nightsoil or sludge. The sale of compost to farmers can help to offset the running costs of a town's waste disposal system. Nearly two-thirds of Indian cities and thousands of villages in China dispose of some or all of their refuse by composting it with nightsoil. Composting is further discussed in Chapter 13.

Choice of method

Although other factors, particularly the public health aspects, cannot be ignored when choosing a refuse disposal system for a particular city, in practice the determining factor is usually its cost. Refuse disposal costs per ton in developing countries are not much less than in the industrialized world, and represent a heavy burden on meagre municipal budgets.

When offsetting the expected income from sale of compost against the higher cost of composting, over-optimistic forecasts should be avoided. Economies of scale in refuse treatment and handling plants are small, and can be approximated by the formula:

$$(\text{capital cost}) = (\text{constant}) \times (\text{capacity})^{0.8}$$

Care should be taken, when comparing alternative systems, to include all the costs of transport, transfer etc., and to compare like with like.

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13

Composting

13.1 AEROBIC AND ANAEROBIC COMPOSTING

The composting of organic refuse with nightsoil or sewage sludge is a method of preparing them for application to the land as fertilizer and soil conditioner, rendering them more beneficial to the soil while killing any pathogens present. Composting may be aerobic or anaerobic. Different species of bacteria are responsible in each case, different chemical changes take place, and different temperatures are reached.

Anaerobic composting or digestion, also known as fermentation or putrefaction, takes place in the absence of air or oxygen. It is the process by which organic muds are broken down by bacteria in marshes, producing marsh gas, consisting mainly of methane (CH_4), but also of ammonia (NH_3) and various sulphur-containing gases, which smell unpleasantly. A small amount of warmth is produced, but more of the energy is stored in the methane gas, which may be used for cooking or heating.

Anaerobic composting is slow and unreliable as a method of pathogen destruction because it does not achieve sufficiently high temperatures. One method, the Bangalore method, requires alternate layers of refuse and nightsoil to be buried in trenches and left for at least six months.

In *aerobic* composting, oxygen-using micro-organisms feed on the organic matter and multiply. This is the decomposition process which occurs naturally on a forest floor when droppings from trees and animals are converted by micro-organisms into humus. Aerobic composting is normally odour-free. Aerobic composting typically produces twenty times as much heat as putrefaction. The centre of a well-aerated compost pile can reach temperatures of over 65°C. It is important to keep the moisture content of the compost between about 40 and 60%. If it is too wet it cannot contain enough air, but if it is too dry it will not conserve heat well enough to warm up, nor provide a suitable medium for bacterial growth. The moisture content can be adjusted by frequent turning if it is too high, and by adding water if it is too low.

The chief advantage of aerobic over anaerobic composting is its higher temperature, which causes greater speed of digestion and

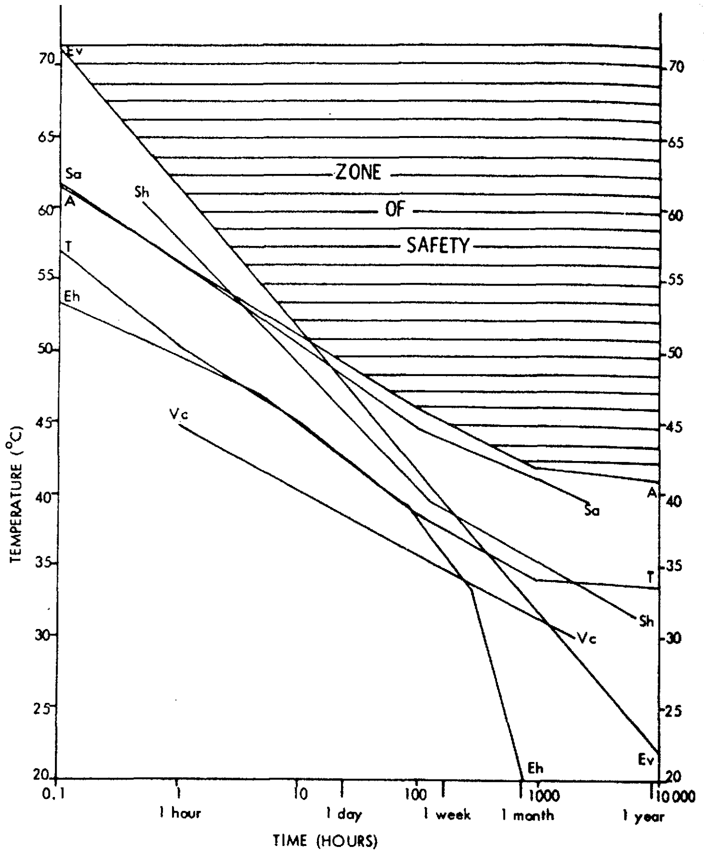


Figure 13.1 The influence of time and temperature on a variety of excreted pathogens. The lines drawn represent conservative upper boundaries for death

Ev	Enteroviruses	Eh	*Entamoeba histolytica cysts*
Sa	*Salmonella*	A	*Ascaris eggs*
Sh	*Shigella*	T	*Taenia eggs*
Vc	*Vibrio cholerae*		

Note: These lines are plotted from the graphs derived in Feachem *et al.* (1983). The lines represent very conservative estimates of the time-temperature combinations required to inactivate various pathogens. A process with time-temperature characteristics lying within the 'zone of safety' should guarantee the inactivation of all excreted pathogens, with the possible exception of hepatitis A virus at short times. Suitable time-temperature properties include:
at least 62°C for 1 hour;
at least 50°C for 1 day;
at least 46°C for 1 week;
at least 43°C for 1 month;
at least 42°C for 1 year; .

effective pathogen destruction. Each group of excreted pathogens has a different ability to withstand raised temperatures for various lengths of time. These properties are reviewed in detail by Feachem *et al.* (1983) and some of the data are summarized in

Figure 13.1. The toughest excreted pathogens are the enteroviruses and *Ascaris* eggs. The lines plotted in Figure 13.1 are conservative and time–temperature combinations within the 'zone of safety' should guarantee destruction of nearly all excreted pathogens. The toughness of *Ascaris* eggs has caused them to be adopted in China as the indicator of compost quality, as *E. coli* alone are an inadequate indicator for this purpose.

13.2 TECHNIQUES

A variety of more or less mechanized techniques exists for composting. A widely applicable technique is to form long mounds, called windrows. These may comprise alternate layers of refuse and nightsoil (or sludge) and are typically about 1.5–2 m in height (Figure 13.2). The windrows are turned (either by hand or by tractor-shovel) every few days, to keep them aerobic and to ensure that all parts of the pile spend some time at the hot centre. The top of each windrow is shaped to throw off the rain.

An alternative is to place the compost in drained, cement-lined pits about 1 m deep, stacking it to 0.3 m above ground level. Pits are easier to load without spillage, and because they conserve heat better they do not need so much turning. The compost can be digested aerobically at first in order to raise its temperature and kill pathogens, and allowed to cool slowly under increasingly anaerobic conditions. However, some turning is necessary to ensure that all parts of the heap undergo the high temperatures in the interior.

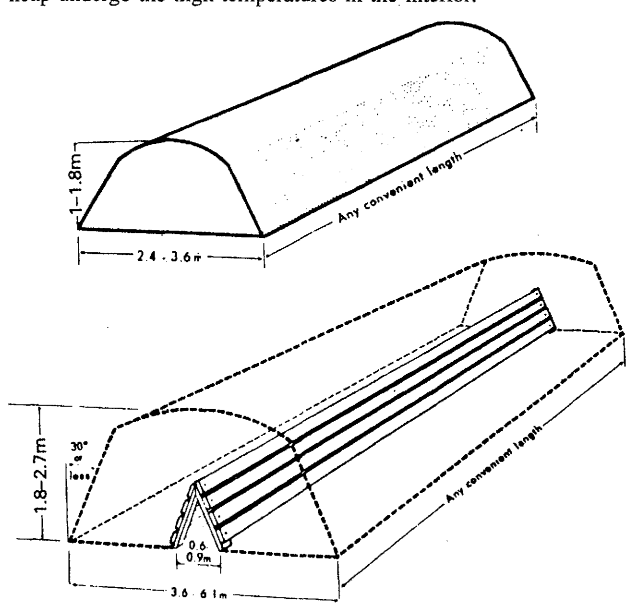


Figure 13.2 Two sizes and types of windrow
Source: From Gotaas (1956)

Up to a quarter of the nutrient content of compost may leach from it in the liquor which seeps from the pile. This may be collected in drains and applied to the same or to other piles or pits, to keep them moist and conserve nutrients.

The frequency with which compost has to be turned will depend on local conditions. The best guide is to turn it when it has become anaerobic, as indicated by foul odours given off when it is disturbed with a shovel, or by a drop in temperature. The effect of turning in enabling the temperature to increase is illustrated in Figure 13.3, which also shows the effect of temperature on *Ascaris* eggs.

Turning a compost pile tends to reduce the degree of pathogen removal achieved by the process, because the parts of the pile which have been hot enough to kill micro-organisms can then be recontaminated by contact with those which have not. Turning also increases the cost and the amount of space required. Avoiding the need for turning can therefore be an advantage.

Another simple method which avoids the need for turning has been developed in recent years. It is particularly suitable for towns and cities. Known as the forced aeration method, it involves blowing air into the base of the pile through a 100 mm diameter perforated pipe (Figure 13.4). A 0.5 hp (37 W) air blower is more than adequate for a 50 tonne pile of material, which is typically 15 m × 4 m × 1.5 m high, with a triangular cross-section. The pipe is buried at the base of the pile in a layer of coarse material, such as

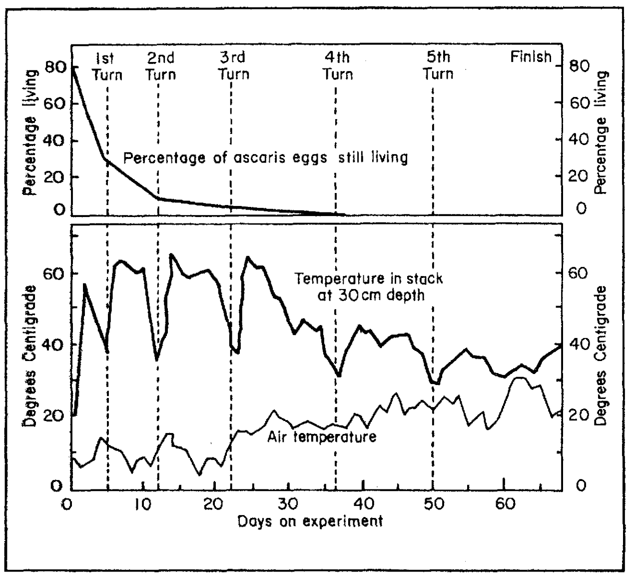
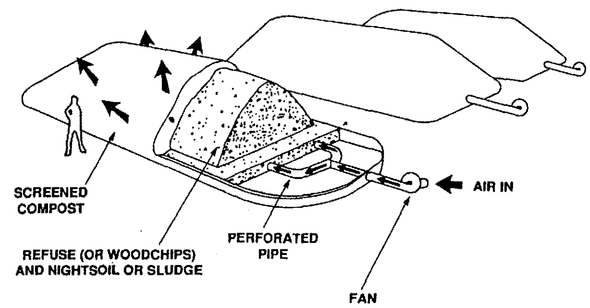


Figure 13.3 The relationship between windrow turning, temperature, and *Ascaris* egg survival in a compost stack
Source: From Gotaas (1956)

Figure 13.4 Forced aeration composting. The method was originally developed by the US National Parks Service, sucking the air through a mixture of woodchips and sludge. *Blowing* the air reduces the odour and avoids the problem of condensate in the outlet pipe, and also helps to ensure high temperatures throughout the pile, and hence better pathogen removal
Source: Adapted from Shuval *et al.* (1980).



straw. The pile is covered with 100–300 mm of screened compost, to retain heat and prevent fly breeding.

A thermocouple buried in the pile can be used to switch the blower on and off so as to keep the pile temperature in the range 50–60°C. Typically, it is on for about 20% of the time initially; this percentage increases to 75% during the first week, and then falls gradually to about 10% at the end of the pile's 30-day life. Finally, the compost is further improved by storage for two to four months.

Although the method was originally developed for mixtures of wood chips and dewatered sewage sludge, it has been adapted for nightsoil and organic refuse. Further details are given by Stentiford *et al.* (1985). More information on the composting of refuse and nightsoil may be found in Flintoff (1984) and Gotaas (1956).

13.3 CARBON/NITROGEN RATIO

The micro-organisms feeding on a compost heap use nitrogen, some of the carbon and other available nutrients to build cell protoplasm, but roughly twice as much carbon is used as a source of energy, producing carbon dioxide (CO_2) which is released. Much more carbon than nitrogen is required, or else some of the nitrogen, an important plant nutrient, may be lost to the air in ammonia.

On the other hand, if insufficient nitrogen is available, the organisms will begin to die when it has been used up, and their own nitrogen and carbon then become available to other organisms. Several generations of bacteria are therefore required to burn up the carbon. This slows down the reaction and prevents it from reaching such high temperatures. Moreover, if the final product is deficient in nitrogen, bacteria in the compost will extract nitrogen from the soil to complete the reaction, thus robbing the soil of fertility.

There is therefore an ideal ratio between the carbon and nitrogen content (the C/N ratio) of the raw compost, of about 30:1 to 40:1. The ratio can be adjusted by blending different ingredients such as straw, domestic refuse, animal manure, and nightsoil. Straw and other vegetable waste has a high C/N ratio, but nightsoil, and especially urine, brings the ratio down. Table 13.1 gives the nitrogen content and C/N ratios of various compostable materials.

Because of its low C/N ratio and its high moisture content, only a limited amount of nightsoil can be added to compost, typically about 20–30%. In many tropical cities, the weight of compostable refuse collected per person per day is about the same as the weight of nightsoil, so not all the nightsoil can be composted with it. However, it is sometimes possible to supplement domestic refuse with agricultural wastes. In rural areas, agricultural wastes are more easily available, although it may be necessary to substitute alternative sources of fuel where vegetable wastes or manure are used for cooking fires.

13.4 PROBLEMS OF COMPOSTING

Composting can be carried out with simple equipment and very little training, and is well suited to many tropical environments. It is particularly appropriate for small cities and towns near to agricultural areas. However, unforeseen problems have sometimes arisen when it has been introduced into new areas without prior experimentation.

First, it may be necessary to separate out glass, metal, and other non-biodegradable matter from the refuse. This may be done mechanically or by hand, before or after the composting process. Polythene bags have been a particular problem in some places; if spread on the land they are dangerous to livestock which may eat them. If it is not possible to sort all the refuse by hand, a cutter/shredder should be used to reduce the material to strips 30 mm wide and 150 mm long.

Table 13.1 Approximate nitrogen content and C/N ratios of some compostable materials (dry basis)

Material	N(%)	C/N
Urine	15–18	0.8
Poultry manure	6	—
Mixed slaughterhouse wastes	7–10	2
Nightsoil	6	6–10
Sheep and pig manure	4	—
Domestic vegetable refuse	2	25
Cow manure	2	—
Wheat straw	0.3	128
Sawdust	0.1	511

Source: From Gotaas (1956).

Second, it may not be easy to persuade farmers to use the new fertilizer, particularly if it includes composted nightsoil or has to compete with subsidized chemical fertilizers, or contains non-biodegradable materials such as splinters of glass, metals, or plastics. A price and a market for the compost should be assured before it is produced on a large scale.

A third problem is the breeding of flies. Organic refuse and nightsoil usually contain some fly eggs and larvae before they come to the composting site, but is it possible to prevent most of them from hatching by turning the compost early and often, for instance on the third and eighth days, taking care to place the surface material in the hot centre of the turned pile. Composting should be carried out on a hard surface, to prevent the larvae from escaping from the heat by burrowing into the soil beneath.

In order to ensure that the technique is workable and appropriate, to find the best combination of materials and turning times, and to be able to test-market the product, it is advisable to experiment with composting on a pilot scale before introducing it for a whole community.

13.5 INDIVIDUAL COMPOSTING TOILETS

The scientific principles which apply to the composting of municipal wastes also apply to individual composting toilets. In practice, these have hardly ever achieved aerobic conditions in a tropical setting, and anaerobic processes take many months (usually at least six months) to produce a compost which is relatively free of pathogens. Ideally, carbon/nitrogen ratios should be adjusted to initial levels of 30 to 40 by the addition of vegetable wastes, ash, or sawdust, and urine should be excluded or drained off; in practice, it is difficult to train the users to do this reliably so that composting toilets are not recommended for introduction to poor communities.

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14

Health Aspects of Waste Re-use

14.1 INTRODUCTION

Human wastes are a valuable natural resource and should not be thrown away (Figure 14.1). Re-use of sewage, nightsoil, organic refuse and sludge derived from sewage treatment processes is possible in most situations. As discussed in Chapter 8, there are three main forms of re-use: agriculture, aquaculture and biogas. There are no specific health risks associated with biogas production other than those due to the handling of excreta which apply to many sanitation systems. We will therefore discuss only those health risks related to agriculture and aquaculture.

Human wastes from all communities contain pathogens (Table 1.3). These pathogens survive to different degrees as the waste is transported, treated and applied to the land or pond. The health risk associated with waste re-use depends on the degree of treatment which has been provided and the nature of the re-use process. A detailed account of this subject is provided by Mara and Cairncross (1989).

14.2 HEALTH AND AGRICULTURAL RE-USE

Sewage and nightsoil are often used in agriculture, sometimes in an organized way but often informally, illegally or clandestinely. In arid areas, such as coastal Peru and the middle East, sewage is at a premium because water is scarce, and in densely populated parts of the world, such as China and India, excreta are valued as a fertilizer.

The river water used for irrigation in many developing countries, and also in Europe and North America, often contains a substantial percentage of municipal sewage. This can also be considered an indirect form of re-use.

Many re-use schemes are found in industrialized countries. For example, the Werribee farm irrigated with treated sewage from the