nonreactor systems in table 8. Some of the important points to consider in planning for composting are discussed later.

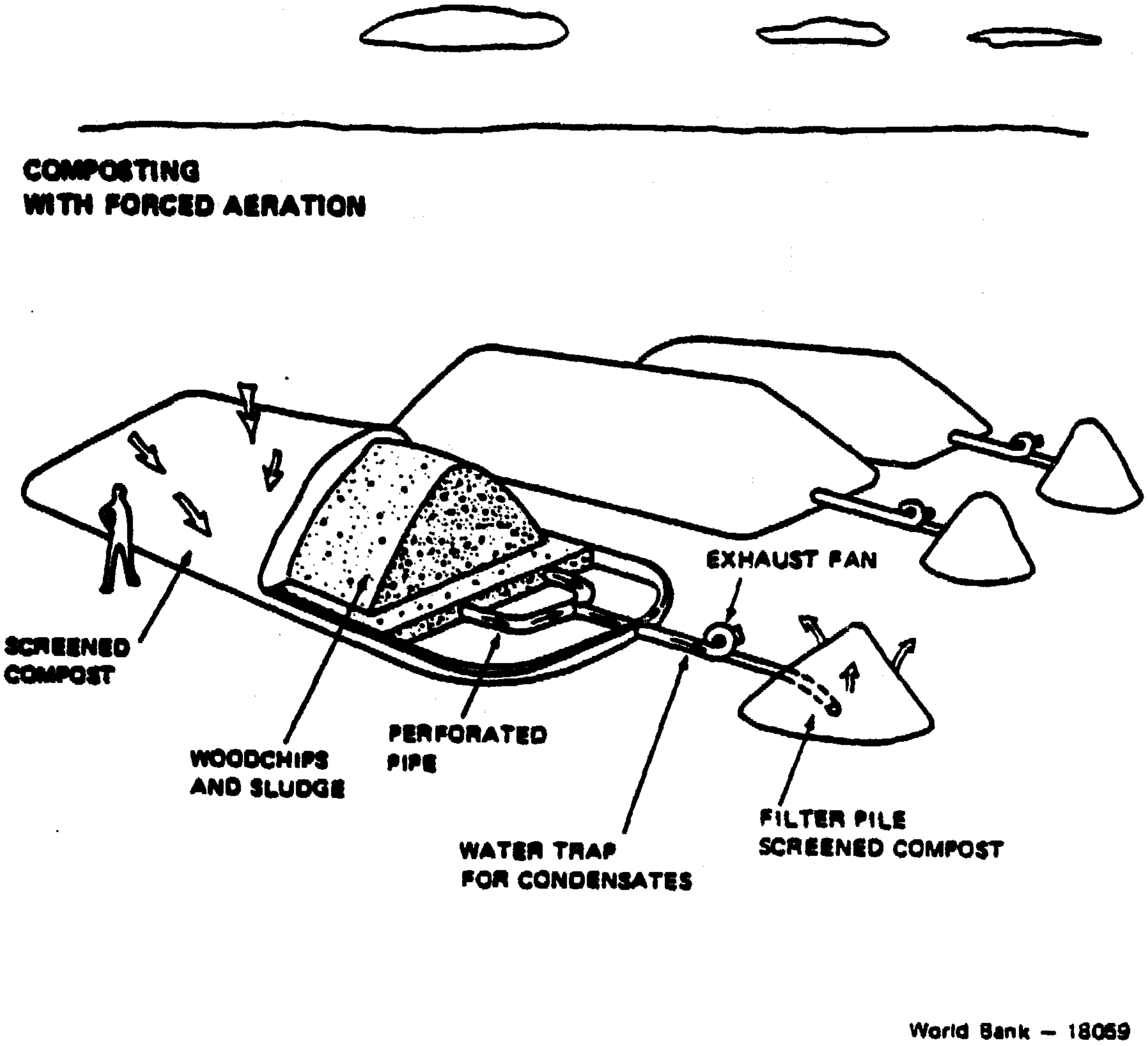

Figure 3. Elements of aerated pile composting system.

Table 8. Comparison of Reactor and Nonreactor Systems

Item	Nonreactor systems		Reactor systems	
	Turned windrow	Aerated pile	Forced aeration, agitation	Forced aeration, no agitation
Capital costs	Generally low	Generally low in small systems; can become high in large systems	Generally high	Generally high
Operating costs	Generally low	High, depending largely on amendment or bulking agents	Generally low, depending on power source	Generally low, depending on amendment or bulking agent
Land requirement	High	High	Low for reactor but can be high where windrow drying is required	Low, but can increase if windrow drying is required
Control of air supply	Limited unless forced aeration is used	Complete	Complete	Complete
Need for subsequent drying	Drying usually occurs in windrow but depends on climate	Drying can be achieved in pile with high air supply; windrow drying may be required	Drying can be achieved in reactor; final drying in windrow or heat dryer may be required	Less drying potential from lower air flowrates; final drying in windrow or heat dryer usually required
Sensitivity to cold or wet weather	Sensitive unless in housing; demonstrated mainly in warm, dry climates	Demonstrated in cold and wet climates	Demonstrated in cold and wet climates	Demonstrated in cold and wet climates
Composting demonstrated on digested sludge	Yes	Yes	Yes	Yes
Composting demonstrated on raw sludge	Yes, but odor problems observed	Yes	Yes	Yes

(cont.)

Table 8 (cont.)

Item	Nonreactor systems		Reactor systems	
	Turned windrow	Aerated pile	Forced aeration, agitation	Forced aeration, no agitation
Control of odors	Depends largely on raw materials	Handling of raw sludge is potentially odorous; filter may be required	Potentially good	Potentially good

Source: Adapted from Haug (1980).

SEWAGE SLUDGE AND NIGHT SOIL CO-COMPOSTED WITH REFUSE

Background

Several European countries, most notably Holland (Oosthoek 1981), France (Hirscheydt 1975), Austria (Ingerle 1978), and the Federal Republic of Germany (Tabasaran 1976), have a long history of refuse composting. Methods of preparing refuse for composting have been described in the literature (see, for example, Breidenbach 1971; Spohn 1978; Rabbani et al. 1983; Savage and Golueke 1986). Sorting processes for refuse and composting are not discussed in detail here as they are also well described in the literature.

In West Germany, the co-composting of sewage sludge with garbage originated out of the need to treat and dispose of ever-increasing amounts of sludge. Co-composting now is a viable alternative in many developing countries where great concern exists about the large amounts of garbage and poorly disposed and treated human wastes that are being produced in urban areas. These waste materials can be reused and recycled through composting, to improve the urban environment and to increase the quality and productivity of soils.

Process

Co-composting of garbage with human waste can be carried out both in reactor systems (Ingerle 1980) and nonreactor systems. Nonreactor systems are best used wherever the refuse does not require much sorting and pulverizing and where funds and other resources are scarce. The different reactor and nonreactor systems for composting already have been described. Table 9 gives examples of different reactor and nonreactor systems and how they have been used to co-compost garbage and human waste. Different types of sludge and night soil can be mixed with the garbage (or sorted refuse). Temperatures reached at composting time are indicative of efficient pathogen control.

Table 9. Examples of Co-composting of Sewage Sludge with Refuse

Country/ city	Plant type/ raw materials	Process description	Reference
Reactors			
W. Germany	Bioreactor cell system; dewatered digested sludge and refuse	Experimental study. The sewage sludge is first pelletized (to a diameter of 10 millimeters) and then mixed together with the sorted pulverized refuse in bioreactor cells. Temperatures of up to 80° C are attained over a number of days.	Spohn (1978), Miersch and Strauch (1978)
W. Germany (Lemgo)	Hazemag drum system with forced aeration; refuse and mixed raw/digested sewage sludge dewatered to 25 percent solids	After refuse is separated and pulverized, it is mixed in a drum together with the sludge for 24 hours; then the raw compost is matured in forced aeration piles for up to 5 months. Temperatures of up to 50° C are attained within the drum. A compost filter is used to control odor.	Grote (1978)
W. Germany (Heidelberg)	Multibacto system; a tower reactor consisting of several levels; refuse and dewatered digested sludge	The sludge is dewatered to 40 percent solids before addition to the sorted pulverized refuse. The mixture falls from level to level within the tower during a period of 24 hours to 1 week during which temperatures of up to 70° C are reached. Maturation occurs in tunneled windrows (i.e., piled with "tunnels" to aid aeration and drying). Experiments using the towers demonstrate the variation in mesophilic and thermophilic populations (described in chapter 2) at the temperatures occurring at different levels within the tower. A compost filter is used to control odor.	Jäger (1977), Farkasdi (experimental, 1968), Sander (1967), Hart (1967)
W. Germany (Duisberg)	Dano drum/ reactor; refuse and digested sludge	Refuse is sorted before being put into the drum, where it is mixed with the sludge. Retention time is about 3 days, after which the raw compost mix is put in windrows to mature. Temperatures up to 72° C are reached and maintained in the drum. A compost filter is used to control odor.	Hart (1967), Hasuk (1979), Hirschheydt (1975), Sander (1967), Ernst (1972)

(cont.)

Table 9 (cont.)

Country/ city	Plant type/ raw materials	Process description	Reference
W. Germany (Flensburg)	Rheinstatil process drum reactor; refuse and dewatered mixed sludge	The refuse is milled and sorted. It is then mixed with the sludge in a drum for 24 hours. The raw compost is then matured in a windrow for 3-4 months. Temperatures of 60-70° C are maintained in the drum during the 24 hours. A compost filter is used to control odor.	Schwabe (1973), Jäger (1974)
W. Germany (Beringen)	Dano drum reactor; refuse and dewatered digested sewage sludge	The refuse is sorted and milled and fed into a Dano drum together with the sludge. The retention time is 48 hours and a temperature of at least 40° C is maintained throughout. The raw compost is matured in windrows for 8-10 months (temperatures of up to 70° C are common). A compost filter is used to control odors from the drum.	Köhler & Hardmeier (1980)
England (Leicester)	Dano; refuse and digested sewage sludge	The refuse is sorted, homogenized, and mixed with the sludge. The mixture is fed into the drum where it stays for about 3 days; then the raw compost is screened and matured in windrows.	Kuchta (1967), Hughes (1977)
Sweden	Vertical reactors each divided into stages by parallel steel bars; refuse and dewatered sludge and night soil	Experimental plant. The refuse is sorted and milled and is then mixed with the sludge and night soil. The mixture is added to a vertical reactor consisting of five stages. The retention time is 5 days and the the average temperature is 55° C.	Hovsenius (1975)
Japan (Toyohashi)	Dano rotating drums and vertitical reactors; refuse and raw/ digested night soil (and poultry wastes)	The refuse is sorted and milled. The night soil is either digested aerobically first or dewatered and mixed with the refuse. The mixture is fed into Dano drums for 2 days, is kept in vertical reactors for another 2 days, and then stored. A temperature of 60° C is reached in both reactors. The raw compost is then stockpiled for 2 weeks before use.	Toyohashi City (n.d.)

(cont.)

Table 9 (cont.)

Country/ city	Plant type/ raw materials	Process description	Reference
Italy		Refuse and sludge are composted using a biotunnel. Temperatures of 65-70° C are observed.	Ferrero (1978)
Nonreactors			
W. Germany (Wiesbaden)	Composting of bales; refuse and raw sludge	Experimental plant. The refuse is sorted and milled and then mixed with the sludge. Next, the mixture is formed into bales using a press and then stored in the open to mature for about 14 months before being broken up. Temperatures (typical of windrow compost temperatures) of between 38° C and 72° C have been measured. Odor is not a problem.	Leonhardt (1979)
W. Germany (Schweinfurt)	Brikollare process briquettes 20 x 25 x 50 centimeters are formed; refuse and dewatered digested sewage sludge	Refuse is sorted, ground, and then mixed with the sewage sludge. The mixture is then compressed into briquettes (which have holes for aeration). They are stored on pallets in a curing shed. Temperatures of 55-60° C are attained during curing (2-3 weeks). The briquettes are broken up before marketing.	Hart (1967), Sander (1967), Nordsiek (1976)
Switzerland (Biel)	Same as above briquettes 20 x 25 x 50 centimeters; refuse and dewatered sewage sludge	The process is similar to the one above except that higher (60-65° C) temperatures are observed in the briquettes during 3 weeks of curing. The briquettes are broken up and seived into different fractions before marketing.	Helfer (1975), Helfer (1977)
Austria	Voest Alpine (platform composting); refuse and sewage sludge	Refuse is sorted and ground and then mixed with sludge. The mix is laid on a platform to a depth of 3-4 meters and composted with forced aeration for 3-4 weeks. Then the compost is matured on open-air platforms for up to 4 months.	Willets (1979)

(cont.)

Table 9 (cont.)

Country/ city	Plant type/ raw materials	Process description	Reference
England (Manchester/ Dorchester)	Refuse and sewage sludge in forced aeration pile	Experimental study. Refuse "fines," which pass through a 50 mm mesh, are mixed with sewage sludge (4-6% solids) with front-end loader, and the mixture is piled over a perforated aeration pipe for composting for about 30 days and then allowed to mature.	Stentiford et al. (1985)
India	Refuse and night soil	The refuse and night soil mixture is placed in brick-lined pits that have aeration and drainage channels. The mixture is turned at least twice during the 30-day composting period.	
Indonesia	Windrows; refuse, manure, night soil	The raw materials are mixed and put in windrows, which are then left for 4-7 months.	Sunawira (1968)
China	Night soil and refuse	Refuse (70-80 percent by weight) and night soil (20-30 percent by weight) are mixed and heaped in piles 4 meters at the base, 2 meters at the top, 1.5 meters high and 4 meters long. Bamboo poles for aeration are inserted at 30-centimeter levels and removed on day 2. The pile is sealed with a 40:60 percent soil-cinder paste. Temperatures of 50-55° C are achieved and maintained for 25 days.	Chinese Academy of Sciences (1975)
Haiti (Port-au-Prince)	Night soil and refuse	Pilot plant, 175 cubic meters of preheated shredded refuse from a refuse treatment plant is mixed with 3.5 cubic meters of pit latrine waste using a front-end loader. Piles are constructed over a system of perforated pipes for forced aeration. Air is drawn through the pipes and exhaust gases conducted into a compost filter (Beltsville Aerated Pile Method).	Dalmat et al. (1982)

Siting and Mixing

Many countries traditionally collect refuse separately from night soil and their refuse treatment and disposal sites differ from sludge production and disposal sites. The logistics of locating a night soil/sludge-garbage co-composting site must be carefully considered. A refuse disposal site is often suitable because of land availability. After the refuse is sorted and the rejects disposed of, it must be mixed with the night soil or sludge. Where windrows are to be used instead of aerated piles or reactors, experiments have shown that specially designed shredder machines are far more efficient at mixing than front-end loaders (Golueke et al. 1980).

Planning

Many factors need to be considered when planning a composting plant. To begin with, the planner must carefully study the local situation before opting for one system or another. Table 10 compares some sludge disposal methods and gives an idea of the costs involved.

According to the figures in table 10, the costs of composting are lower than the costs for treatment processes such as heat drying and incineration but comparable to disposal-reuse processes such as landfilling, landspreading, and ocean disposal. As noted earlier, different methods of treating and disposing of wastes are often compared. Composting may not always be the most economically viable method of treating waste, sludge, and/or refuse, and thus governments, city councils, and private companies are often faced with the difficult task of deciding whether or not to compost.

Table 10. Comparative Costs for Various Sludge Disposal Processes (1976 U.S. dollars)

Item	Range of costs per dry ton (US$/ton)	Reference
Digested sludges		
Ocean outfall	10-35	Wyatt and White (1975),
Liquid Landspreading	20-54	Carroll et al. (1975),
		Smith and Eilers (1975),
		USEPA (1974)
Digested and dewatered sludge		
Ocean barging	31-44	Wyatt and White (1975),
Landfilling	23-53	USEPA (1975),
		Wyatt and White (1975),
Landspreading	26-96	Camp Dresser & McKee (1975)
Dewatered sludges		
Trenching [a]	116-134	Resources Management Associates (1975)
Incineration [b]	57-93	Brinsko (1974), Camp Dresser and McKee (1975), Van Note et al. (1975)
Heat drying [b]	62-115	Camp Dresser and McKee (1975), Stern (1975)
Composting [a,b]	35-50	Colacicco, Derr, and Kasper (1977)

a. Costs exclude transportation of sludge to site.
b. Costs exclude cost of removal of residues and benefits from resource recovery.

Source: Colacicco, Derr, and Kasper (1977).

It is important to note, however, that significant health benefits (even though difficult to quantify) derive from converting these highly pathogenic organic wastes into compost that is relatively pathogen-free. Furthermore, the application of compost to poor soils helps to improve their fertility and general condition.

Another important factor is the nature of the raw material(s) to be used, as this determines the complexity of the treatment plant required. If the raw material is refuse containing little organic matter, for example, a considerable amount of sorting and pulverization -- by machinery or manpower, or both -- will be required before the refuse can be composted. Other factors that need to be taken into consideration, especially since they may require extensive expenditure, are summarized in table 11.

Table 11. Factors To Consider in Planning a Composting Plant

Waste material	quantity and composition of waste type of waste collection of waste pretreatment required cost of bulking material transport of raw wastes to plant transport of compost disposal of noncompostible materials marketing possibilities alternative disposal options
Compost plant	location of plant capital costs land requirement (also for storage) site development equipment costs expansion possibilities applicability of existing types
Compost process	system required choice of equipment energy/fuel requirements laboratory needs maintenance needs maintenance costs personnel costs
Compost demand	market research market promotion marketing costs

As table 11 indicates, planners must weigh many factors in deciding how to best compost garbage and human waste. They should not just pick any system and hope that it can be operated efficiently under local conditions. (Some of the questions on costs are discussed in Chapter 6.)

CHAPTER 4

CONTROL OF EXCRETED AND OTHER PATHOGENS

Excreted pathogens occur in sewage sludge at varying concentrations depending on their ability to survive the various sewage treatment processes and whether they accumulate in the sludge. Concentrations in night soil depend almost entirely on the levels being excreted at any one time and on the ability of the pathogens to survive in the external environment. Table 12 summarizes the survival times of pathogens excreted in feces, night soil, and sludge, and table 13 summarizes survival times on crops. Golueke (1983) has reviewed their survival in soil. The literature on the survival of enteric pathogens during various treatment processes has been thoroughly reviewed by Feachem et al. (1983), who present detailed information on health and other aspects of excreta-related infections. Furthermore, Blum and Feachem (1985) review the health aspects of night soil and sludge use in agriculture and discuss survival and health risks.

Table 12. Survival Times of Excreted Pathogens in Feces, Night Soil, and Sludge at 20-30°C

Pathogens	Survival time (days)
Viruses	
Enterovirus*	<100 but usually <20
Bacteria	
Fecal coliforms	<90 but usually <50
Salmonella spp.	<60 but usually <30
Shigella spp.	<30 but usually <10
Vibrio cholerae	<30 but usually <5
Protozoa	
Entamoeba histolytica cysts	<30 but usually <15
Helminths	
Ascaris lumbricoides eggs	Many months

* Includes polio, echo, and coxsackieviruses.

Source: Feachem et al. (1983), p. 66.

Table 13. Survival Times of Excreted Pathogens on Crops at 20-30°C

Pathogens	Survival time (days)
Viruses	
Enteroviruses*	<60 but usually <15
Bacteria	
Fecal coliforms	<30 but usually <15
Salmonella spp.	<30 but usually <15
Shigella spp.	<10 but usually <5
Vibrio cholerae	<5 but usually <2
Protozoa	
Entamoeba histolytica cysts	<10 but usually <2
Helminths	
Ascaris lumbricoides eggs	<60 but usually <30

* Includes polio, echo, and coxsackieviruses.

Source: Feachem et al. (1983), p. 62.

Some pathogens may not survive the sludge production process. In addition, open-air drying of sludge and night soil eliminates pathogens, depending on the length of drying time. The key factors in determining the survival of pathogens are the temperature-time interactions. Feachem et al. (1983) have suggested various temperature-time regimes for selected pathogens to ensure their death in sewage sludge and night soil. These have been based on an evaluation of survival times for numerous pathogens over a wide range of temperatures (see figure 4).

Samples of sludge or night soil should be free of excreted pathogens (with the possible exception of hepatitis A virus and heat-resistant bacterial spores such as those of clostridium perfringens) if they are heated for 1 hour at > 62° C, 1 day at > 50° C, or 1 week at > 46° C. These regimes are all within the safety zone shown in figure 4. Small-scale studies using 20-30 tons of compost material have shown that e. coli and salmonella spp. are destroyed by heat more easily than fecal streptococci, and that even c. perfringers numbers decrease during composting and maturation (Pereira-Neto, Stentiford, and Mara 1986). Other workers have proposed different criteria for determining pathogen destruction in compost on the basis of work using other media as well as compost. For example, Burge, Cramer, and Epstein (1978) and Burge, Colacicco, and Cramer (1981) suggest that F2 bacteriophage be used as an indicator of pathogen destruction since this organism is more resistant to heat than many excreted pathogens. Results of work done on this organism have shown that a 15-log reduction in F2 bacteriophage numbers can be expected if they are maintained at 55° C for 2 days (for example, a 7-log reduction of an infective dose of 10^7 - Vibrio cholerae would leave 1 Vibrio cholera bacterium). Maintaining pathogens at 55° C for 2 days as a minimum is within the safety zone shown in figure 4. This figure is a reliable indicator of survival times, especially since the use of standard fecal coliform counts may not be reliable (these have been shown to multiply in mature compost (Burge et al. 1981)).

BACTERIA

The main bacterial pathogens of interest are listed in table 14. The survival rate of excreted bacterial pathogens in night soil and sludge is variable and depends in part on the temperature and the length of time involved. At temperatures above 20° C, these pathogens will generally survive up to one month in samples of sludge and night soil. (Annex table B-1 indicates survival times for various bacteria. The data are based mainly on the absence of pathogens in the compost at the end of the sampling time, and in many cases there is no indication of the initial concentrations, which would

Table 14. Bacterial Pathogens Excreted in Feces

Bacteria	Disease
Campylobacter	Diarrhea
Pathogenic Escherichia coli	Gastroenteritis of diarrhea
Salmonellae	Salmonellosis and other types of food poisoning
Salmonella typhi	Typhoid fever
S. paratyphi	Paratyphoid fever
Shigella	Bacillary dysentery
Vibrio cholerae	Cholera
Other vibrios	Diarrhea
Yersinie	Yersiniosis

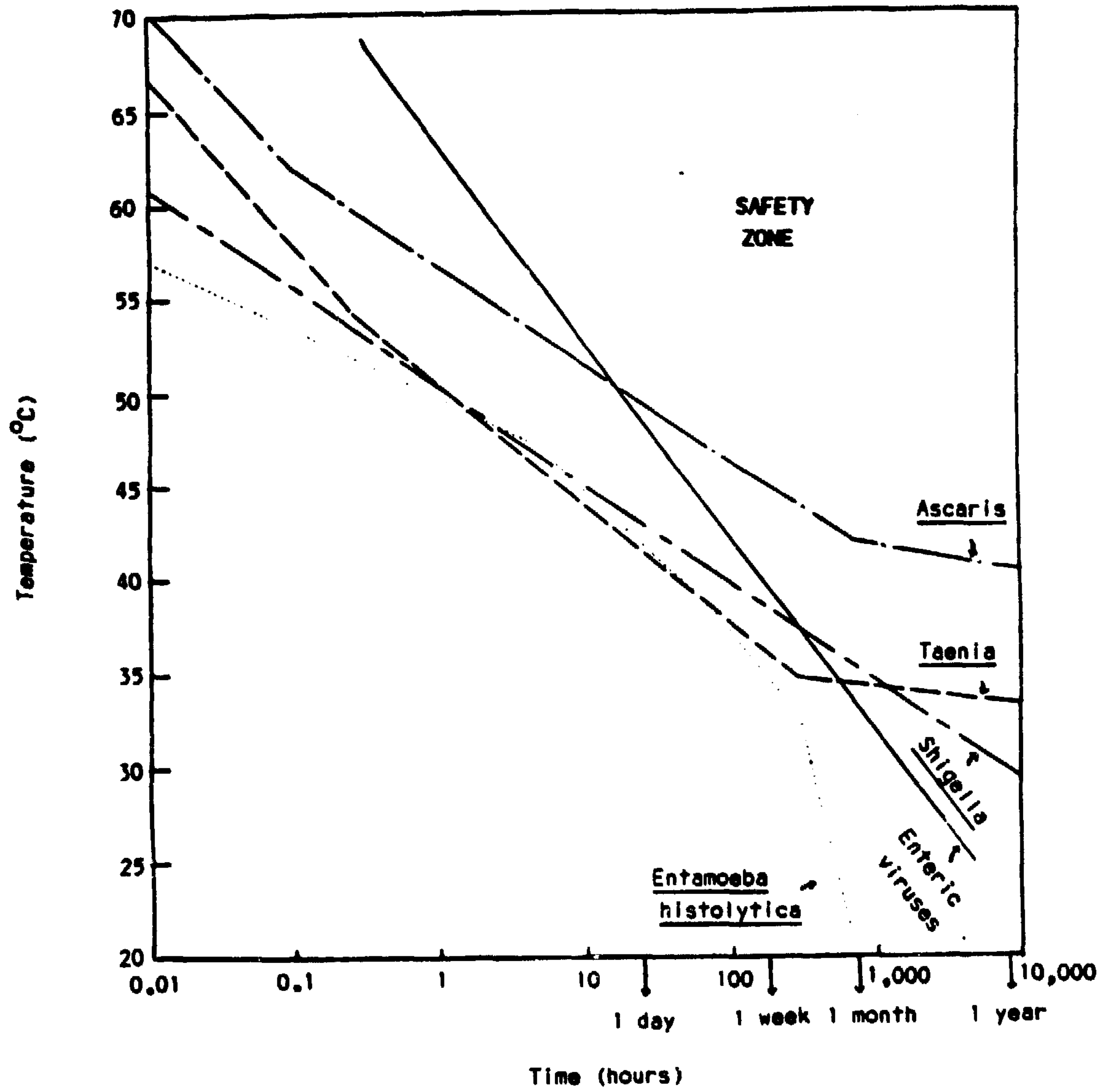

Figure 4. Survival of pathogens at different temperature/time regimes. Source: Feachem et al. (1983).

have an effect on the time for complete destruction or of frequences of sampling.) However, in general, when the composting mass was maintained at temperatures above 50° C, complete destruction was shown to occur within 2 weeks (see examples in annex B table B-1).

VIRUSES

The main viral pathogens of interest here are listed in table 15.

Data on the survival of viruses in sludge and night soil are less abundant than in the case of bacteria, principally because the methods used to determine viruses in samples are difficult to carry out and are often unreliable.

Survival of viral pathogens in compost of different materials is reduced to low levels within 2 weeks at temperatures between 35 and 70° C for most of the pathogens presented in annex table B-2.

Table 15. Viral Pathogens Excreted in Feces

Viruses	Disease
Adenoviruses	Numerous conditions
Coxsackieviruses	Numerous conditons
Echovirus	Numerous conditons
Hepatitis A virus	Infectious hepatitis
Reoviruses	Numerous conditions
Rotavirus	Diarrhea or gastroenteritis in children
Poliovirus	Poliomyelitis

PROTOZOA

The main protozoal pathogens of interest here are listed in table 16.

Reported survival of some of these pathogens in compost is presented in annex table B-3. The figures there indicate that in general the protozoal pathogens survive for short periods.

Table 16. Protozoal Pathogens Excreted in Feces

Protozoa	Disease
Entamoeba histolytica	Amoebic dysentery and liver abscess
Giardia lamblia	Diarrhea and malabsorption
Balantidium coli	Mild diarrhea and colonic ulceration

HELMINTHS

The main helminths of interest are presented in table 17. Certain helminths can survive in night soil and sludge up to a period of 3 months or longer, especially at cooler temperatures (<25° C). The most resistant ones are Ascaris and hookworm ova (annex table B-4). In compost, survival is generally very low at temperatures maintained over 35° C for a few days (annex table B-4).

Because the survival times for the different pathogens vary greatly at the different temperature-time regimes measured by researchers and composting plant operators, it is extremely important to establish reliable temperature-time criteria for pathogen destruction during composting. The regimes within the safety zone proposed by Feachem et al. (1983) and Burge, Colacicco, and Cramer (1981) may be of great use in this regard.

VETERINARY PATHOGENS

Pathogens excreted by animals may find their way into sludge or night soil if the wastes containing them become mixed with human wastes. Several infections can be transmitted from animals to man (see table 18). Only some of these diseases are enteric and are of interest here.

Enteric pathogens that may be isolated from animal waste include bacteria, viruses, protozoa, and helminths. They occur in varying numbers depending on the type of disease and the physical and chemical composition of the waste. Since these pathogens are enteric, their optimum growth occurs around body temperature. Thus the thermophilic temperature (> 45° C) achieved during aerobic composting should be sufficient to destroy or inactivate the enteric pathogens, especially if the temperatures are maintained for sufficient lengths of time. Some exceptions to this may be spores of spore-forming bacteria found in animal wastes (such as Bacillus anthracis and some clostridia), which survive at high temperatures.

Table 17. Helminthic Pathogens Excreted in Feces

Pathogen	Disease
Ancylostoma duodenale	Hookworm
Necator americanus	Hookworm
Ascaris lumbricoides	Ascariasis
Clonorchis sinensis	Clonorchiasis
Opisthorchis felineus	Opistorchiasis
Opisthorichis viverrini	Opistorchiasis
Diphyllobothrium latum	Diphyllobothriasis
Enterobius vermicularis	Enterobiasis
Fasciola hepatica	Fascioliasis
Fasciolopsis buski	Fasciolopsiasis
Gastrodiscoides hominis	Gastrodiscoidiasis
Heterophyes heterophyes	Heterophyiasis
Hymenolepis spp.	Hymenolepiasis
Metagonimus yokogawai	Metagonimiasis
Paragonimus westermani	Paragonimiasis
Schistosoma haematobium	Schistosomiasis (Bilharziasis)
Schistosoma mansoni	Schistosomiasis
Schistosoma japonicum	Schistosomiasis
Strongyloides stercoralis	Strongyloidiasis
Taenia saginata	Taeniasis
Trichuris trichiura	Trichuriasis

Table 18. Animal Pathogens Capable of Causing Infections in Man

Pathogen	Infection	Mode of infection
Bacteria		
Bacillus anthracis	Anthrax	Direct contact, excreta
Brucella abortus	Brucellosis	Cow to man, direct
Brucella suis	Brucellosis	Swine to man, contact
Brucella melitensis	Brucellosis	Goats to man, ingestion
Leptospira icteroheremorrhagiae	Leptospirosis	Urine
Rikettsial typhi	Typhus	Excreta
Salmonella	Salmonellosis	Excreta
*Listeria monocytogenes**	Listeriosis	Cattle/dogs to man, direct contact
Viruses		
Arboviruses	Togavirus	Ingestion
Herpes virus[a]	B virus	Monkey to man, direct contact
Pox virus cowpox[a]	(cow to man)	Direct contact
Protozoa		
Toxoplasma gondii	Toxoplasmosis	Mammals/birds to man, ingestion/inhalation feces
Helminths		
Fasciola hepatica	Fascioliasis	Sheep and cattle to man
Taenia saginata	Taeniasis	Cow to man
Taenia solium	Taeniasis	Pig to man
Fungi*		
Microsporum canis	Ringworm	Dog to man, direct contact

*Not enteric.

SECONDARY PATHOGENS

Secondary pathogens affect people whose defense systems have been weakened by certain diseases or therapies. They may be present in sewage sludge or night soil and some are able to grow in compost. Examples of secondary pathogens are some thermophilic fungi and actinomycetes. These infect people who have had respiratory infections or prolonged antibiotic or steriod treatment (Hart, Russell, and Remington 1969). The probability of people in good health becoming infected is very low (Olver 1979; Willson et al. 1980; Burge and Millner 1980).

The main thermophilic fungus of concern here is Aspergillus fumigatus, which causes a respiratory disease known as asperigillosis. The thermophilic actinomycetes (for example, Thermopolyspora polyspora and Micromonospora vulgaris) cause allergic reactions such as Farmer's Lung (Lacey 1974; Marsh, Miller, and Kla 1979). Millner (1982) lists several other actinomycetes reported to grow at the thermophilic temperatures attainable during the composting process (50° C). These secondary pathogens are ubiquitous and are very common in agricultural situations. Asperigillus fumigatus, for example, is found in soils, hay, wood, cereals, forage, and various moldy farm wastes. From the data on maximal concentrations of thermophilic actinomycetes in different materials (see table 19), it appears that the concentrations in compost are generally lower than those in the other materials (more mature compost usually has higher concentrations - up to 10^8 per gram of dry weight). Compost is able to support the growth of fumigatus and the actinomycetes because of the temperatures achieved during the process. Aspergillus fumigatus grows at temperatures of less than 20° C to about 60° C (Cooney and Emerson 1964; Kane and Mullins 1973a,b) and has been readily isolated from wood chips at 50° C (Tansey 1971). The actinomyecetes have a similar temperature range (Lacey 1974). High concentrations have been isolated between 55° C and 60° C (Millner 1982). Certain factors can inhibit the growth of these secondary pathogens: low pH, anaerobic conditions, excessive moisture and high temperatures (> 65° C).

Toward the end of a composting process, when the compost is cooling down and becoming drier, the secondary pathogens may predominate. Their spores are readily dispersed from dry and dusty compost piles especially during and after mechanical agitation (Millner, Bassett, and Marsh 1980).

Table 19. Concentrations of Thermophilic Actinomycetes
in Different Materials
(numbers per gram, dry weight)

Growth material	Concentration
Moist hay	1.7×10^7
21-day sewage sludge compost	5.7×10^5
4-month sewage sludge compost	1.8×10^8
Bagasse	9.6×10^6
Mushroom compost	6.6×10^6
Moist grain	10^5

The degree of dispersal also depends on meteorological factors such as wind and rain (Millner et al. 1977). Experiments carried out to measure concentrations of these secondary pathogens at locations downwind of compost piles at treatment plants have shown that conditions differ for each compost plant, but that concentrations tend to be lower than those associated with secondary infections from moldy hay (Burge and Millner 1980; Millner 1982).

As already noted, the risk of infection in healthy individuals is low. Certain measures can be taken, however, to improve the general health standards at a composting plant and thus reduce the risk of these secondary infections even further:

1. Workers should be encouraged to maintain high standards of hygiene.
2. During periods of dry weather, the composting area should be sprinkled periodically with water to reduce dust dispersal.
3. During adverse weather conditions, workers should be encouraged to wear masks or respirators or some other covering to reduce dust inhalation.
4. Workers should be isolated from the spore-dispersing parts of the process, such as mechanical turning.
5. The composting plant should be located at "discreet" distances from hospitals and residential areas (the distance will vary from plant to plant, but in general should be at least 1 kilometer).

PLANT PATHOGENS

Numerous pathogens cause plant diseases. Most agricultural soils are infested with nematodes, bacteria, viruses, and fungi (Sasser 1971). Some of these may be present in compost made from garbage, vegetable, and other gardening wastes. Knoll (1980) has described standard laboratory methods that can be used to isolate and measure the concentrations of indicator plant pathogens in compost. Table 20 lists some pathogens that have been associated with compost as an indicator or that have been isolated from it. The most important ones are those that produce heat-resistant spores, such as the fungi listed in table 20 or some viruses. Most other pathogens are mesophils and would therefore be inactivated under thermophilic composting temperature-time regimes (although heat resistant spores present in compost may persist in the soil for long periods after being spread on land). Recent research has revealed that compost may have a beneficial effect on plants and soil-borne diseases. The application of compost to soils containing diseased plants has been followed by immediate and long-term reduction in the incidence and severity of certain diseases such as root rot of beans, cotton, and radish.

Table 20. Plant Pathogens in Compost

Pathogens	Plants affected
Bacteria (various)	Cabbage Beans Tomatoes
Viruses, tobacco mosaic	Tobacco Potato
Helminths, meloidogyne type, nematodes	Cucumber Tomatoes Lettuce Carrots
Globodera rostochiensis	Potatoes
Fungi, *Plasmodiophora brassicae*	Cabbage Rape
Olipidium brassicae	Cabbage Lettuce Other vegetables
Sclerotinia	Lettuce

CHAPTER 5

USES OF COMPOST

This chapter briefly reviews the uses of compost. The degree of use depends greatly on whether or not material of fecal origin is culturally and socially acceptable.

QUALITY OF COMPOST

A well-produced, mature compost is free from odor and easy to handle, store, and transport. A raw compost (one that has not matured) does not have these qualities, but will acquire them with time if it is allowed to mature. Table 21 lists some of the differences between raw and mature compost.

Mature compost contains trace and essential elements, of which the most important are nitrogen, phosphorus, potassium, and sulphur. These are available to the soil and plants, depending on their initial concentrations in the raw compost materials and on the degree of mineralization that occurs (Tester, Parr, and Paolini 1980). (Concentration in compost from sludge/night soil and garbage compost are considered equivalent, although concentrations of other elements will vary depending on the raw materials.) These elements are released by the compost and become available in the years following application. The compost can therefore be used in somewhat the same way as an inorganic fertilizer (except that in many cases the concentrations of these elements are so low that excessively large application rates would be required). As a result, compost is often considered a low analysis fertilizer or soil conditioner (Golueke 1972; Hand, Gershman, and Navarro 1977; Parr et al. 1978). However, the NPK values (and other mineral content) of compost can be fortified with chemicals to enhance its fertilizing capacity (Hileman 1982). Unlike inorganic fertilizers, compost has a humuslike quality that makes it even more useful, especially in areas of the world where the humus content of soil is being rapidly depleted as a result of excessive cultivation and land erosion (Tietjen 1975; Pagliali et al. 1981). That is to say, compost can replace lost humus.

Compost may contain high concentrations of heavy metals, depending on the source of the raw materials. If sludge from a mixed industrial-domestic source is used, concentrations of lead, zinc, and nickel may be very high. Some typical heavy metal concentrations in compost, night soil, and sludge are presented in table 22. Concentrations in night soil are negligible. Garbage and human waste plants utilizing night soil will produce compost low in heavy metals, especially if the refuse is largely organic. Other hazardous chemicals such as detergents and those in certain industrial wastes that may be composted will appear in the product if they are nonbiodegradable.

Table 21. Differences between Mature and Raw Compost

Mature compost	Raw compost
Nitrogen as nitrate ion	Nitrogen as ammonium ion
Sulphur as sulphate ion	Sulphur still in part as sulphide ion
Lower oxygen demand	Higher oxygen demand
No danger of putrefaction	Danger of putrefaction
Nutrient elements are in part available to plants	Nutrient elements not available
Higher concentrations of vitamins and antibiotics	Lower concentrations of vitamins and antibiotics
Higher concentrations of soil bacteria, fungi, which are decomposed, easily degradable substances	Higher concentration of bacteria and fungi, which decompose organic materials
Mineralization is about 50 percent	High proportion of organic substances not mineralized
Higher water retention ability	Lower water retention ability
Clay-humus complexes are built	No clay-humus complexes generated
Compatible with plants	Not compatible with plants

APPLICATION OF COMPOST TO LAND

The most important use of compost is its application to land. This takes several forms: It can be applied to land as a fertilizer, soil conditioner, or mulch, or can be used as a means of land reclamation. Furthermore, the use of compost can range from domestic applications by the home gardener to large-scale applications by commercial farmers to their cropland or by municipalities for parklands.

The application of compost to land has several advantages. Its positive effects on plant growth, fruit, crop yields, and other factors compared with the effects of fertilizers alone are well documented (see, for example, Arditti 1973; Hornick et al. 1979; Tokyo Metropolis 1979; Kurzweil

Table 22. Metal Concentrations in Compost and Human Waste

Source material	Concentrations	Cadmium	Chromium	Copper	Nickel	Lead	Zinc	Reference
Refuse/sludge compost	kg/100t	-	6.0	10.0	4.4	10.0	34.0	Rhode (1972)
Refuse/sludge	kg/t	0.006	-	0.24	-	0.19	0.77	Bucher (1974)
Sewage/sludge compost	mg/kg	4.9	200.0	150.0	77.0	160.0	960.0	Faust and Romano (1978)
Sewage/sludge compost	mg/kg	6.0	200.0	400.0	80.0	300.0	1,200.0	Faust and Romano (1978)
Night soil	mg/kg	0.024	-	-	0.15	0.25	-	Japan Sewage Works Agency (1980)
Night soil	mg/kg	-	-	-	2.1	0.5	4.6	Japan Sewage Works Agency (1980)
Mixed domestic/ industrial sludge	mg/kg	16.0	-	-	80.0	7.00	3,000.0	Japan Sewage Works Agency (1980)
Mixed domestic/ industrial sludge	mg/kg	25.0	-	-	290.0	1,550.0	1,930.0	Japan Sewage Works Agency (1980)
Sludge, digested, industrial	mg/kg	110.0	-	-	320.0	1,360.0	2,790.0	Willson et al. (1980)
Sludge, digested	mg/kg	72.0	-	-	129.0	735.0	2,010.0	Willson et al. (1980)
Mixed domestic/ industrial sludge	mg/kg	3.4	-	299.5	17.8	216.0	546.0	Stentiford et al. (1983)

- = not measured.

1980; Angle, Wolf, and Hall 1981; and Sridhar et al. 1985). The advantages it has over inorganic fertilizers lie in its effects on the soil. Table 23 summarizes some of these effects with respect to clay or sandy soils. In both cases, the quality of the soil is improved and it is more productive. Some recommendations and criteria for the application of compost to land are presented in tables 24-26. Compost may not only amend the physical properties of the soil, but it may have other beneficial effects, such as raising the pH of acid soils. Production of compost may be of great interest, especially in countries with poor, arid soils.

Table 23. Physical Effects of the Addition of Compost to Clay or Sandy Soils

Sandy soil + compost	Clay soil + compost
Water content is increased	Aeration of soil increased
Water retention is increased	Permeability of soil to water increased
Aggregation of soil particles is enhanced	Potential crusting of soil surface is decreased
Erosion is reduced	Compaction is reduced

Compost may be used on land for the following purposes: agriculture, horticulture, home gardening, vegetable gardening, viticulture, landscaping, landfill, forestry, or commercial farming. It is usually applied as mulch, soil conditioner, or fertilizer for many of these applications.

OTHER USES OF COMPOST

Apart from the traditional applications to land, compost has some other uses. For example, sewage sludge or refuse compost can be fed to piglets. Pigs are omnivores and so compost is palatable to them. The compost has to be ground into a fine material (< 4mm) and is fed only to piglets. In Switzerland it is bagged and sold on the market at about 120 SF per cubic meter (Helfer 1975). As noted earlier, animal enteric pathogens should in general be inactivated or destroyed.

Compost from night soil and vegetable matter has been used in fish farming experiments, where the compost has acted not only as a nutrient for the growth of algae but also as fish feed (Polprasert et al. 1981). Compost has also been used to make bricks porous. It is incorporated into the bricking material before firing; during firing the organic matter burns, leaving the fired bricks porous, as desired.

Table 24. Criteria for the Specific Applications of Compost

Application	Compost type	Frequency (years)	Quantities (tons per hectare)
Grain crops	Fresh/mature	2-4	20-60
Root crops	Fresh/mature	2-4	40-100
Grassland and cultivation of fodder plants	Fine fresh/mature	2-4	20-50
Fruit growing	Fresh/mature	3	100-200
Vine growing	Fresh/mature	3-4	50-100 (light soils) 80-240 (heavy soils)
Vegetables (outdoor)	Fresh/special*	2-4	50-100
Vegetables (greenhouse)	Mature/special	2-4	10-15
Landscaping slopes	Fresh/mature	2	100-300 20-40
Pig feed	Special mix with iron	-	(30 kilograms per farrow in first three weeks)
Control of erosion	Fresh	-	up to 300

*Special compost has added minerals or is very fine in texture.

Source: Adapted from Bundesrepublik (1979) and Tabasaran, Bidlingmaier, and Bickel (1981).

Table 25. Compost Application Rates: Uses and Application Rates of Sewage Sludge Compost to Achieve Fertilizer Benefits and Improve Soil

Use	Compost (metric tons per hectare)	Remarks
Vegetable crops		
Establishment	50-150	Rototill into surface 1-3 weeks before planting or in previous fall. Do not exceed recommended crop nitrogen rate.
Maintenance	50	Rate is for years after initial garden establishment. Rototill into surface 1-2 weeks before planting or in previous fall.
Field crops		
Barley, oats, rye, wheat	50-60	Incorporate into soil 1-2 weeks before planting or in previous fall.
Corn	150-185	Incorporate into soil 1-2 weeks before planting. Supplemental potash may be required, depending on soil test.
Legumes		Legumes can be grown in rotation with corn, oats, or other nitrogen-required crops.
Forage grasses		
Establishment	195-340	Incorporate with top 4-6 inches of soil. Use lower rate on relatively fertile soil and higher rate on infertile soil. Supplement during first year's growth with 1/2 pound per 1,000 square feet (25 pounds per acre) of soluble nitrogen fertilizer when needed.

(cont.)

Table 25 (cont.)

Use	Compost (metric tons per hectare)	Remarks
Maintenance	50-60	Broadcast uniformly on surface in fall or early spring 1 year after incorporated application.
Nursery crops and ornamentals (shrubs and trees)		
Establishment (soil incorporation)	90-350	Incorporate with top 6-8 inches of soil. Do not use where acid-soil plants (azalea, rhododendron, etc.) are to be grown.
Maintenance	10-25	Broadcast uniformly on surface soil. Can be worked into soil or used as a mulch.
Potting mixes	Equal ratio of material	Thoroughly water and drain mixes several times before planting to prevênt salt injury to plants.
Reclamation		
Conservation planting	Up to 450	Incorporate with top 6 inches of soil. Use maximum rate only where excessive growth for several months following establishment is desirable. For each inch beyond 6 inches of incorporation, add 1,000 pounds per 1,000 square feet on soils where groundwater nitrogen will not be increased.
Mulch	15-35	Broadcast screened or unscreened compost uniformly on surface after seeding; unscreened is more effective.

(cont.)

Table 25 (cont.)

Use	Compost (metric tons per hectare)	Remarks
Turfgrasses		
Establishment (Soil incorporation)	100-300	Incorporate with top 4-6 inches of soil. Use lower rate on relatively fertile soil and higher rate on infertile soil.
Surface mulch	30-35	Broadcast uniformly on surface before seeding small seeded species (bluegrass) or after seeding large seeded species (fescues).
Maintenance	20-40	Broadcast uniformly on surface. On cool-season grasses apply higher rate in fall or lower rate in fall and again in early spring.
Sod production, incorporated with soil	150-300	Incorporate with top 4-6 inches of soil.
Sod production, unincorporated with soil	300-900	Apply uniformly to surface. Irrigate for germination and establishment.

Source: Adapted from Hornick et al. (1979).

Table 26. Application Rates for Sewage Sludge Compost in the First Year of Use Based on N or P Fertilizer Recommendations

	N-based fertilizer recommendations (tons compost per hectare)	P-based fertilizer recommendations (tons compost per hectare)	Remarks
Nursery crops and ornamentals (shrubs and trees)			
Establishment	100-380	35-100	Incorporate with top 6-8 inches of soil. Do not use where acid-soil plants (azalea, rhododendron, etc.) are to be grown. Broadcast uniformly on surface soil. Can be worked into soil or used as a mulch.
Reclamation			
Conservation planting	Up to 500	n.r.	Incorporate with top 6 inches of soil. Use maximum rate only where excessive growth for several months following establishment is desirable. For each inch beyond 6 inches of incorporation, add 22 tons per acre on soils were groundwater nitrogen will not be increased.
Mulch	17-40	n.r.	Spread screened or unscreened compost uniformly on surface after seeding; unscreened is effective.

(cont.)

Table 26 (cont.)

	N-based fertilizer recommendations	P-based fertilizer recommendations	Remarks
	(tons compost per hectare)		
Field Grass			
Barley, oats, rye, wheat	50-	10	Incorporate into soil 1-2 weeks before planting or in previous fall.
Corn	105-200	15-17	Incorporate into soil 1-2 weeks before planting. Supplemental potash may be required depending on soil test.
Legumes	n.r.	5	Legumes can be grown in rotation with corn, oats, or other nitrogen-requiring crops.
Forage grasses			
Establishment	220-380	10-30	Incorporate with top 4-6 inches of soil. Use lower rate on relatively fertile soil and higher rate on infertile soil. Supplement during first year's growth, using 25 pounds per acre of soluble nitrogen fertilizer when needed.
Maintenance	50-70	10-12	Broadcast uniformly on surface in fall or early spring 1 year after incorporated application.

(cont.)

Table 26 (cont.)

	N-based fertilizer recommendations	P-based fertilizer recommendations	Remarks
	(tons compost per hectare)		
Turfgrasses			
Establishment (Soil incorporation)	100-330	27-37	Incorporate with top 4-6 inches of soil. Use lower rate on relatively fertile soil and higher rate on infertile soil.
Surface mulch	32-40	n.r.	Spread uniformly on surface before seeding small seeded species (bluegrass) or after seeding large seeded species (fescues).
Maintenance	22-44	7-10	Spread uniformly on surface. On cool-season grasses apply higher rate in fall or lower rate in fall and again in early spring.
Sod production, incorporated with soil	165-330	27-37	Incorporate with top 4-6 inches of soil.
Vegetable crops			
Establishment	55-165	7-17	Rototill into surface 1-2 weeks before planting or in previous fall.
Maintenance	55	7	Rate is for years after initial garden establishment. Rototill into surface 1-2 weeks before planting or in previous fall.

n.r. = not recommended.

Source: Adapted from Hornick et al. (1979).

CHAPTER 6

METHODOLOGY FOR EVALUATING THE ECONOMIC FEASIBILITY OF CO-COMPOSTING

In developing countries the waste stream is relatively higher in organic matter than that of industrialized countries. Since compost is derived only from the organic wastes, it would seem that developing countries have a relative advantage in the production of compost. In addition, domestic solid waste in developing countries contains few, if any, toxic materials which minimizes the risks of recycling them in the domestic solid waste to the land in the form of compost. The purpose of this chapter is to present and analyze the economic parameters underlying co-composting operations. This will be done by presenting the fundamental information needed to assess the viability of co-composting, followed by development of hypothetical models in financial and then economic terms, along with a discussion of the differences between them. The models will then be computerized and results and sensitivity analysis presented. The methodology followed conforms to World Bank guidelines for project economic analysis.

Analysis is being limited to co-composting domestic solid waste with night soil, although with minor modifications it would be applicable to compost operations using domestic solid waste or sludge separately. Direct composting of domestic solid waste would be more closely correlated to the figures presented here, since the night soil component is relatively small (less than 10 percent of total inputs). Direct composting of night soil/sludge, however, requires the use of a bulking agent or organic amendment to reduce its moisture content. (For a detailed description of night soil composting, see Shuval et al. 1981.) Co-composting utilizes the domestic solid waste to serve as a bulking agent for the night soil.

COMPOSITION OF WASTE AND VALUE OF RESOURCES RECOVERED

The hypothetical models developed in this chapter assume a typical composition of solid waste for developing countries, which limits the capital requirements for equipment such as hammermills or rasps (to grind incoming domestic solid waste) by the waste composition (highly organic) and the use of a manual picking or sorting process. The specifics of the waste stream and its need for size reduction would vary for each municipality. Typical domestic solid waste generation rates for developing countries that will be used as the basis for these models are 0.3 kilograms/person/day of domestic solid waste with a moisture content of 50 percent and a density of 250-400 kilograms per cubic meter and 1.5 liters of night soil/person/day with a solids content of 3 percent. The quantity of night soil that can be processed by the co-composting operation depends on the moisture content of the material

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This chapter was written by World Bank staff economists Frederick Wright and Edward F. Quicke.

to be composted; this should be no greater than 55 percent. The analysis assumes fresh night soil is collected and used by the co-composting operation, which severely limits the amount used. The use of pit latrine sludge (20-25 percent solids), dried sewage sludge (10-20 percent solids), or dewatered sludge would allow a greater population base to be handled. The use of a lower moisture liquid human waste would change the analysis slightly by increasing the amount of compost produced in direct proportion to the increased solids but would have little if any impact on compost-processing costs. Local conditions will determine the source of liquid material for the co-composting operation.

For the purposes of modeling, the domestic solid waste composition as given in table 27 has been assumed.

Table 27. Domestic Solid Waste Composition

	% Domestic solid waste*
Vegetables/putrescible	58
Paper/carton	20
Textiles	3
Metals (ferrous)	4
Glass	3
Plastic and rubber	4
Inerts, ash, rejects, etc.	8
	100%

* Moisture content of 50 percent, density of 400 kg/m^3.

Domestic solid waste composition and quantities generated are subject to wide variations as shown in chapter 1, table 1, and depend a great deal on the local collection/scavenging system. Waste composition and quantity also vary according to season (higher ash content in winter, higher moisture levels during wet season, etc.) and source (industry, economic level, etc.). In many areas, the waste stream may consist almost entirely of organic material, the recoverable material of any value having been removed by scavengers before collection and delivery to the composting plant. Because variations in composition could have a substantial impact on the operating viability of a composting system, waste composition must be determined prior to consideration of composting as a waste management option. Variations in quantities of waste may also effect the capacity utilization of the co-composting operation or the need for alternative disposal systems, particularly where co-composting operations are used for a significant portion of the waste stream. The moisture content of the domestic solid waste is very important when co-composting is done, since the lower the domestic solid waste moisture the greater the amounts of night soil (3 percent solids) or sewage sludge (10-20 percent solids) that can be disposed of. The domestic solid waste collection system is not being analyzed here but plays a very important role and should be examined when composting as a disposal option is considered. Since composting is only possible on the organic material, the inert material (including metals, glass, plastics) needs to be sorted out if good quality compost is to be made. The percentage of available materials recovered will not approach 100 percent of their content in the domestic solid waste unless sophisticated recovery technologies are used. Table 28 illustrates reasonable resource recovery coefficients (for manual sorting) estimated from the available literature.

Table 28. Resource Recovery Coefficients

	% Recovered
Paper	60
Textiles	70
Metals (ferrous)	85
Glass	50
Plastic and rubber	60

The remainder consists of compostable material (most of the unreclaimed paper and some textiles also fall in this category) and rejects. The rejects (comprising mainly inert material such as construction waste and unrecovered recyclable materials) must be disposed of in an appropriate manner -- a sanitary landfill, for example -- or some other recycling technology such as construction land reclamation fill or waste-derived building blocks where feasible. Therefore, in many cases the appropriate site for the co-composting is the landfilling site, where sorting and separation and disposal of rejects will be done.

For modeling purposes, the US dollar equivalent prices for recovered materials will be assumed as given in table 31.

Table 29. Recovered Material Values

	$/Ton*
Paper	20
Textiles	20
Metals (ferrous)	15
Glass	20
Plastics and Rubber (mixed)	50

* Prices are ex-plant.

The actual prices received for recovered materials are relatively unstable and highly dependent on the local market (rural, industry, transport availability, etc.). In addition, these materials tend to be bulky and transport costs constitute a high percentage of the end users cost. Also, the size of the composting operation has some bearing on prices for recovered materials. A small-scale plant would only be able to offer material users significant quantities after a period of time, whereas a large facility would be in a better position to negotiate a long-term sales contract. Prior to investing in a composting/resource recovery plant, detailed estimates must be made of the local market (quantity and price) for recovery materials. Table 30 estimates the value of recovered materials from one ton of waste, based on the assumed waste composition (table 29), resource recovery coefficients (table 30), and material values (table 31).

Table 30. Recovered Materials,
Revenue/Ton of Domestic Solid Waste
(US$)

Material	Domestic solid waste content kg	Recovery coeff. %	Quantity recovered kg	Price $/ton	Revenue $/ton
Paper	200	60	120	20	2.40
Textiles	30	70	21	20	.42
Metals	40	85	34	15	.51
Glass	30	50	15	20	.30
Plastics	40	60	24	50	1.20
TOTAL	340	--	214	--	4.83

As can be seen, the gross revenue generated for most items is rather small (particularly for textiles, metals, and glass) and one might assume it is not economical to recover them (recovery, of course, depends on local labor costs and potential markets). Yet, except for the paper, these are not compostable materials. Therefore, they would still need sorting and would then become rejects (requiring disposal) if not recovered and sold, and a significant percentage of the end cost has to be invested for both recycling and co-composting.

The other revenue-generating item will be the compost. The price (value) of compost is also sensitive to local conditions such as cropping patterns (vegetables or other high value crops), soil condition, availability of alternative soil conditioners (such as livestock wastes or crop residues), and costs of agricultural inputs (for example, inorganic fertilizers and water). Other potential buyers of compost include greenhouses and horticultural plant nursery operations (as a substitute for other more expensive growing media, such as peat moss), land reclamation projects (strip mining or landfill cover), and public works (parks, landscaping, etc.).

The amount of compost produced depends on the quantity of compostable material, content of volatile solids, and its initial and final moisture content. Particle size, moisture content, as well as the carbon/nitrogen ratio (the mixing of night soil or sewage sludge with the compostable part of the domestic solid waste generally improves the C/N ratio) and oxygen content are the critical factors affecting the speed of the composting process and the quality of the finished compost.

A review of the available literature indicates a substantial variation in the yield of compost, particularly from solid waste. For example, the research done by the TVA at Johnson City indicates a 20-30 percent reduction in total solids (after removal of noncompostables) for municipal waste compost. Other sources show reductions in solids as low as 10 percent (Flintoff) and as high as 50-55 percent, again based on total compostable solids. Other reports make specific reference to reduction in volatile solids and show values ranging from 42 percent (Neto and Stentiford) up to 62 percent (Diaz). Still others report yields of compost based on the total waste stream, with figures ranging from 37-50 percent (EQI). Other factors that compound the problem of comparing these compost yields are the variations in waste composition, the final moisture content, and the degree of compost maturity. Before a decision is made on the economic viability of composting, the yield of the proposed co-composting plant needs to be estimated based on trials that utilize the local waste stream.

For modeling purposes the input/output balance for one ton of waste and 80 kilograms of night soil[1] is as presented in table 31.

The compost product, in addition to being a soil conditioner, would have some value as a low-grade fertilizer with analysis closely correlated to the waste input. Typical N (nitrogen), P (phosphate), and K (potassium) values for municipal waste and night soil compost are 1.3, 0.9, 1.0, respectively; however, wide variations exist. Because of the unmineralized nature of the nitrogen, much of it is unavailable for immediate plant use (typically, only 10 percent is available in the first year) and therefore acts much like a low-grade, slow-release fertilizer. The major value of compost is derived from its organic content which improves soil texture. Improved soil structure increases water retention capabilities resulting in either greater yields or lower irrigation requirements. Other benefits come from compost's ability to provide and/or improve utilization of plant nutrients, particularly micronutrients, and enhance the crop utilization of artificial fertilizers (thought to be a function of slower leaching). One point of caution when using compost on food crops is that waste-derived co-compost (particularly

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[1] The 80 kg of night soil (3% solids) added after the separation step raises the moisture content of the compostable material to 55%. Use of pit latrine wastes or sewage sludge at 20% solid would be 140kg and increase the amount of compost to 360kg/1 ton domestic solid waste.

Table 31. Material Balance Per
1 Ton Domestic Solid Waste [a]

	Kg
Recovered Materials	214
Rejects[b]	86
Compost[c]	335
Loss of volatized solids and water	445
	1080

a. Assumed to have an initial moisture content of 50%.

b. Rejects consist of inerts (excluding ash and fines), and unrecovered metals, glass and plastics.

c. Quantity of compost produced is based on 700 kg of compostable material at 50% moisture plus 80 liters of night soil at 3% solids. During the composting process 33% of total solids are consumed and the final product has a 30% moisture content for a total weight reduction of 57%.

when sewage sludge is used) may contain heavy metals (lead, cadmium, nickel, zinc, mercury) which would limit the acceptable application rates. However, in the majority of urban areas in developing countries the potential percentage of heavy metals is negligible.

SCALE AND TECHNOLOGY OF CO-COMPOSTING PLANT

In order to present a wide range of composting alternatives, four different scale base case models of one nonreactor composting system, the windrow, will be developed and analyzed. The descriptions of the 3- and 50-ton-per-day plants are from Flintoff (1976) for India, and the 150- and 300-ton-per-day from consultants' work done for the recently appraised Egypt Solid Waste Management project. Interpolation of physical components was also done as a cross check to get a degree of consistency across the four hypothetical base case models. Financial prices used are based on the consultants' report for Egypt. It should be explicitly understood that, while efforts have been made to be realistic, these base case models are hypothetical and should be used with caution, although attempts have been made to make them as realistic as possible. Their main purpose is to allow the reader to work through the methodology using data from his or her specific situation. A description of these four base case models is given below in table 32.

Table 32. Description of Base Case Models

Model designation	Capacity/description
A	3 tons/8-hour day (Domestic solid waste input), entirely manual/windrow-style operations on an unpaved site of 500 m^2, with storage tank (night soil) and a manual rotary screen (waste from 10,000 people and night soil from 160 people or sludge from 1,900 people).
B	50 tons/8-hour day, using a 2 ha paved site, windrow-style operations with conveyors, rotary screen, ballistic separator, storage tank (night soil), front-end loader, tractor and trailers (waste from 160,000 people and night soil from 2,500 people or sludge from 30,000 people).
C	150 tons/16-hour day, windrow-style operation using a 18.5 ha paved site with weigh bridge, storage tank (night soil), civil works, conveyors, shredding drums, magnetic separator, hydraulic baler windrow turning machine (1), frontend loaders (2), tipper trucks (4), workshop, laboratory generator, and bagging line (waste from 500,000 people and night soil from 8,500 people or sludge from 93,000 people).
D	300 tons/16-hour day, using a 25 ha site, same description as in C with two times equipment and throughput.

In addition to these windrow (periodic-turning) systems, there are at least two other viable co-composting systems suited for conditions in developing countries, such as the static aerated pile, and reactor systems. These were described in some detail in chapter 3. The basic input/output relationships are the same for all co-composting systems. For the static aerated pile there would be minor changes in capital costs (suction fans and process controls but no windrow turning equipment) and reduced operating costs (less turning). For the enclosed reactor systems, the capital and operating costs would increase dramatically but have lower land requirements (only for the composting, not maturation). Analyses of these additional co-composting options will be approximated using sensitivity analysis that makes changes in both capital and operating costs as outlined in chapter 3, table 8. The physical operating parameters (waste input, recovery rates, and compost production) are the same for all models and technologies.

CAPITAL AND OPERATING COSTS

Base case investment costs for the four windrow models are detailed in table 33 below. Models A and B could be constructed in less than one year, while the larger models would require a two-year construction period. Staffing and operating coefficients are given in tables 34-36.

Table 33. Estimated Capital Costs (Base Case)
(thousands of US$)

	Model			
Description	A (3tpd)	B (50tpd)	C (150tpd)	D (300tpd)
Civil Works				
Site preparations	1.0	25	160.0	240.0
Fences and gates	2.0	15.0	180.0	120.0
Administrative building	5.0	25.0	160.0	240.0
Composting area	-	75.0	200.0	320.0
Maturing area	-	25.0	80.0	120.0
Paving to roads and Receiving area	-	25.0	80.0	120.0
Water supply	4.0	7.0	32.0	48.0
Storage tank (night soil)	1.0	3.0	8.0	12.0
Drainage	-	10.0	40.0	60.0
Electrical installation	-	15.0	160.0	280.0
Miscellaneous buildings	1.0	25.0	1,040.0	40.0
Subtotal	14.0	250.0	1,040.0	1,600.0
Equipment				
Weigh bridge	-	-	25.0	25.0
Conveyors and feeding assembly	10.0	300.0	675.0	1,290.0
Baling equipment	-	20.0	80.0	110.0
Screening assembly	5.0	30.0	120.0	175.0
Electrical equipment	-	50.0	150.0	250.0
Compost-turning machines	-	-	150.0	300.0
Front-end loaders	-	75.0	150.0	300.0
Internal transport[a]	-	30.0	250.0	500.0
Spare parts	2.0	50.0	150.0	230.0
Laboratory	1.0	5.0	10.0	10.0
Workshop/clothing/tools	1.0	5.0	15.0	35.0
Generator	-	50.0	100.0	150.0
Bagging plant[b]	-	50.0	150.0	150.0
Installation & Engineering	1.0	200.0	850.0	1,325.0
Training and Tech. Asst.	10.0	25.0	125.0	150.0
Subtotal	30.0	890.0	3,000.0	5,000.0
Physical Contingency (15%)	6.6	171.0	606.0	990.0
TOTAL	50.6	1311.0	4646.0	7590.0

a. Either tipper trucks or tractors and trailers.

b. Used for fine-grade compost only.

Table 34. Estimated Staffing Requirements (base case)

Description	A	B	C	D
Management staff*	1	4	8	8
Labor	5	10	36	47

* Management staff includes some or all of the duties; supervisor, mechanical engineer, accountant, maintenance engineer, electricians and lab technicians.

Table 35. Miscellaneous Base Case Operating Requirements (units/year)

Description	A	B	C	D
Electricity (thousands of kw-hr)	-	125.0	415.5	780.0
Water (thousands of m^3)	0.5	6.5	18.0	40.5
Fuel (thousands of liters)	-	70.0	232.5	435.0
Lubricant (thousands of liters)	-	.3	.9	1.8

Table 36. Financial Input Prices (base case)

Item	Price
Electricity	1.6 US ¢/kw-hr
Water	2.3 US ¢/m3
Fuel	20 US ¢/liter
Lubricant	1.20US$/liter

Maintenance costs are estimated at 2 percent/year of total equipment costs.

Average financial wage rates used for the base case analysis are $1,620/person/year for management and $1,250/person/year for labor. These rates, as with other input prices, would of course vary from country to country and should be adjusted to the specific location being studied. Other operating cost parameters are listed in table 37.

Table 37. Operating Cost Estimate (base case)
(thousands of US$/year)

Description	A	B	C	D
Labor				
Management	1.6	6.5	13.0	13.0
General	6.3	12.5	45.0	58.8
Fringe benefits @ 25percent	2.0	4.7	14.5	17.9
Overtime 25percent	2.0	4.7	14.5	17.9
Subtotal	11.9	28.5	86.9	107.6
Other				
Electricity	-	2.0	6.6	12.5
Water	0.0	.1	.4	.9
Fuel	-	1.4	4.7	8.7
Lubricant	-	.4	1.1	2.2
Maintenance	0.9	22.8	80.8	132.0
Subtotal	0.9	26.7	93.6	156.3
Total Plant Running Costs	12.8	55.2	180.5	263.9

Management of the co-composting operation should be stressed, particularly since the handling of pathogens is involved. Proper training and record keeping is essential to production of good quality hygienic compost.

LAND VALUE AND LANDFILL REQUIREMENTS COSTS

The plant must also bear the cost of reject material disposal (amounting to at least 119 kilograms/ton domestic solid waste input). These costs will include transport to a sanitary landfill facility, its capital (including land), and operating costs. For base case modeling purposes the land price for both the landfill and the composting facility is assumed at $25,000/hectare (nearby urban areas). Transport cost to the landfill is being assumed at a nominal US$1.0/ton of rejects (i.e., the compost plant is close to the landfill and transport equipment from the plant will be used). Typical densities for rejects, which consist primarily of inorganic waste (stones and building materials such as concrete, brick, etc.), are relatively higher (approximately 30 percent) than generally landfilled wastes. Assuming the sanitary landfill depth is 3 meters (excluding thickness of cover material), and the rejects have a compacted density of 0.67 tons/cubic meter, each ton of rejects therefore requires 1/2 square meters of land area. For without the project case a reasonable density for compacted landfilled waste (without composting/resource recovery, i.e., without project) is 0.5 tons/cubic meter which would require 0.67 square meters of land area per ton. Base case landfill operating costs have been estimated at US$2.43/ton (including costs of equipment, civil works, and operations) excluding land. It is worth noting that the landfilled rejects, because of their low organic content, would create a landfill that did not produce methane gas. This can either be considered a plus or a minus depending on long-term management of the landfill (reduced risk of explosion, or lost income potential from gas recovery). Also, for the same reasons, there should be fewer rodent and odor problems associated with the landfilling of rejects and it should be possible to use them for land reclamation (swamp, coastal) activities, which would result in almost total elimination of landfill requirements. In addition, since the rejects are of very low value, they should not attract scavengers to the landfilling site.

Landfill disposal or a give-away program may also be required for the poorer quality compost if it cannot be marketed. Compost has been successfully used for landfill cover and surface reclamation of sanitary landfills in place of soil. For modeling purposes compacted compost is estimated to require 0.55 square meter of land per ton (depth of 3 meters). Costs for transport and landfill operations would be approximately the same as for rejects.

All of the base case model assumptions (quantities and prices) are subject to a fairly high variation, and should be modified to reflect the circumstances of any specific project environment under review. As part of the analysis, sensitivity tests will be performed to vary assumptions systematically for individual and groups of line items in the models. The intent will be to determine general viability of composting and highlight the key parameters. The base case models have been developed using Lotus 123 (a popular personal computer spreadsheet) which can be modified easily to reflect particular situations.

OTHER FACTORS AFFECTING FINANCIAL COSTS AND REVENUES

In addition to the basic quantitative capital/operating parameters and prices outlined earlier, the planner must consider several other items, a few of which are discussed here.

Transport distances to the compost facility (or landfill) and local systems for domestic solid waste and night soil collection are a major cost of any waste management scheme. These costs are not being addressed here since it is assumed that the collection costs are almost equal regardless of the final disposal method. This is not to say that collection options should not be examined. For example, for domestic solid waste it is generally accepted that it is more economical to separate the recoverable materials at the source, prior to mixing with the general waste stream. Source separation or widespread scavenging would reduce the recycling revenue of the compost plants to almost zero while having only a limited impact on operating costs since sorting of rejects (with no value) must still be carried out. Another factor to consider is the type of domestic solid waste collection vehicle. Compacting trucks are generally inadequate for the developing countries due to maintenance difficulties and the already high density of the waste. Vacuum trucks for pit latrines, septic tanks or cess pools are often very effective since they limit the health risks involved in human handling and can discharge the human wastes to the composting plant directly. Still another consideration is the organization of the collection process (transfer stations, utilization of capital, and labor). All of these will depend a great deal on local conditions and practices. The compost plant has been assumed to be located near the currently used landfill. It is important to analyze the specific situation -- it may be less expensive to locate the compost plant either closer to the waste generation point (lower collection transport costs) or closer to the agricultural areas (lower transport costs for the compost).

The seasonality of the waste stream will also affect the viability of the compost facility. In general, two elements pertain: (1) the volume of domestic solid waste and night soil, and (2) the composition (moisture and ash content in particular). The design capacity of the compost plant must allow for either adequate storage and processing flexibility (multiple shifts) to meet peak loads or alternative disposal systems. The plant capacity utilization will also have a significant impact on operating efficiency. For the purposes of the four models, it is assumed that they average 80 percent of design capacity from the year after investments are completed, and only 50 percent during final year of construction. This figure allows for variations in the waste stream and down-time for equipment and site maintenance. Another seasonal factor would be the efficiency of the composting process during the rainy season when the windrows may require temporary covers or more frequent turning. In areas with heavy rain seasons, a simple roof shelter may be built (adding to the capital cost but maximizing the potential operating throughput).

It is typical of most waste disposal operations that they operate at a loss, which is true for almost all compost operations in both industralized and developing countries (depending of course on operating costs and the value of compost and recovered materials). This net composting operating cost of domestic solid waste disposal is generally covered by charging a "tipping fee" for accepting the waste from the collection system. The tipping fee (if set high enough) would make composting a viable activity for the private sector. A waste management planner would try to set the tipping fee as far as possible below the costs of alternative disposal (dumping, landfill, sanitary landfill, incineration, etc.), yet high enough to make composting financially viable. For the purposes of the four financial models, the initial tipping fee will be set at US$1.0/ton waste input,[1] and sensitivity tests will be carried out to determine the level of tipping fee needed to run a financially viable composting facility. If the municipality runs both the collection and composting operations, the tipping fee becomes a proxy for the estimated savings on landfilling costs and allows the municipality to compare the alternatives. In this case, one could substitute a collection fee that is then allocated to the collection/disposal operations for costs recovery. This fee, of course, must be compared with the waste generator's willingness and ability to pay.

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[1] This tipping fee would be extremely low in comparison with that found in some parts of the United States where landfills are scarce and tipping fees for landfills or incineration facilities can range up to US$30/ton, or even higher for certain wastes such as sewage sludge.

The marketability and price received for compost are probably the most important financial factors. As mentioned earlier, the demand for compost is very crop- and location-specific. In temperate winter or tropical monsoon climates, the land application of compost may be seasonally restricted and require storage capacity either at the application area or composting site. Compost, due to its moisture retention abilities, is often in greater demand for certain higher-valued and higher-risk crops. Moreover, the quality of the compost, that is, nutrients, particle size, and maturity, has a great impact on its price. Throughout the available literature, the need for a well-thought-out and executed compost marketing program is stressed. Failure to market the compost adequately has been cited as the main cause for the failure of composting operations. In many areas, compost users will need to have its use and value demonstrated to them. The demonstration of composts agricultural usefulness may be dramatic in developing countries where farmers often cannot get or do not use fertilizers or manure since the potential for incremental yield increases from using compost would be more than in other regions of the world. For existing compost plants the range of prices is from $0/ton (actually it is given away) up to a reported US$40/ton. This range of prices certainly covers different quality composts being used for different purposes. For base case modeling purposes, it is assumed that there are four compost market outlets (table 38).

Table 38. Compost Markets and Prices (base case)

Markets	% of Production Sold to	Price ($/Ton)
Horticulture	10	14
Land reclamation/Agriculture	50	10
Public works	30	7
Landfill cover	10	0

These prices are assumed ex-plant and would of course depend greatly on local conditions and marketing efforts. These four market outlets would not all get the same quality compost. The last category, landfill cover, would include the poorer quality product and in some cases would not have a value of zero, since alternative landfill cover may have a value, particularly if it must be transported from a significant distance. The horticulture market would only get the highest quality compost. Costs of transport and disposal for the landfill cover compost are included as a cost in the models.

The financial factor most often overlooked by planners is the working capital requirements. Working capital breaks down into: (1) permanent (minimum resource requirements for carrying operations), and (2) variable (seasonal requirements for such things as unsold compost). For modeling purposes net working capital requirements are estimated at one month's gross revenue and costed in the model at a 12 percent annual interest rate (i.e., 1 percent of annual gross revenues).

FROM FINANCIAL COSTS/REVENUES TO ECONOMIC COSTS/BENEFITS

The basic thrust of project economic analysis is to determine if the co-composting process is a beneficial (productive, or lower cost disposal, waste management) use of scarce resources (capital, material, and labor). There are several fundamental differences in this process from the financial accounting system -- the object here is to quantify the impact on the economy and not simply assess the financial operations. Considerations include the "economic" cost of labor, transfer payments, and other external and nonquantifiable effects of the project in terms of the economic costs and benefits.

The most significant adjustment to the financial base case model comes from the use of "shadow prices," or economic conversion factors, which attempt to adjust imperfect financial market prices to their true economic values. These financial prices often include government transfer payments, such as taxes, subsidies, and quotas, and are adjusted through their exclusion and through the use of international (free trade) border prices.

The economic valuation of goods that are not usually traded internationally (e.g., recycled goods -- paper, glass, low-grade metals, textiles; compost; labor) is less refined, and it is often impossible to estimate the correct economic exchange price. Several valuation options exist. The simplest would be to assume that the economic price equals the financial price (economic conversion factor = 1.0), that is, assume a free market does exist. Another option is to value these goods in terms of other traded goods; for example, the recycled materials can be valued based on the energy saved -- the oil equivalent -- through their use in the production process. For the compost, with more research, estimates could be made of its value in terms of reduced agricultural inputs, such as soil conditioners, fertilizer, and water, or increased production of internationally traded agricultural products (wheat, corn, fruits, vegetables, etc.), or both. When using the latter method -- tradable resources saved or incremental tradable goods produced -- the analysis should include the incremental costs of realizing these benefits. Examples of incremental costs include transport of recycled materials to the processing factory or transport and spreading for the compost.

There are several problems with either of these economic valuation methods. For each country/location a different approach might be more realistic. Where there is already an active recycling trade, the use of market prices adjusted for macromarket imperfections makes the most sense. It is also worth noting that many developing countries do not have internal sources for virgin materials and therefore have only two alternatives, importation or recycling. In addition, many of these countries are extremely short of foreign exchange for imports. This would argue for the relative economic advantages of recycling, which should be accounted for by a properly calculated conversion factor. The same is true for compost, but there will rarely be an active, significant volume soil conditioner trade. In addition, it has proved to be very difficult to isolate the agricultural value of compost within the extremely complex agroeconomic system, which includes sun, water, nutrients, soils, plant varieties, and farming methods. However, there have been numerous experiments that have conclusively shown increased yields, over a wide range, attributed to the use of compost. The yield impact of compost depends greatly on the existing conditions, with less impact on high quality soils and often resulting in dramatic yield increases on poor soils. It is also very risky to use market prices if the composting/resource recovery facility is large: an oversupply may be created and cause prices to fall.

It is also worth stressing here that economic benefits should not be counted twice. For example, if the market price (adjusted by a conversion factor) is used to estimate economic value, one cannot also count the energy savings or agricultural impact. This would be double counting since the market price includes the consumers' "economic" benefits of using the material or compost.

Nonquantified impacts include the project's impact on land values and quality of life. The value of land near the compost plant may decline and values near the forgone landfill, which would now be smaller or more sanitary, may increase. Health and sanitation benefits can result from composting, and particularly co-composting, when it is compared with more traditional waste disposal options such as open dumping of solid waste or direct land disposal of night soil, sludge and septage.

External environmental impacts of composting/resource recovery could possibly be of value. There are both positive effects -- reduced health water and soil pollution hazards and raw material needs, as well as improved soil structure resulting in less erosion -- and negative ones -- smell, leachate -- which depend on how well the composting operation is managed. If the composting facility is well designed and managed, it is expected to have little if any negative impact on the environment and numerous benefits. Some of these benefits are captured elsewhere in the analysis in such things as recycled materials, less land for landfill, or the market value of compost. Others are not, such as improved sanitation and health. These nonquantifiable benefits are excluded from the analysis. It should also be noted that most of these nonquantifiable benefits of composting may not accrue to the composting enterprise.

For any particular investment, there is also the consideration of sunk costs, for example, existing landfill operations, including land and equipment. For composting, this is not usually significant since rejects would continue to be landfilled and it is unlikely that composting would handle the entire waste stream, more often being only a component in the overall waste management scheme.

Another significant adjustment to the financial model is needed for labor. The economic price of labor depends on the local market supply-and-demand curves, which in turn depend on the opportunities for alternative work and valuation of leisure. For the purpose of these four models, the assumption is that skilled labor is in relatively short supply, with an economic conversion factor greater than 1.0, for example, 1.5, and that there is a relative surplus of unskilled labor, a factor of, say, 0.5 -- a typical situation in developing countries.

For the illustrative calculations below, capital cost estimates from the financial base case models will remain unchanged in the base case economic models. These costs were originally estimated in US dollars and therefore will serve as economic values for our purposes.

As mentioned earlier, the labor costs for the base case economic models will be adjusted by factors of 1.5 and 0.5 for management and general labor, respectively. Fringe benefits and overtime will remain at 25 percent each, although there may be some small element of a transfer payment in the fringe benefits. Other operating costs will be adjusted to reflect economic prices as discussed previously (table 39).

Table 39. Economic Input Prices (base case)

Item	Value
Skilled labor	2,430 US$/year
Unskilled labor	625 US$/year
Electricity	10 US ¢/year
Water	2.9 US ¢/m^3
Fuel	40 US ¢/liter
Lubricant	1.20 US ¢/liter

The base case financial price for water has been adjusted upward by an arbitrary 25 percent, even though its economic value is very difficult to estimate; in any case, it is a very small input. The price of water would be more significant if it were used to value the compost's agricultural input savings.

The base case economic models will value the recycled materials at the financial prices, which are rather conservative. The alternative valuation, energy saved, has been estimated for the United States (table 40).

If the energy costs of mining the virgin ore are also included, the values of scrap in terms of energy savings increase. In many cases, these figures are misleading; for example, steel energy savings are dependent on the type of furnace, type of scrap, and end product. For glass the energy savings would be much greater if intact containers were recycled. The type and amount of contamination in plastics greatly affect both the recycling options and energy savings. For paper the quality of the fibers decreases during reprocessing, thereby making it less valuable.

Table 40. Energy Used to Process Virgin and Recycled Materials

Material	Virgin ore	Recycled material		Savings	(%)
	(thousands of BTU/kg)				
Steel	18.3	9.7	(100% Scrap)	8.6	(47)
Glass	17.2	15.9		1.3	(8)
Plastics (polyethylene)	109.1	3.0		106.1	(97)
Newsprint	25.1	19.4		5.7	(23)

Source: Adapted from Hayes (1978).

Assuming that the above figures are reasonable and that the marginal source of energy is imported oil, the approximate energy-based economic value of the recovered materials is shown in table 41.

Table 41. Recycled Material Valuation - Energy Based

Material	$/ton/1	Value $/ton/2 Domestic solid waste
Paper	30.0	3.60
Textiles[a]	30.0	.63
Metals	45.4	1.54
Glass	6.9	.10
Plastics & rubber[b]	280.0	6.72
Total		12.59

/1 Based on table 43 and World Bank Commodity Price Data.

/2 Calculations done as in table 32.

a. No data available for rag recycling, value based on newsprint.

b. One half polyethelene.

Except for glass, these energy-based valuations are higher than the financial prices and will only be used for a sensitivity test. This valuation would need adjustment for transport to the recycling plant and any processing overheads beyond the use of virgin materials.

For the economic value of compost in the models, three alternative valuations will be tested. The compost's economic value for a specific project area depends on its quality and ultimate use. As an upper value it is assumed that compost has value equivalent to peat, which is a traded good. Recent peat export prices for Ireland have been about US$70/ton,[1] excluding transport which can be costly. The world trade in peat moss is relatively small and is primarily sold to the home garden or commercial nursery markets. Compost should not be considered the full equivalent of peat moss. Therefore, as an upper value of compost we will use the value of peat without any adjustment for transport, that is, US$70/ton.

Compost is at its lowest value as a low-grade fertilizer; the soil structure value is not included. This would represent a floor on its value if the necessary transport and application costs were ignored.

Approximate 1984 fertilizer prices are listed in table 42.

Table 42. 1984 Fertilizer Prices (approx.)

Fertilizer	$/Ton
Urea (46 percent N)	170
TSP (46 percent P_2O_5)	130
Muriate of potash (60% K_2O_5)	85

Based on a co-compost nutrient mix of 1.3, 0.9, 1.0 (N, P, K),[2] the approximate value would be US$8.75/ton (ignoring some obvious benefits including the slow-release nature of the nitrogen and the value of the micronutrients). The World Bank projections for fertilizers in constant terms show that prices should rise by 37 percent for N, 12 percent for P, and 15 percent for K through 1995. To keep the economic analysis simple, these as well as any other (energy, land) relative increases in economic prices will not be included in this analysis. The fertilizer value needs to be reduced by the

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[1] 50% moisture content fob costs 5 Irish pounds/300 liter bale.

[2] If greater amounts of dried sewage sludge were used, these nutrient values would be higher, but in any case they will vary depending on local waste composition.

increased handling, transport, and application costs compared with the equivalent amount of inorganic fertilizer. This cost is estimated at US$2.75/ton which, when deducted, gives a low-end economic value for compost of US$6.0/ton ex-factory.

As a realistic base case value for the compost, a conservative estimate was to be used of yield increases and inputs saved that were attributable to compost. Because of the many factors affecting crop yield, this valuation method is probably the least certain but would be the most realistic economic value. For example, typical net incomes for field crops in the developing countries range between US$200-500/ha, and up to US$1,200/ha for fruits and vegetables. The reasonable application rate of compost for vegetable crops can be estimated from the figures presented in chapter 5, table 24 and amounts to 50-100 tons every 2 to 4 years. If we assume that 25 tons/ha of compost per year allows net income to increase approximately US$500-600/ha (switching from field crops to vegetables), the upper agriculture value would be US$20-24/ton. From this figure we must deduct transport from the plant and application costs. A compost value of US$20/ton will be used as a proxy in the base case economic models.

This value is very subjective in that it is a substitute for input savings on fertilizer, soil conditioners, and water, which accrue over a period of years; the value of increased crop yields, which depend on the local cropping patterns, soil conditions, etc; and the transport/application costs to achieve these benefits. For areas with badly overexploited soils and/or shortages or lack of fertilizer inputs, the yield response from using compost could be dramatic and therefore its economic value may be much higher in specific locations. There is a lack of data on the benefit of compost resulting from the improvement of the physical structure of soil, and this may be a constraint on the increased demand for, and value of, compost. The market outlets for compost will remain the same for the economic analysis but prices will be equal for all but landfill cover (lowest quality), which will remain at zero.

The base case economic values for other cost factors such as landfill, miscellaneous operating expenses, and working capital, will remain unchanged from the financial models.

RESULTS FROM HYPOTHETICAL MODEL CALCULATIONS

The computer model developed (using Lotus 1-2-3) takes the form of a simple line-item budget covering a 20-year period. All of the parameters discussed in this chapter are included. The models assume replacement of equipment in year 10, with no salvage value. There is no provision for resale of the land, or re-use of the landfill. The base case models are built up from the financial price assumptions adjusted by a factor that is set to 1, for the financial analysis, and set to the shadow economic conversion factor for the economic analysis. These factors can readily be substituted to adapt any "base case" situation to a particular investment situation. There are also some standard input/output operating coefficients -- waste composition and density -- and four sets (one for each base case model) of physical parameters as described in this chapter.

Capital investments are assumed to take one year for models A (3 tons per day) and B (50 tons per day) with a 50 percent capacity utilization reached in that year. For the larger models C (150 tons per day) and D (300 tons per day) investments occur over a two-year period (50 percent each year) with a 50 percent capacity utilization in year 2. For the remainder of the 20 years, capacity utilization is 80 percent.

Since this chapter is not intended to evaluate the financing of investments, no calculation has been included for funding the initial capital investments.

Analysis indicators are calculated at two stages or bottom lines in the hypothetical models. The first is based on the "net with project" (with), which represents the compost facility operations including tipping fee and would be a good indicator if the private sector were running the composting plant but had no responsibility for the landfill. The second indicator is the "net incremental" (incr), which takes into account the benefits of reduced landfill (without project) and excludes the tipping fee (transfer payment). The latter situation would be typical of a situation where the operations -- composting and landfill -- are run by the same entity, that is, municipality. Both bottom lines are calculated for the financial and economic factors, although the "net with" is not really meaningful for the economic analysis. The incremental bottom line is more relevant, even in the financial model, if the compost plant is to be run by the municipal government.

The indicators calculated for each hypothetical model include internal rate of return (IRR), net present value (NPV) per ton of domestic solid waste, which is the cashflow NPV at 12 percent divided by the discounted (at 12 percent) amount of waste processed (NPV/ton). This last indicator adjusts the models to a consistent unit for comparison and is traditionally used in calculating average incremental costs for utility rate setting. In the context of this analysis it gives an indication of the average cost incurred for each ton of waste processed by the co-composting operation.

The results for the hypothetical base case financial models indicate that co-composting is not a financially worthwhile operation even if the forgone landfill benefits are counted. It seems clear that co-composting (including recovery of recyclable materials) will not reduce the cost of waste management and more likely would only increase the financial burden of waste management on municipalities. The base case economic analysis has similar implications and shows that co-composting is likely to be a higher cost waste management alternative than sanitary landfill. See table 43 for the base case financial results and table 44 for the base case economic results.

Sensitivity analysis on the hypothetical financial base case indicates that either the compost or the recycling revenues would need to increase by a factor of 4-5 times for the composting plant (with) to break

Table 43. Base Case Results -- Financial
NPV(12%)$/Ton Domestic Solid Waste Processed

Category	Model A	Model B	Model C	Model D
COSTS				
Capital	-10.9	-17.5	-23.1	-18.7
Operating	-15.6	- 5.2	- 5.5	- 4.4
REVENUES				
Recycled materials	4.8	4.8	4.8	4.8
Compost	2.9	2.9	2.9	2.9
Tipping fee	1.0	1.0	1.0	1.0
Net With Project	-17.8	-14.0	-19.9	-14.4
WITHOUT PROJECT				
Reduced landfill	4.1	4.1	4.1	4.1
Tipping fee	- 1.0	- 1.0	- 1.0	- 1.0
Net Incremental	-14.7	-10.9	-16.8	-11.3

Table 44. Base Case Results -- Economic
NPV(12%)$/Ton Domestic Solid Waste Processed

Category	Model A	Model B	Model C	Model D
COSTS				
Capital	-10.9	-17.5	-23.1	-18.7
Operating	-11.9	- 5.9	- 6.0	- 5.1
REVENUES				
Recycled materials	4.8	4.8	4.8	4.8
Compost	6.0	6.0	6.0	6.0
NET WITH	-12.0	-12.5	-18.3	-12.9
Reduced landfill	4.1	4.1	4.1	4.1
NET INCREMENTAL	- 7.9	- 8.5	-14.3	- 8.9
Internal Rate of Return% - Incremental	- 9.0	- 0.8	- 4.6	0.0

even (IRR = 12% or NPV/ton [12%] = 0) at a 12 percent discount rate. The increase in either compost or recycled revenues required would be somewhat less -- approximately three to four times as high -- if the compost plant received a tipping fee equal to the forgone landfill costs of about US$4/ton (i.e., net incremental). A tipping fee of 14-20 US$/ton (equivalent to the net with project loss) would be required for the plant to break even financially at a 12 percent discount rate. The required increase in total revenues -- compost plus recycled materials -- would need to more than double from the base case for the "with project" to have a 12 percent rate of return.

Sensitivity on compost revenues in the hypothetical economic base case indicates that the use of a peat-based valuation (US$70/ton) would make co-composting viable. The use of the N-P-K valuation for compost results in about a US$4/ton decrease in NPV from the economic base case. Energy valuation for recycled materials makes significant impact on the economic base case, decreasing waste processing costs about US$7/ton in PV from the base case. The substitution of sewage sludge for night soil would raise compost production and revenues about 7 percent.

Table 45 outlines the results of adjusting the base economic models to approximate the aerated pile and an enclosed reactor system (Model A is excluded since it is using manual processing).

Table 45. Alternative Technologies -- Results (Economic Values)
NPV (12%) $/ton Domestic Solid Waste Processed

	Model		
Composting technology	B	C	D
Reactor[a]			
NPV/ton (with)	-25	-33	-25
NPV/ton (incr)	-21	-29	-21
Aerated pile[b]			
NPV/ton (with)	-15	-13	- 8
NPV/ton (incr)	-11	- 9	- 4

a. Investment costs (excluding land) up 60%, operating costs up 20%, land for plant down 20%.

b. Investment costs up 20% for model B and down 20% for models C & D (to reflect the addition of fans to all models and deletion of windrow-turning machines in models C & D), operating costs down 20%.

The reactor option is much more costly; the aerated pile costs, however, are slightly worse for labor-intensive model B and slightly better for models C & D by about US$4/ton in NPV terms than the base case economic models. The potential advantage of the aerated pile system is that the process is somewhat more controlled in terms of uniform temperature achieved, which is critical in destroying the pathogens in the night soil sludge and septage and thus removing them from the environment. The aerated pile system should be investigated as the system of lowest cost when considering co-composting.

Sensitivity of the economic models to land pricing was also tested. There was a marginal impact of higher land prices on the models' indicators for the with or incremental bottom lines since land is a relatively minor component of the compost plant net with project, and increased costs there are offset by increased benefits (landfill forgone) in the without. The real impact of land prices was seen in the widening of the difference between the net with and net incremental indicators. The relative land valuation might become critical in the situation where sanitary landfill options are no longer available within a reasonable distance to the waste source.

Sensitivity tests on a combination of factors were also carried out. These are intended to demonstrate the potential cost effectiveness of co-composting in specific local situations that might be more favorable than assumed for the base case analysis. These sensitivity results are presented for Model A - 3tpd economic base case in table 46 below.

Table 46. Sensitivity Tests - Multiple Change

Category	Model A - 3tpd - Economic % Change from Base Case				
Line Item Changes					
Compost revenues	+100	+50	+ 25	+100	0
Recycled revenues	+100	+50	+ 25	+50	0
Reduced Landfill costs (without project)	0	+100	+100	+50	+200
Results					
IRR - incremental	+18.3	+15.5	+9.6	+17.5	+3.3
NPV/Ton - incremental (12%)	+ 3.0	+1.6	-1.1	+2.6	-3.8

From the illustrative calculations done here one may conclude that, if local conditions correspond to any of these sensitivity scenarios, further detailed investigation is warranted. However, any significant investment in composting should be done only after detailed analysis of potential markets and a commitment has been made to actively market the compost and recovered recyclables.

Many other sensitivity tests have been carried out and a copy of the Lotus 1-2-3 template can be made on diskettes (one 5-1/4" IBM format required) sent in by interested persons. A short user's manual will also be provided on the diskette explaining the structure of the template. There are customized menus that allow the selection of model size, economic or financial prices (factors), as well as various sensitivity tests for IRR and NPV/PV on investments, operating and maintenance, recycled materials, sales, compost sales, tipping fee and without project (-100 percent, -50 percent, +100 percent, +200 percent, +300 percent, +400 percent, +500 percent). A custom menu for printing the assumptions, or results, is also included. For those readers familiar with the Lotus 123, any of the assumptions outlined in this chapter can, of course, be changed to allow for analyses of specific situations: (1) where compost values (prices) may be higher than the base case assumptions because of, for example, scarce or poor quality land, large horticulture industry, or shortages of inputs; (2) where a subset of the domestic solid waste collected may not require sorting prior to co-composting, as in produce markets; or (3) where sanitary landfill of domestic solid waste is not an option such as when there exists a high water table or scarcity of land and co-composting is thought to be a cost-effective component of the waste management.

CHAPTER 7

SUMMARY

Refuse collection, treatment, and disposal is one of the major problems facing urban planners and operators in many developing countries today, in addition to the problems associated with inadequate treatment and disposal of human wastes.

Unsightly piles of waste, drains clogged with refuse and night soil, open sewers filled with human and domestic wastes, and septic tank sludge dumped in the open are all examples of ways in which the urban environment is being polluted today in many cities and towns of the developing world. City dwellers are being exposed to diseases transmitted by pathogens present in these wastes as well as to the nuisances produced by the situation. Furthermore, the volume of waste being produced is rapidly increasing with the influx of rural dwellers into the urban environment. Indeed, proper refuse and human waste management is fast becoming a priority in many cities in developing countries that are rapidly growing in size.

In the preceding chapters, co-composting of garbage with human wastes has been described in detail through both a review of the literature and economic and financial models, with discussion centering on the following issues:

- the robustness of the aerobic composting process
- the variety of available composting systems
- the possibilities of co-composting different wastes
- the effectiveness of efficient composting systems in destroying disease-causing organisms
- the many uses of compost
- the economics of different-sized composting systems.

The choice of co-composting as a waste treatment alternative for garbage and human waste must be considered in the light of other existing treatment alternatives such as landfilling, incineration, and the ocean dumping of sludge.

Before deciding to compost, the planner must consider and review several basic factors already described in previous chapters. This includes information on the waste material; transport of the wastes and the compost that is produced; marketing of the product; the construction, operation, and maintenance costs; the location and land requirements of the plant; and the type of plant that would be most suitable for producing compost under local conditions. If the decision is taken to consider composting as an option for waste treatment and management, the role these factors will play in ensuring the success of a composting operation must be stressed. Some of the more significant elements are reiterated below.

WASTE MATERIAL

It is important to determine the nature and composition of the wastes to be composted. Such basic information will be of use later when the time comes to choose an appropriate composting system. Furthermore, it is useful to know how the collection of these wastes would fit into the overall waste management system (e.g., landfilling and incineration) and if there are already waste-recycling activities to which this could be added, such as organized sorting of garbage for recyclables or scavenging and biogas operations.

MARKET

Is there a market for any compost that might be produced? Perhaps there are crop farmers or horticulturists in the city outskirts who would use it to improve the quality and productivity of their crops. Maybe the public or private sector is involved in a landscaping program, or perhaps there is badly eroded topsoil or sandy and/or clay soils that could be reclaimed for productive use. The financial viability of co-composting garbage and human waste is dependent on a well-developed market that is willing to pay at least for the costs of production.

COMPOST PLANT

Next, we ask about the type of plant, taking into consideration possible location, availability of trained technical staff and manual labor, and financial resources to cover capital and operating costs, in order to determine which system would be most appropriate for the city. Economic and financial feasibilities will be of importance in considering the costs involved for a specific system. The planner may often find that a simple windrow or forced aeration system will best suit the capabilities of the establishment and will be therefore most effectively run. There is also the consideration of the potential for manufacture nationally, thus reducing the requirement for foreign exchange components.

PILOT SCALE COMPOSTING

Once the waste materials and composting system have been identified, it is useful, if a large-scale operation is being planned, to start with a pilot plant. This will serve two purposes: first, the prospective operators will become familiar with the process; second, it will serve as a good public relations exercise to produce small amounts of compost for sale or as samples for the potential market.

BENEFITS AND JUSTIFICATION

Finally, what benefits accrue from the separation/compost operation? There are those that can be readily quantified, such as reducing the need for sanitary landfill of garbage and recovering materials for industry, which often obviate importation or mining of similar industrial materials. For specific waste management activities, the careful integration of composting operations should allow for more efficient collection networks, the savings of which can easily be quantified and used to offset the cost of composting. In addition, it should be relatively simple to demonstrate the benefits of compost in terms of improved soil productivity, measured as increased yields and/or reduction of other inputs (fertilizers and water), and easier tillage. This can easily be carried out in a controlled trial using compost produced locally on a trial basis for two or three cropping seasons perhaps at the pilot compost plant.

Other benefits, such as the effect of compost on the quality and longevity of the soil, the reduced health risk of having pathogenic material in the environment, and the improved aesthetic quality of the surroundings, are difficult to quantify but are of importance in ensuring adequate maintenance of the environment.

There are many examples in the world where the high costs of environmental degradation are plainly seen with hindsight but were not quantified at a time when something could have been done to prevent them. The valuation of productive soils in the future may be much greater than we now can quantify and, with hindsight, composting may eventually look more attractive.

Situations in which the economic models will show that composting is economically viable or the least-cost waste management alternative are quite site-specific. Where landfilling of waste is very costly due to high land values or high transport costs, composting may become the least-cost alternative for waste management. Often the composting plant can be located in such a way as to reduce collection and landfill costs, both of which should be included as benefits when evaluating least-cost waste management alternatives. The marketability for the compost is the other critical benefit. At the present time horticultural nurseries in peri-urban areas and desert land reclamation areas offer the best economic returns. It is possible, however, that the economic benefits from improved soil structure are considerably greater than has been generally appreciated, although the analysis in this report does not attribute any specific economic value to such improvement, simply because there is a lack of empirical field data from which to quantify economic returns. Were such quantification to be available, it is likely that the models prepared for this report would show that composting is also economically attractive under other conditions.

To embark on a large composting operation is to embark on a long-term activity which ensures both the improvement of soil for agricultural purposes, at a time when increased food production is so important, and the conversion of waste materials into resources.

ANNEX A

OTHER METHODS OF CO-COMPOSTING WITH SEWAGE SLUDGE AND NIGHT SOIL

SEWAGE SLUDGE AND NIGHT SOIL COMPOSTED WITH BARK

The composting of sludge and night soil together with bark is carried out in both reactor and nonreactor systems. The use of bark depends, of course, on the availability of the material (for example, on the location of a wood-processing plant in the vicinity or within easy transport distance). Table A-1 describes some of these systems. In all cases, the temperatures achieved during the composting period would indicate adequate pathogen removal. In compost plants where bark is used as a bulking agent, odor control does not appear to be a problem, possibly because of the odor-absorbing properties of the bark. Problems can occur if the wood has been treated with pesticides, since they may persist in the compost.

SEWAGE SLUDGE AND NIGHT SOIL COMPOSTED WITH STRAW

Straw is a waste material that is readily composted with sewage sludge in reactor as well as nonreactor systems. The examples described in table A-2 are of both types (though mainly the latter). The use of straw in composting is common in farming communities but is not limited to them. As table A-2 indicates, a windrow compost product can be ready within 4 months of starting the process. Forced aeration would speed up the composting process.

SEWAGE SLUDGE AND NIGHT SOIL COMPOSTED WITH WOOD CHIPS

The Beltsville aerated static pile composting process is well documented and reviewed in the literature (see, for example, Nurizzo 1981). The windrow method of composting sludge with wood chips is also well documented. The two processes are similar in terms of product quality but the windrow method appears to be more suitable for digested than for raw sewage sludge. The forced aeration process is also used for composting night soil (Patterson and Rogers 1979; Shuval, Gunnerson, and Julius 1981).

Table A-1. Composting of Sludge and Night Soil with Bark

Raw material	Process	Description	Reference
Night soil and bark	Dry (summer) toilet	Bark was added to night soil in dry toilets at the rate of 4 parts bark to 1 part night soil. Temperatures of over 60° C were achieved.	Alestalo and Koistinen (1975)
Sludge and bark	Windrows	Bark and sludge (and other wastes) were mixed together and composted to produce "Bambe," a marketable product.	Adams (1971)
Digested sewage, sludge, and bark	Open baskets	Dewatered digested sewage sludge was mixed with bark (1:3) and composted in large baskets that could be easily stacked. Temperatures of up to 75° C were attained. The retention time in the baskets was 9-12 weeks followed by 3-4 weeks maturation in piles to produce "Rindekompost."	
Raw dewatered sewage sludge and bark	Windrows	Dewatered sewage sludge (25 percent solids) mixed with bark (1:3) and composted in windrows for at least 21 days. In general, temperatures of 50-75° C are maintained for at least half of this time, although it is less in the winter.	Wesner (1978), Olver (1980)
Dewatered sewage sludge and bark (and recycled compost)	Vertical reactor with 10 levels Dambach Schnoor	Dewatered sludge (22-25 percent solids) is mixed with bark (2:1) and fed into a 10-level reactor. Retention time is 30 days and movement from level to level through traps in floor occurs every 3 days. Temperatures are usually maintained at 70° C or higher for about 10 days and over 50 ° C more than 15 days.	Schwänhauser (1978), Bidlingmaier (1979), Tabasaran (1980), Tabasaran et al. (1981)

Table A-2. Composting of Sludge and Night Soil with Straw

Raw material	Process	Description	Reference
Raw dewatered sewage sludge and straw	Windrows	(Full-scale experimental plant.) The sewage sludge (25-30 percent solids) was mixed with straw (1:1 volume) and composted in windrows, which were turned regularly (8 times) for 3 months. At the end of this time the compost was ready for use. Temperatures of 55-60° C were regularly achieved even in some of the colder months.	Mühlacker (1980)
Raw dewatered sewage sludge and straw	Windrows	Experiments. The sludge (21.8 percent solids) was mixed with straw at a ratio of (28:1). Temperatures of 55-62° C were maintained in windrows, which were turned once weekly for 3 months (in earlier stages there were problems with fly control).	Tabasaran and Lausterer (1979)
Digested sludge and straw	Windrows	Experiment. Digested sludge was mixed with straw at a ratio of 1:1.25 in windrows for 6 weeks during which temperatures of 65-70° C were achieved as above, except the ratio of mixture was 1:5 of sludge to straw.	Klausing (1975), Bidlingmaier and Tabasaran (1980), Bidlingmaier (1979), Bidlingmaier and Bickel (1980), Strauch, Berg, and Fleischle (1980)
Sewage sludge and straw	Biomist windrow	The straw is chopped and mixed with the sewage sludge and then sprayed out into a windrow.	Bidlingmaier (1979), Bidlingmaier and Bickel (1980), Bidlingmaier and Tabasaran (1980)

(*cont.*)

Table A-2 (cont.)

Raw material	Process	Description	Reference
Sewage sludge and straw	Dambach Schnorr reactor	Dewatered sewage sludge is mixed with chopped straw (and/or other bulking agents) and fed into the reactor, which has a retention time of 30 days.	Bidlingmaier and Bickel (1980)

Table A-3. Description of the Beltsville Aerated Static Pile and Windrow Composting

Raw material	Process description	Reference
Sewage sludge and wood chips (windrow)	Digested sewage sludge is mixed with wood chips (1:3 volume ratio) in windrows 1.8 meters high and 2.1 meters wide. The windrows are turned daily for at least 2 weeks, then they are spread out, dried, and cured for 30 days. The wood chips are screened out for reuse.	Dallaire (1978)
Sewage sludge and wood chips (aerated pile)	Raw sewage sludge (22 percent solids) is mixed with wood chips, and then transferred to a composting pad consisting of wood chips spread over perforated piping. Air is drawn through the pipe into a compost filter. The pile is maintained for 21 days followed by screening and drying. Temperatures of 55° C are achieved throughout the pile.	
Night soil (toilet wastes), paper, wood chips (aerated pile)	The night soil is mixed with paper and wood chips on a concrete pad and then transferred to the composting pad, which is a bed of wood chips covering a perforated pipe. Air is drawn through the pipe into a compost filter. The pile is maintained for 21 days at temperatures of 60° C for most of this time. The compost is then cured for 30 days.	

The two processes using sewage sludge are described briefly in table A-3 together with a process using night soil (from chemical toilets). It should be noted that it is not essential to use only wood chips in the Beltsville process; other organic bulking agents (for example straw, woodbark) may also be used. Detailed experiments carried out on pathogen removal using the Beltsville aerated pile process have shown it to be efficient at reducing the pathogen content of the product (Burge, Cramer, and Epstein 1976; Burge, Marsh, and Millner 1977; Burge and Millner 1980).

SEWAGE SLUDGE AND NIGHT SOIL COMPOSTED WITH OTHER MATERIALS

Many other raw materials have been composted together with sewage sludge and night soil. Some of these are described in table A-4 to show the versatility of the process.

In many areas, animal wastes are composted together with sewage sludge and/or night soil. As noted in chapter 3, this should have no adverse effects on pathogen control.

Table A-4. Methods of Composting Sewage Sludge with Other Bulking Agents

Raw material	Process	Description	Reference
Sludge, mushroom wastes, poultry wastes, organic bulking agent	Biomist windrow	The mixture is sprayed out onto a windrow.	Mach (1978)
"	Kneer bioreactor (BAV system)	The mixture is retained in the reactor for 14 days. Temperatures of 60-85° C are maintained for most of this time. Then the raw compost is matured for 6-8 weeks in a windrow.	Mach (1978)
Raw sewage sludge and sawdust and recycled compost	BAV bioreactor (open)	Dewatered raw sewage (25 percent solids) is mixed with sawdust and return compost (50, 10, and 40 percent, respectively) and fed into a cylindrical reactor, which is open at the top. Retention time is 3 days. This is followed by 6-8 weeks of maturation in windrows. Temperatures of 75-80° C are reached.	Oger (1981), Bidlingmaier (1979), Bidlingmaier and Tabasaran (1980), Tabasaran et al. (1981)

(cont.)

Table A-4 (cont.)

Raw material	Process	Description	Reference
Raw sewage sludge and peat, straw lignite.	BAV bioreactor (open)	As above, except mixture is 1:1.	Wolf (1974)
Raw sewage sludge and sawdust and recycled compost.	Weis bioreactor (closed)	The dewatered sewage sludge (25 percent solids) is mixed with sawdust and recycled compost and fed into a closed cylindrical reactor, where it is retained for 10-14 days.	Bidlingmaier (1979), Bidlingmaier and Bickel (1980), Bidlingmaier and Tabasaran (1980), Tabasaran et al. (1981)
Sewago sludge and peat	Biohum process windrow	The raw materials are mixed together and composted in a windrow.	Mach (1978)
Sewage sludge and rice hulls and recycled compost	Trough fermenter	The digested sewage sludge is mixed with rice hulls and finished compost (1:1:1 volume) and fed into a trough where it is composted for 2 weeks by forced aeration and turning. This is followed by 1-2 months of maturation. Temperatures reach up to 70° C.	
Sewage sludge and shredded paper	Fairfield digester reactor	Dewatered sewage sludge is mixed with shredded paper and fed into a reactor. The retention time is 7 days and temperatures reach 70° C during this time.	Wesner (1978)
Sewage sludge and sawdust (also recycled compost)	Triga process cell reactor	The sewage sludge (15-20 percent solids) is mixed with sawdust at a ratio of 1:5 wt and fed into a vertical reactor consisting of four cells. The retention time is 12-15 days and temperatures of 70-80° C are achieved. Maturation occurs in piles (in a shed) in which temperatures often reach 50° C.	Schneider (1981)

(cont.)

Table A-4 (cont.)

Raw material	Process	Description	Reference
Sewage sludge and sawdust (and other bulking material)	Windrows	The windrows are turned for 3 months and then sold as a product "Grow Rich." The contents of the windrows are dewatered sewage sludge (30 percent solids) and sawdust at weight ratios 80:20. The maximum temperature achieved is 74° C.	Heaman (1977), Breer (1980)
Water hyacinth, night soil, rice straw	Windrow/ piles	Experiment. Night soil, water hyacinth, and (in some cases) rice straw were mixed and composted in piles for 2-3 months. Temperatures of 43-64° C were maintained for at least 8 days in the coolest parts of the piles.	Polprasert and Muttamara (1980), Polprasert et al. (1982)
Night soil rice husks, grass cuttings, briquette cinder	Windrows aeration by various methods	Night soil is mixed with different amounts of rice husks, grass cuttings, or briquettes of cinder into windrows. These are aerated by various methods. Temperatures of up to 70° C are achieved and >50° C maintained for at least 8 days.	Kim and and Bae (1981)

SEWAGE SLUDGE AND NIGHT SOIL COMPOSTED WITHOUT THE ADDITION OF BULKING AGENTS

The processes described in table A-5 indicate some of the ways in which sewage sludge or night soil can be composted without the addition of any bulking agents. In all the examples given, the sludge has to be dewatered before being mixed with the recycled compost. (If night soil is used instead, some dewatering may also be required.) The temperatures achieved during composting in the examples given here should be sufficient to ensure a relatively pathogen-free product if they are maintained for almost all the retention time and are kept uniform throughout the reactor.

Table A-5. Methods of Composting Sewage Sludge and Night Soil Alone

Raw material	Process	Description	Reference
Sewage sludge and recycled compost	Laboratory reactor	Dewatered sludge cake was successfully composted in a laboratory scale reactor in which temperatures of 60-70° C were maintained.	Schuchardt and Baader (1979)
Digested sewage sludge and recycled compost (also some sawdust)	Bioreactor	Dewatered digested sewage sludge (20-25 percent solids) is mixed with recycled compost in a vertical reactor for 14 days. Temperatures of 60-70° C are reached. The air drawn out of the reactor is passed into an activated sludge tank. Maturaration of compost takes place for 6 weeks in windrows.	Mollliet (1981)
Sewage sludge and recycled compost	HKS process	The sludge and recycled compost are added to a slowly rotating drum (which is stopped at night). The retention time is 24 hours followed by a 2-week maturation period in a windrow. Temperatures of 60-75° C are attained.	Bidlingmaier (1979), Tabasaran (1980), Bidlingmaier and Bickel (1979), Spennes and Britsch (1977)

(*cont*.)

Table A-5 (cont.)

Raw material	Process	Description	Reference
Dewatered sewage sludge and recycled compost	Windrow	The sewage sludge is mixed with recycled compost at a ratio of 3:2 and deposited as a windrow, which is turned by a composter for 4 weeks. This is followed by 30 days of maturation.	Gunn (1980)
Sewage sludge (dewatered) and recycled compost	Roediger Ferment-technik	The sewage sludge is mixed with recycled compost and put in a vertical reactor. The retention time is 4-6 days, after which the compost is put in a dryer for a further 4-6 days; it is then pelleted and stored for sale. Temperatures of over 65° C are attained in the reactor.	Widmer and Konstandt (1978), Bidlingmaier (1979), Bidlingmaier and Bickel (1978), Tabasaran et al. (1981), Bidlingmaier and and Tabasaran (1980)
Dewatered sewage sludge and recycled compost	Forced aeration through fermenter	The sewage sludge and recycled compost are mixed and ground and fed into the fermenters, where the mixture is aerated and turned. The retention time is 10 days and temperatures of up to 75° C are attained. The compost is then graded and bagged.	
Raw or digested sewage sludge and recycled compost	Vertical reactor (pilot plant)	The dewatered sludge is mixed with recycled compost and fed into a vertical reactor consisting of two levels. Retention time is 7-9 days, during which temperatures of 65-70° C are reached and maintained.	Maebashi (1980)

(cont.)

Table A-5 (cont.)

Raw material	Process	Description	Reference
Raw sludge and recycled compost		The dewatered sludge (60 percent moisture) is mixed with finished compost three parts to two and the mixture is laid as a windrow over a bed of straw on a concrete floor having an aeration-and-drainage system. A Cobey composter is used to mix the materials. The retention time is 4 weeks, followed by 30 days of curing. Temperatures reach 76° C during this time.	
Digested or conditioned sludge and recycled compost	Pellets in piles	The sludge is dewatered and passed through a mincer to make pellets. These are piled for up to 8 weeks after mixing with recycled compost.	Spohn (1978)

ANNEX B

PATHOGEN SURVIVAL

Table B-1. Survival of Bacterial Pathogens during Composting

Pathogen	Raw Material Type	Temperature (°C)	Time	Survival %	Source
Bacillus anthracis	Refuse/sludge in reactor	40-43	3 days 7 days 15 days	0 0	Miersch and Strauch (1978)
B. anthracis	Refuse/sludge in windrow	65	2 weeks	0	Miersch and Strauch (1978)
B. anthracis	Refuse/sludge in reactor	58 74	12 days 12 days	0 0	Miersch and Strauch (1978)
Escherichia coli		55	-	0.01	Wiley (1962)
E. coli	Dewatered raw sludge and wood chips in windrow	50-70	14 days	1	Burge and Cramer (1974)
E. coli	Refuse and sludge in drum	55 55	2 days 7 days	0 0	Krogstad and Gudding (1975)
E. coli	Night soil and rubbish in pile, aerobic and anaerobic	29 40	- -	0.01 0	McGarry and Stainforth (1978)
E. coli	Raw sludge, digested sludge	50-70 40-60	3 days 14 days	(low) 0	Burge et al. (1978)
Mycobacterium tuberculosis	Refuse	65	14 days	0	Morgan and MacDonald (1969)

(cont.)

Table B-1 (cont.)

Pathogen	Raw Material Type	Temperature (°C)	Time	Survival %	Source
Salmonellae	Sludge windrow	60	8 days	0	Faust and Romano (1978)
Salmonellae	Activated and primary sludge windrow		1-5 weeks	high	Wesner (1978)
Salmonella	Refuse compost (DANO)	55	3 days 17 hours	0	Golueke and Gotaas (1954)
Salmonella spp.	Refuse and sludge in windrows	55-70	50 days	0	Knoll (1959), quoted Wiley (1962)
Salmonella spp.	Sewage sludge and wood chips	50-70	14 days	0	Burge and Cramer (1974)
Salmonella spp.	Refuse and sludge windrow		7-21 days	0	Gaby (1975)
Salmonella spp.	Sludge windrow		10 days	0	Epstein et al. (1976)
Salmonella dublin	Refuse and sludge in windrow	65	2 weeks	0	Miersch and Strauch (1978)
S. dublin	Refuse and sludge in reactor, 48 percent H_2O, 15 square centimeters	40-43	3 days 7 days 15 days	0 0 0	Miersch and Strauch (1978)
S. newport	Sewage sludge	60-70	15 hours	0	Wiley and Westerberg (1969)
S. paratyphi	Refuse and sludge in windrows	50	2 days	0	Knoll (1958)

(cont.)

Table B-1 (cont.)

Pathogen	Raw Material Type	Temperature (°C)	Time	Survival %	Source
S. paratyphi	Garbage	30-65	68 hours	0	Barth and Brauss (1967)
S. paratyphi	Feces and garbage windrow	68	14 days	0	Savage, Chase, and MacMillan (1973)
S. seftenburg	Refuse and sludge in reactor, 48° C to H_2O, 15 centimeters	40-43	3 days 7 days 15 days	0 0 0	Miersch and Strauch (1978)
S. seftenburg	Refuse and sludge in windrow	65	2 weeks	0	Miersch and Strauch (1978)
S. typhi	Garbage	30-65	68 hours	0	Barth and Brauss (1967)
S. typhi	Feces and garbage windrow	55	40 days	0	Savage et al. (1972)
S. typhi	Night soil and garbage	50 55	1 month 5 days	0 0	Chinese Academy of Sciences (1975)
S. typhimurium	Refuse and sludge	65 55	2 days 4 days	0 0	Krogstad and Gudding (1975)
Shigellae	Refuse compost DANO	55	3 days 17 hours	0	Golueke et al. (1954)
Sh. sonnei	Garbage	60 55	1-3 days 3-7 days	0 0	Baetgen (1962)
Sh. dysenteriae	Night soil		5 days	0	Feachem et al. (1980)

- not stated.

Table B-2. Survival of Viral Pathogens during Composting

Pathogen	Raw Material Type	Temperature (°C)	Time	Survival %	Source
Bacteriophage	Sewage sludge and grass,	40	6 days	0	Krige (1964)
			14 days	0	
	sewage sludge and refuse	38-60	6 days	0	
			14 days	0	
Bacteriophage f_2	Sewage sludge and wood chips,	50-70	2 weeks	1	Burge and Cramer (1974)
	sewage sludge and wood chips turned once	50-70	2 weeks	10	
	" "	50-70	2 weeks and 70 days	0	
	" "	mesophilic	1 month	1	
Bacteriophage f_2	Raw sludge and wood chips,	50-70	50 days	0	Kawata, Cramer, and Burge (1977)
	digested sludge and wood chips	40-60	70 days	0	
Coliphage f_2	Sludge and wood chips	50	13 days	0	Burge et al. (1978)
			21 days	0.001	
Poliovirus	Sludge	35-58	7 days	0	Krige (1964)
Poliovirus 1	Sewage sludge	60-70	3 days	0	Wiley and Westerberg (1969)
Poliovirus 1	Refuse and sludge	-	8 days	0	Cooper and Golueke (1975)
Poliovirus type 2 (inserted)	Sludge and refuse mix	-	3-7 days	0	Gaby (1975)

- not stated.

Table B-3. Survival of Protozoal Pathogens during Composting

Pathogen	Raw Material Type	Temperature (°C)	Time	Survival %	Source
Protozoan cysts	Vegetable matter and feces	55-60	3 weeks	0	Scott (1952)
Entamoeba histolytica	Refuse and sludge	49 55	8 days 7 days	0 0	Gaby (1975)

Table B-4. Survival of Helminthic Pathogens during Composting

Pathogen	Raw Material Type	Temperature (°C)	Time	Survival %	Source
Helminthic ova	Refuse/sludge	-	7 days	0	Gaby (1975)
Helminthic ova	Refuse/sludge	40	28 days	6-0	McGarry and Stainforth (1978)
Ascaris lumbricoides ova	Night soil and garbage	65	1 month	5	Stone (1949)
Ascaris lumbricoides ova	Feces and vegetable matter, ash soil	65	5 days 12 days 22 days 67 days	15 4 0.3 0	Scott (1952)
Ascaris lumbricoides ova	Sludge	55-70	2 months	15-0	Murray (1960)
Ascaris lumbricoides ova	Sludge	60-76	1 hour	0	Wiley and Westerberg (1969)
Ascaris lumbricoides ova	Garbage and night soil	5-64	105 days	1-0	Chinese Academy of Sciences (1975)
Hookworm ova	Night soil	35-55	24 hours	0	Nicholls and Gunawardena (1939)
N.americanus	Night soil	35-65	24 hours	0	
		35-60	24 hours	0	

- not stated.

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