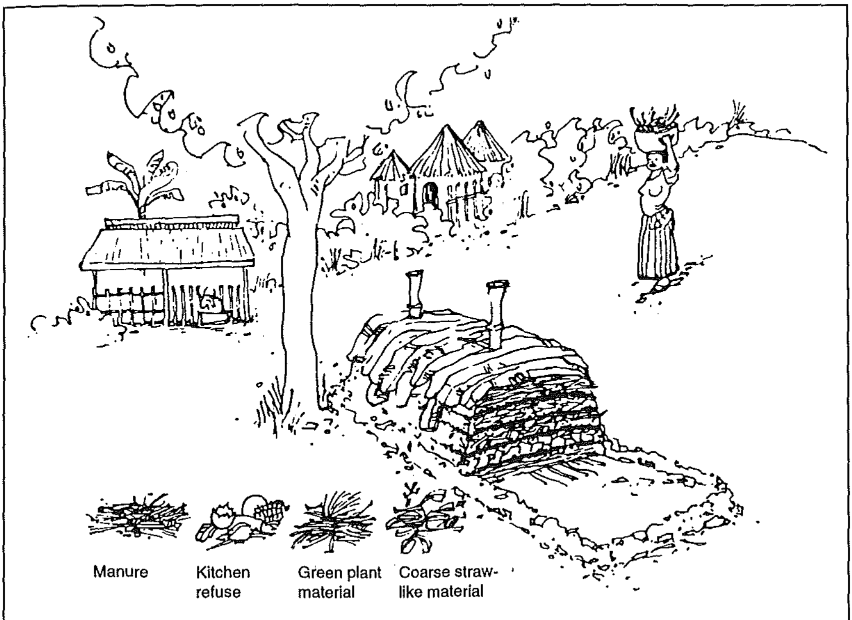
6. Composting and compost application

6.1 Introduction

Composting is the deliberate biological and chemical decomposition and conversion of organic or plant refuse and residues for the purpose of producing humus. This process takes place under controlled conditions in heaps or pits. Composting is thus a method of recycling organic matter. The aim of applying compost is to improve soil fertility. Figure 6.1 shows a simple compost heap, covered with banana leaves and located in the shade of a tree near a stable and settlement.

Figure 6.1. Simple compost heap based on the Indore method.



Note: The tree provides shade and the low earthen wall prevents flooding.
Source: MÜLLER-SÄMANN (1986)

Depending on the situation and site, composting can solve various problems associated with the management of plant residues. For example, diseases and pests, including weed seeds, are destroyed by the high temperatures that develop in a good compost during the composting process (DALZELL et al. 1979).[99] Viruses are destroyed provided a sufficiently high temperature is reached in the compost heap.[100] Plant refuse infected with viruses should therefore be placed in the center of the compost heap and quickly covered to prevent it from becoming a source of (re-)infection (for example via sucking cicadas). Rodents (rats, mice) tend to nest and breed in scattered heaps of plant litter. This can easily be prevented by composting plant residues (BHARDWAJ 1981).

Plowing fresh plant material into the soil as green manure can cause problems in the wet season on soils where water tends to stagnate. This is because substantial losses of nitrogen can be expected under semi-anaerobic conditions or as a result of constant leaching (MENGEL 1979; GUIRAUD et al. 1980). Under these conditions composting the biomass has definite advantages. This also applies to plant residues with a high C/N or C/P ratio (e.g. grain straw). If plowed into a field, these residues will temporarily fix N or P in the soil, inhibiting subsequent plant growth. This can be avoided by composting the residues, preferably with other green, N-rich materials. This reduces the C/N ratio and breaks down inhibitors, to produce a humus which can easily be applied as fertilizer. The alternative solution of burning the plant residues would entail losing valuable organic matter and nitrogen.

The end product of the composting process is a fertilizer with valuable properties and multiple functions. The most important of these are:

* **Nutrient function:** Nutrients are stored by being adsorbed into the organic matter, into the tissues of the micro-organisms, into their waste products, and into the humus compounds themselves. Compost is a slow-release fertilizer, the nutrient content of which varies according to the raw material and composting method used.

* **Improving soil structure:** Increasing the percentage of organic matter improves the soil structure.

* **Stimulation of soil organisms:** Adding humus increases the biological activity of the soil. It improves water holding capacity and crumb formation, promotes infiltration, protects against erosion and facilitates the spread and penetration of plant roots (ARAKERI et al. 1962; DALZELL et al. 1979; FLAIG 1975).

* **Strengthening resistance:** It has frequently been observed that crops fertilized with compost are more resistant to pests than those which have either been given mineral fertilizers, or no fertilizer at all (HOWARD 1943; GRUSSENDORF, cited in SCHAERFENBERG 1955; BRUCE no date).

Finally, compost is a fertilizer made from renewable resources which can be produced by farmers themselves.

For smallholders, many of whom have little or no manure available, composting offers a means of ensuring long-term soil fertility without the need for external inputs (HOWARD 1943). Moreover, unlike other fertilizers, compost does not have only a short-term effect. Applied regularly over many years, it can improve the long-term productive capacity (the permanent properties) of the soil (MÜCKENHAUSEN 1956). The deep, man-made rice soils of China have been developed in this way over centuries. Similarly, the more than one-meter deep ash soils of Germany's Lüneburg Heath (originally acidic podsols) owe their existence to many years of composting the turf with manure.

---

1 In the savannas, heat-resistant seeds may cause problems. In Yucatán, Mexico, NEUGEBAUER (personal communication) observed how catsin seeds (*Acacia* spp.) eaten by livestock got into the manure used to make compost. As these seeds can easily tolerate temperatures over 80°C, the plant reappeared in vast numbers in fields treated with compost. The seedlings of this plant have sharp thorns, so that weeding is unpleasant.

[100] According to HOLST (personal communication), it can be assumed that when tomato seeds have been killed, any viruses have too.

6.2 Principles of composting

6.2.1 Organisms

The composting process may be seen as a series of attacks on the original structure of organic materials by different groups of micro-organisms (MINNICH et al. 1979). First to arrive are bacteria, fungi, earthworms, isopods, millipedes and snails. These gradually give way to protozoa, springtails, mites, etc, while increasing numbers of ground beetles, centipedes, ants and predator mites appear in the final stage (see Figure 6.2).

Micro-organisms play a leading role in the process of decomposition. The larger organisms are particularly active in fostering physical decomposition (breaking down the material into smaller particles).[101] To ensure the success of the composting process, optimal conditions must be created for the micro-organisms. Their food supply, air, moisture, warmth, and the pH value of their environment should all be as favorable as possible.

6.2.2 Composting material

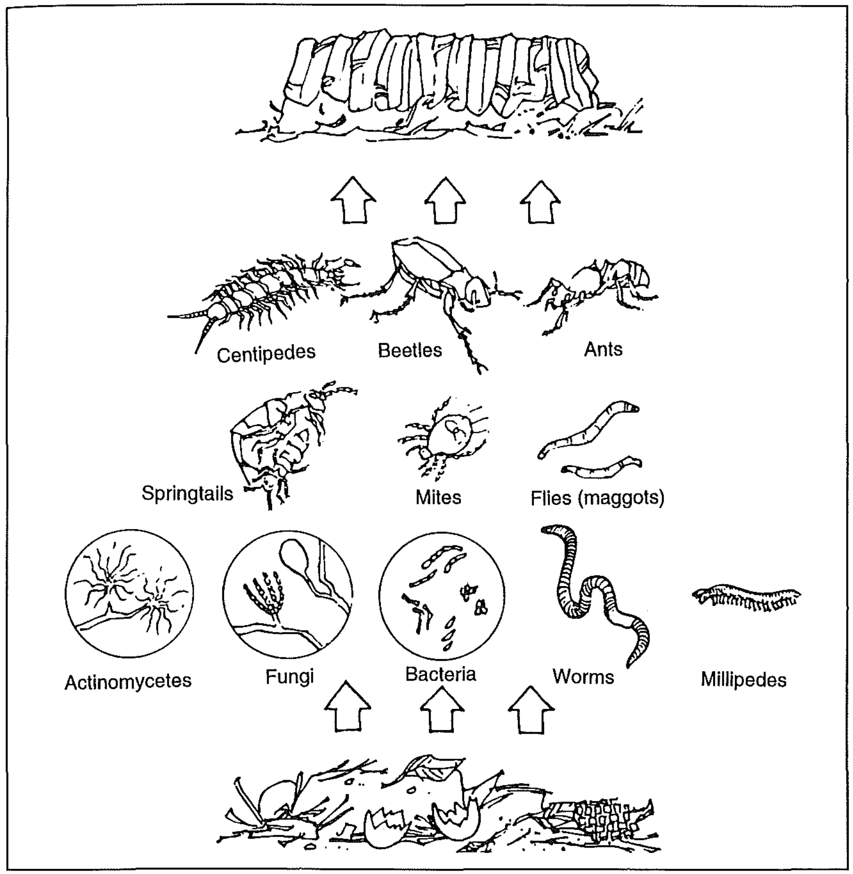
All organic matter (plants, dung, refuse, paper, etc) is suitable in principle for composting. However, human excreta and feces from carnivores require separate treatment. Extra precautions must be taken with these to ensure adequate sanitation (see also Section 6.3.4).

Organic matter is food for micro-organisms, providing them with energy and nutrients for growth and reproduction. Starches, soluble sugars, carbohydrates and amino acids are readily available and micro-organisms can process these very rapidly by oxidation to CO_2 while producing heat. However, cellulose, and particularly lignin (wood), is

3 For specific methods of earthworm composting, see specialist literature such as MINNICH (1977) and RALOFF (1980). Their practical implementation is concisely described in FAO (no date).

highly resistant to decomposition and must first be broken down by enzymes. The higher the proportion of such non-readily available matter, the slower will be the decomposition process.

Figure 6.2. From harvest residues to compost: the order in which different organisms enter the decomposition process.



Nitrogen is the most important nutrient in the composting process. If the material to be composted contains enough nitrogen, sufficient amounts of the other nutrients needed by micro-organisms are usually present as well (DALZELL et al. 1979). The C/N ratio of the compost mixture should ideally be around 30:1. A number of authors offer some guidelines for achieving this ratio. HOWARD (1943) recommends a mixture of 75% (by volume) of heterogenic plant refuse and 25% manure, while RAABE (1980) writes that a combination of 50% fresh plant matter with 50% old, dry material will yield approximately the same ratio. Nevertheless, plant residues should be composted with animal dung whenever possible, as this helps to achieve the right composition, accelerates the composting process and produces a better compost.

Table 6.1 lists a number of composting materials. Using this table it is possible, with practice, to estimate the rough composition of a compost heap.

If the C/N ratio is too low nitrogen is lost, and the compost will smell of ammonia. Adding earth or sawdust can reduce the loss, but it is better to rebuild the heap at once (MINNICH et al. 1979, JAISWAL et al. 1971). If the C/N ratio exceeds 35:1, the composting process will take place very slowly and little warming will occur.

Different types of materials from various sources compost better than homogeneous materials. The better the materials are mixed, the better the compost.

No more than around 10% of very coarse material (branches, twigs, fibrous stems, etc) should be used (HOWARD 1943). To improve this material's suitability for composting, it should first be spread out on the road to be trampled and run over by vehicles, or used overnight in the stable as bedding, where it can also absorb urine and dung. All materials, and especially bulky ones, should be chopped into 5 to 12 cm lengths, to increase their surface area. Soaking or pre-composting bulky materials may also be helpful. Mud from ponds and water weeds (water hyacinths, seaweed, etc) should be dried or pre-composted before being added to the compost heap (MINNICH et al. 1979). Straw should be left on the fields whenever possible, to begin rotting (this protects the soil at the same time). Large amounts of fresh weeds should generally be wilted before being composted.

Table 6.1. Approximate composition of some materials suitable for composting

Material	N (% of total dry matter)	C/N ratio	P_2O_5 (%)
Urine	15-18	0.8	
Blood meal	10-14	3	
Horn meal	12	-	
Bone meal	3	8	21
Fish scrap (scales)	7-10	5.1	4-10
Hair	14	-	
Chicken manure	3-6	10-12	2-3
Sheep manure	3.8	-	
Pig manure	3.8	-	
Horse manure	2.3	25	
Cow manure	1.7	18	1
Farmyard manure	2.15	14	
Night soil	5-6	8	
Cassava leaves	4.35	12	0.72
Cotton seeds (mixed)	7	-	2-3
Young grass hay	4	12	
Grass clippings	2.4	20	
Purslane	4.5	8	
Amaranthus	3.6	11	
Cocksfoot	2.6	19	
Groundnut straw	2.8	20	
Lucerne	2.4-3	16-20	
Crotalaria juncea	1.95	26	0.4
Water hyacinth	2.2	20	
Cowpea hay	1.5-3	20-39	
Soybean hay	1.5-3	-	
Cassava stems	1.3	40	
Tobacco stems	3	-	
Pigeonpea stems	0.7	70	
Coconut shells	1	-	1.5
Maize stalks and leaves	0.7-0.8	55-70	
Millet stems	0.7	70	
Wheat straw	0.4-0.6	80-110	
Fallen leaves	0.4	45	
Rice straw	0.4	100	
Sugar cane trash	0.3	150	
Rotted sawdust	0.2	200	
Fresh sawdust	0.1	500-800	0.01
Azolla	4-5	10	1-2
Bean straw	1.5	-	0.75
Groundnut shells	1	55	-
Cocoa pods	1.3	-	-
Beer draff (Abidjan)	3.6	14	-

Sources: Compiled from DALZELL et al. (1979), NAS (1981), MINNICH et al. (1979)

Difficult choices often arise when deciding whether and what to compost. In Asia, TANAKA (1974) describes more than 10 alternative uses for rice straw alone. Weeds and other compost materials are often fed to livestock. Cow dung is a common household fuel. This means that in practice materials with a low N content are often the only ones available for composting. In such cases, extra efforts should be made to collect urine and slurry. Some manure at least should be saved for making compost, as composting can increase the effect of even small amounts of manure. Straw can be composted using relatively little dung (4:1 by weight), by mixing the dung with water and pouring it over the straw (MINNICH et al. 1979).

PEAT & BROWN (cited in WEBSTER & WILSON 1980) report that in Ukirigura, Tanzania, 3 tonnes of manure can be produced per head of cattle each year (containing an average of 1.5% N and 0.69% P_2O_5). If this were used in composting, 15 tonnes of compost could be produced (averaging 0.93% N and 0.52% P_2O_5) - a sizable increase in the volume of organic fertilizer.

If no N-rich organic matter is available to counterbalance C-rich composting material, mineral fertilizers (N and P) can be added to the compost heap. In Japan, for example, rice straw is composted with calcium cyanamide at a ratio of 100:2 (EGAWA 1975). However, proponents of organic farming condemn this practice because they feel it reduces the organic quality of the compost. DALZELL et al. (1979) also warn that although it is cheap and frequently recommended, $(NH_4)SO_4$ should not be used as it can harm the fungi in the compost.

6.2.3 Water

For a compost to flourish, it must contain enough water to enable its fungi and bacteria to develop. The process of decay stops if the water content falls to 12-15%; but even a water content as high as 40-45% may limit the compost's development (MINNICH et al. 1979). Ideally, a compost heap should contain between 50 and 60% water. More than this will produce anaerobic conditions, leading to putrefaction, not to mention a nasty smell of rotting. As a practical indicator, the compost should look like a squeezed sponge.

The various compost ingredients react to moistening in different ways. Straw can absorb a lot of water without losing its structure, and pre-soaking is advisable. However, materials with a weak structure, such as paper, grass clippings, etc, quickly become compacted, which hinders ventilation and hence the composting process. To ensure good water distribution, the different materials should be composted in thin layers (max. 8-10 cm).

The ideal moisture level is usually more difficult to maintain in the tropics than in temperate climates, where drying takes place more quickly and rainfall is more intensive. The composting materials should be thoroughly moistened at the outset. According to HOWARD (1943), this is best done while adding the material, after adding it, and again the next morning.[102] Where no water supply is available, compost heaps can be built during rainfall, spreading out the materials first so they become thoroughly wet before being heaped.

The following guidelines will also help to ensure the right moisture content:

* Shady places protected from the wind are advantageous;
* The moisture level should be checked and corrected each time the compost is turned;
* Covering the compost heap with banana leaves, woven straw mats or similar materials that allow air through helps prevent evaporation and excessive soaking or leaching caused by heavy rainfall;
* If a live cover plant is to be used for the mature stage of the compost (e.g. spiderwort or pumpkin), this should not be planted on the heap itself, but immediately next to it. Plants growing on the compost heap may cause it to dry out too much;

[102] A watering can or sprayer is better than a bucket, as the material needs time to absorb the water.

* A solid roof over the compost can protect against intense heat or heavy rain. An adjustable structure is best;

* In dry regions or during the dry season, a composting pit (see below) is preferable to a heap. A flat-topped heap may also be considered;

* A heap is better during the rainy season to prevent too much water from being retained. A domed heap shape allows rainfall to drain off.

In many regions water scarcity remains a primary constraint on the use of compost over large areas (JAISWAL et al. 1971). According to DALZELL et al. (1979), 2700 liters of water may be needed to produce a tonne of compost, which at 25 t/ha represents about 67,500 liters of water or 6.7 mm of rainfall per hectare. Such a large quantity can only be provided if the water supply is good. Frequently, however, there are rival uses for the available water, such as irrigation. DALZELL et al. (1979) concluded that composting (using up to 25 t/ha) is more beneficial than irrigation if account is taken not only of the benefits to a single crop but also of the long-term benefits.

6.2.4 Ventilation

Besides adequate moisture, the compost needs good ventilation so that oxygen can enter and CO_2 can escape. HOWARD (1943) writes that it is not always easy to fulfill both requirements at the same time. If the compost does not get enough air, it may revert to silage or rot, while too much ventilation may cause it to dry out. The following principles should be observed to ensure good ventilation:

* The materials should be properly prepared; material which is too coarse and long-stemmed will stack too loosely, while material which is chopped too finely (< 5 cm) tends to become compacted;

* With materials that pack relatively densely, the compost heap may be built over a layer of fine branches; in extreme cases a ventilation base can be used. Although turning is usually unnecessary in these cases warming may, however, be insufficient;

* No part of the composting mass should be further than 70 cm from a surface point at which air enters freely; compost pits should therefore be no deeper than 50-70 cm;

* The sides of composting boxes should have air holes to permit the exchange of gases;

* Coarse and fine materials should be carefully mixed;

* The compost should not be trodden or stamped down;

* Ventilation channels can be created by inserting small posts or bamboo pipes vertically into the compost, or horizontally as KING (1911) reports from China (see Section 6.3);

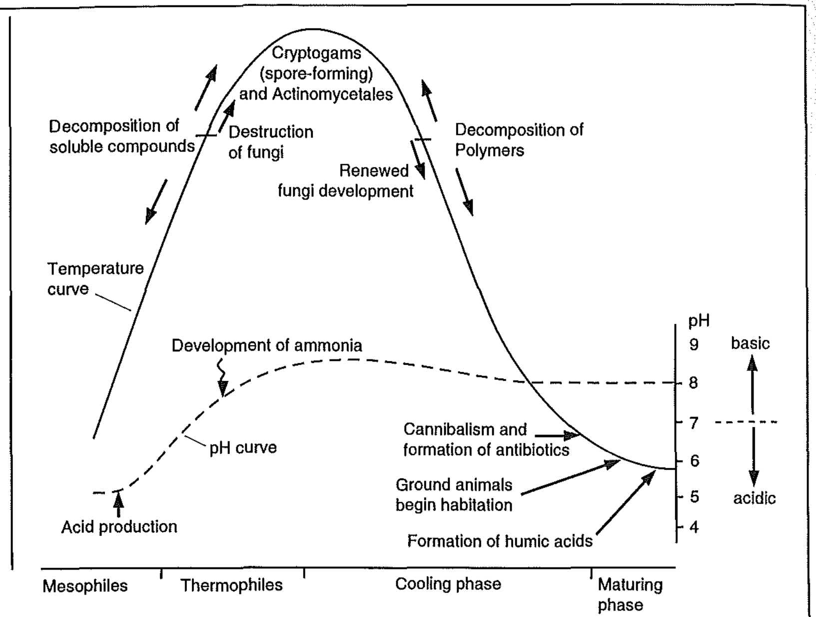
* The compost heap should be turned two to three times in its early stages, after its temperature has fallen.

6.2.5 Temperature

A satisfactory temperature is the best indication of successful composting.
If a compost heap has been correctly built, it goes through several temperature phases, as illustrated in Figure 6.3.

The temperature climbs sharply at first as the readily available (soluble) compounds oxidize, reaching a temperature of 60° to 70°C in 1 to 3 days. The temperature continues at this level for a day or so and then drops slowly. The conversion processes are most efficient during the hot phase. Micro-organisms which thrive at high temperatures achieve populations of up to 10 billion per gram of organic residue (NAS 1981). Most agents of disease and weed seeds are destroyed during this hot phase, which is why it is so vital to the composting process. To ensure a temperature increase, especially in smaller compost heaps, it is advisable to build a heap consisting of several layers (BRUCE no date, RAABE 1980). Size also affects this process; a compost heap should measure at least 1 cubic meter to ensure that the temperature rises. However, too large a heap can overheat, destroying almost all the microorganisms. Heaps should not therefore be more than 2.5 m wide and 1.5 m high (DALZELL et al. 1979).

Figure 6.3. Temperature and pH changes in a compost heap



Source: DALZELL et al. (1979)

During the cooling phase, the decomposition of straw and fibres by fungi (actinomycetales) begins. Each time the heap is turned (after 2 to 14 days, depending on the method), another rise in temperature begins.

High temperatures are present only in the center of the compost heap. RAABE (1980), found them only in the inner 50 to 60% when plant refuse was the major ingredient. For this reason, when turning the heap material should be moved from the outside to the inside and from the top to the bottom.

During the mature stage, increasing numbers of small animals and worms re-enter the compost heap.

If the matured compost is to be stored, it must be protected from rain and sun in order to minimize the loss of nutrients.

6.2.6 pH Value

If care is taken in composting, lime need not be added to achieve the natural pH progression shown in Figure 6.3.[103] Nevertheless, many authors and experienced compost makers recommend working ashes, gypsum or lime into each layer. If used at all, these materials should be sprinkled very thinly (powdered) over each layer (20-25 cm), because too much alkali causes an excessive loss of gaseous nitrogen. This is especially acute in composts in which no earth is used, as earth absorbs escaping N compounds well.

6.2.7 Composting aids (additives)

Provided the conditions for feeding and reproducing are right, the microorganisms already present on the compost materials will develop rapidly and well. Any substance that has a low C/N ratio or contains a large amount of available energy (dung, molasses, neem cake, etc) can serve as a natural activating agent. Good results have also been achieved by mixing a little earth - or even better, some old compost - into the heap (HOWARD 1943; JAISWAL et al. 1971).

[103] Except when composting pine needles and similar acidic materials (MINNICH et al. 1979).

Composts which consist mainly of one kind of material are more specific in their requirements. MINNICH et al. (1979) report, for example, that inoculation with a fungus culture (*Caprinus ephemerus*) accelerated the composting of wood refuse in the USA.

Adding nitrogen-fixing micro-organisms may also be appropriate in some cases (see FAO no date). The addition of ground rock phosphate and other mineral powders (basalt powder, dolomite dust, etc) is often recommended. Potash feldspar is useful for producing potassium-rich composts, but water hyacinths, banana refuse and water weeds are also good sources of potassium.

Especially in the tropics, where the soils have a strong phosphate-fixing tendency, it may be advisable to add phosphate to the compost rather than applying it to the fields. The intense biological activity in the compost breaks down the crude phosphate and the organic matter prevents fixation when the compost is applied to the fields. This enhances the effectiveness of phosphate, producing a slow-release source of this important nutrient. BHARDWAJ (1981) reports that adding 1-2% crude phosphate intensified the activity of azotobacter bacteria, so that these composts had a higher N content than the controls in the study.

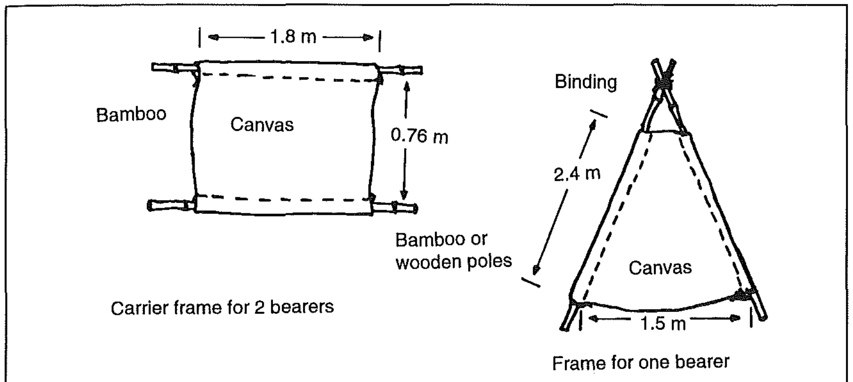
In biodynamic farming, herb composts are made and mixed into the upper layers of the compost heap. These are said to increase yields even in homeopathic doses (KOEPF et al. 1980). BRUCE (no date) activates compost with a herbal solution consisting of common yarrow, nettle, dandelion and chamomile. Successful results are frequently reported for such activating methods, but no clear explanation of why they work has yet been given. Studies by GILBERT & GRIEBEL (1969) suggest that the herbs may have a stimulating effect. Their findings show that volatile compounds based on lucerne increase the activity of soil organisms by several hundred percent for short periods.

6.3 General practice and methods of composting

6.3.1 Collecting materials

Kitchen and garden refuse can easily be collected in baskets or similar containers. Local forms of transport should be used for collecting crop residues. Carrier frames, such as those pictured in Figure 6.4, are a simple and inexpensive way of collecting bulky material in the field and bringing it to a cart or compost heap.

Figure 6.4. Carrier frames for transporting refuse



Source: DALZELL et al. (1979)

When building a compost heap, it is best to collect the components first and store them separately, if necessary, so that when the time comes sufficient materials are available to enable individual heaps or sections to be built as rapidly as possible (taking no more than 7 days according to HOWARD 1943). The more rapidly the layers can be stacked, the better the conditions for conversion. Small amounts of daily refuse (which have already undergone cold pre-composting) can later be layered into the compost. Soft, green materials should be left to wilt in the sun for 2-3 days before being stored for composting (FAO, no date).

6.3.2 Building the compost heap (Indore method)

Almost all composting methods commonly used today are based on the "Indore method" developed by HOWARD (1943), which in turn owes a debt to KING's (1911) experience in China.

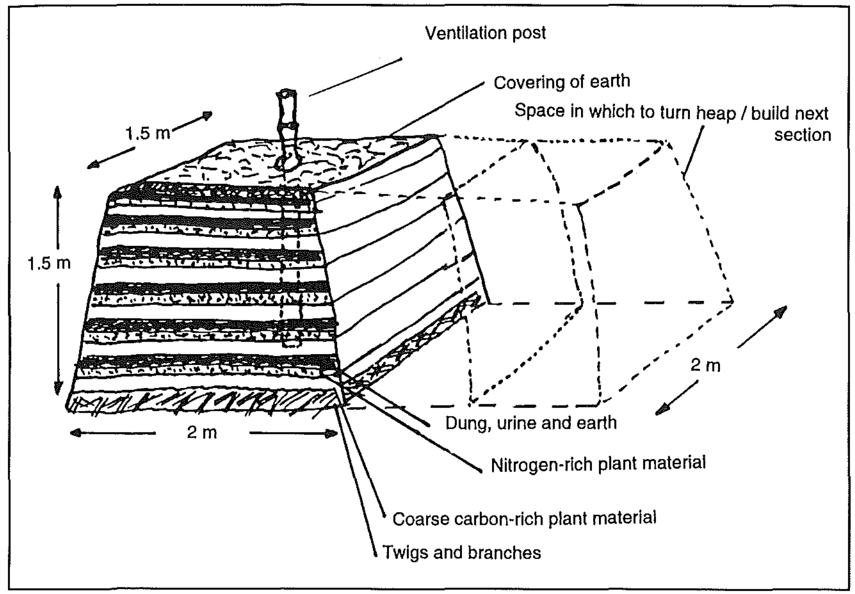
The ground area for an Indore compost heap should be 2 meters square. A further area 2 meters square must be allowed for turning the heap. For larger composting operations, a row of 2-meter square sections can be built, leaving the first position empty to allow room to turn the sections one after the other. It is better to stack one heap to a final height of at least 1 meter as quickly as possible, rather than slowly building up a number of sections evenly. A movable wooden divider can be used to separate the sections during stacking.

The Indore method involves mixing plant refuse with manure (including urine), earth and some ashes. These materials are added to the compost heap in layers (see Figure 6.5). A foundation of twigs and small branches (10-20 cm) is built to permit drainage and ventilation, and is covered with the following:

* A layer of coarse plant material, chopped into lengths of 10-15 cm (preferably after being used overnight as stable bedding),
* A layer of fresh but wilted plant waste (7-8 cm),
* A 5 cm deep layer of manure which is sprinkled with a mixture of urine, earth and wood ash.

Some 3-4 kg of old compost earth can be added to each layer to aid the composting process (JAISWAL et al. 1971). Each layer is moistened. Seven layers, each 20-25 cm deep, make a compost heap 1.3-1.5 m high. This is then covered with a layer of earth. Thin posts are stuck into the heap from the second layer onwards to provide ventilation (see Figure 6.5). Moving the posts gently creates sufficient air vents. Sections are completed one at a time.

Figure 6.5. Structure of an Indore compost heap



An Indore compost heap reaches its maximum temperature within a week at most, after which it collapses due to the decomposition taking place within. It is first turned after 2-3 weeks, again in layers. The materials are mixed in the process, moving material from the outside to the inside and from the upper layers to the lower. Ventilation channels are produced as above and the moisture level is checked and corrected. The heap is turned again 2 weeks later, after which the compost should rest and mature. In about 3 months it is ready for use. Indore composts can be produced on the ground or in 60 to 70 cm deep pits in dry weather.

According to HOWARD (1943), about 22 m³ or 22-26 t of compost can be produced per year on a farm with one ox, using litter (e.g. crop residues) and dung or urine from the stable floor, mixed with soil.

JAISWAL et al. (1971) list the following disadvantages of the Indore method:

* It is labor-intensive
* It requires considerable attention and experience
* The compost must be turned
* A lot of water is required, and
* A large amount of soil must be carried to the heap,
* The aerobic conditions cause rapid conversion, but considerable losses of C and N.

6.3.3 The Bangalore method

The Bangalore method avoids many of these disadvantages. This method works aerobically during the early stages (1-2 weeks) and becomes semi-anaerobic later on. The pits or heaps are arranged as in the Indore method, on slightly sloping ground. After using the materials overnight as livestock bedding, they are thoroughly mixed with urine and dung before being added to the heap.

Sections built using this method must be no more than 60 cm wide. New layers are added daily until a section reaches its final height. After being thoroughly wetted, the dome-shaped heap is sealed with a 2.5 cm layer of soil or mud.

The compost takes 8-10 days to heat up and is ready for use after 6-8 months, with no further turning or watering. This method takes two to three times longer than the Indore method, but has advantages where compost is needed only twice a year and where water is scarce.

6.3.4 Composting fecal matter

In India the Bangalore method (never the Indore method) is used to compost night soil, and a smaller version of this kind of compost heap is also used in China. Animal and human waste is thoroughly mixed with plant waste at a ratio of 1:4, moistened,

and sealed with mud. For ventilation, hollow bamboo canes are pressed into the dome horizontally and vertically and pulled out when the mud has hardened. When the compost has heated after 4-5 days, the air holes are plugged with soil to maintain the temperature. After 2 weeks, the heap is opened, turned over and resealed (NAS 1981).

Composting human excreta generally requires greater care and a longer composting time or pre-composting. EGAWA (1975) recommends the method practised in Japan, where night soil is stored in pits for several months before being used. Some 2-3% superphosphate may be added to prevent gaseous N loss. Storage in pits for 1 year with some earth and ashes is also recommended.

With care and with some composting experience, the inclusion of human excreta can markedly improve the return of nutrients into the system. Table 6.2 lists some of the agents of disease and their behavior under various conditions. On hygiene problems, see also KAMPF et al. (1964), and FAO (1975).

6.3.5 Garden compost heaps

Garden compost heaps are built according to the same principles as the heaps described above. BHARDWAJ (1981) describes composting in a pit using 10% manure by weight and 1-2% crude phosphate, with a later addition of azotobacter bacteria after turning the heap for the second time. The heap was turned three times, producing compost in 2-3 months.

A quick method using two boxes is described by RAABE (1980). By turning the heap once or twice daily, he was able to produce ripe compost in 3-5 weeks without the help of additives (although he does recommend some herbivore manure). It was necessary to cover the heap well to avoid heat loss and achieve a high temperature.

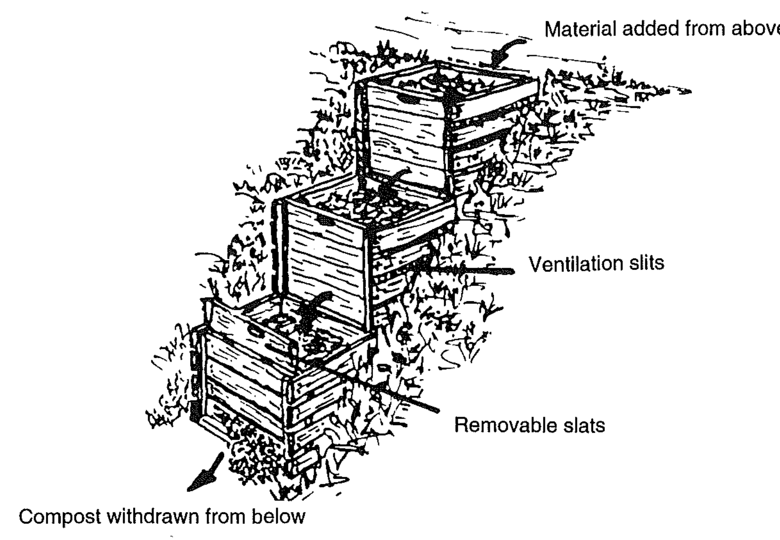
Table 6.2. Pathogen survival in night soil after composting or after direct application to fields

Organism	Survival time if: Composted	Applied to field
Intestinal virus	Quickly killed at 60°C	Up to 5 months in soil
Salmonella	Killed in 20 hrs at 60°C	*S.typhi*: up to 3 months in soil; other types: up to 1 year
Shigella (dysentery)	Killed in 1 hr at 55°C; killed in 10 days at 40°C	Up to 3 months in soil
Escherichia coli	Quickly killed at 60°C	Several months
Cholera vibrio	Quickly killed at 55°C	Not more than 1 week
Leptospira (hemorrhage, jaundice)	Killed in 10 min at 50°C	Up to 15 days in soil
Hookworm eggs	Killed in 5 min at 50°C and in 1 hr at 45°C	Up to 20 weeks in soil
Eelworm eggs (*Ascaris*)	Killed in: 2 hrs at 55°C 20 hrs at 50°C 200 hrs at 45°C	Several years
Schistosoma eggs (bilharzia or blood fluke)	Killed in 1 hour at 50°C	Up to 1 month on moist ground

Source: WORLD BANK (1980); cited in NAS (1981)

Another quick method for gardeners was developed by BRUCE (no date). Due to the addition of a herbal activator, the heap does not need to be turned. A heap consisting of plant refuse, 15-20% manure and a little lime is built in 1 to 2 months and covered with 8-10 cm of earth. Several holes are bored into the heap at heights of up to 15 cm above the ground. Some 85 ml of an activating agent is poured into the holes, which are then filled with dry earth. The compost is ready for use in 2-4 months without turning. The activator used is made up of 1 teaspoon of dried herbs in a half liter of rainwater with 1 drop of honey added. Leave to stand for 24 hours before using.

Figure 6.6. Small-scale compost container on a slope.*



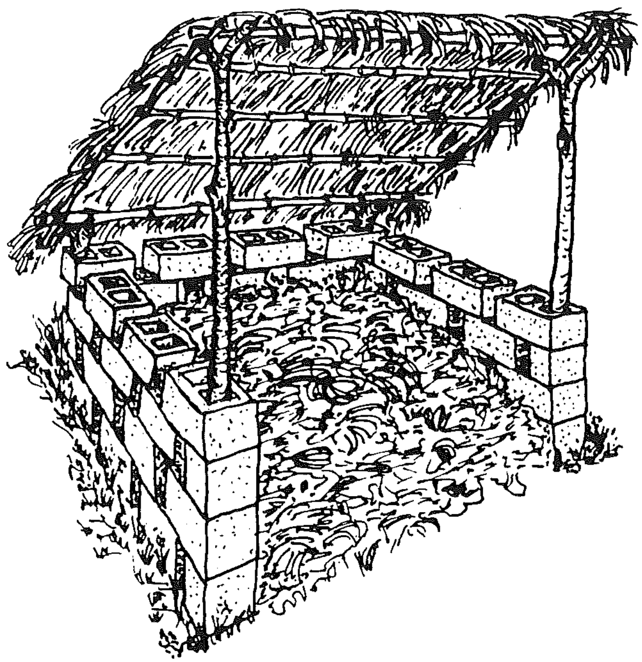
* This terrace design makes turning and restacking easier.

Source: Adapted from MINNICH et al. (1979)

Relatively N-rich materials should be used for quick composting methods. Generally speaking, the more often the compost is turned, the sooner it is ready, but because frequent turning is laborious, quick composts are only used in special cases.

Wherever possible, garden compost heaps should be built in a container or pit, otherwise the surface area exposed is too large in relation to the amount of compost, which inhibits warming as well as increasing the risk of drying or soaking. Various materials can be used to construct a container. Designs can also vary greatly. Figures 6.6 and 6.7 provide examples. However, the containers need to be at least 1 m^3 in size, and must have some sort of ventilation and protection from drying or flooding.

Figure 6.7. Simple household compost container with a protective roof*



* Made of hollow cinder blocks.
Source: MÜLLER-SÄMANN (1986)

6.4 Using compost

Once the compost has been brought to the fields, it should be worked into the top 10 cm of the soil as soon as possible (before the beginning of the growing period). If, for labor availability reasons, it has to be applied before or during the dry season, when it will be less effective, it should be plowed deeper into the soil (20-30 cm). As much compost as possible should be used: there is no such thing as too much compost.

In the tropics, where organic matter decomposes rapidly, it is best to apply compost every year. However, if the amount to be applied is less than 7.5 t/ha, distribution is more difficult and labor costs may outweigh benefits. In this case it is better to fertilize sections in rotation (DALZELL et al. 1979). HOWARD (1943) recommends applying 20-25 tonnes per hectare.

Other applications for compost include lining furrows with it before sowing or transplanting, and putting it directly into the holes for crops such as tomatos. Compost can also be hoed in lightly as a top dressing at the height of the growing season.

A 1:4 slurry of compost and water, left to stand for 24 hours, is often recommended for watering seedlings. Compost is also strongly recommended when planting trees, especially banana. It should always be generously applied to plant holes (MINNICH et al. 1979).

Compost can also be used to prepare trench beds. Soil is removed to a depth of 50 cm and replaced with compost, and the beds are then planted.

6.5 Socio-economic considerations

6.5.1 Fertilization value

Fertilization values vary considerably between composts, depending on the raw material and composition. Table 6.3 provides some examples.

In Brazil, KIEHL et al. (1978) produced a relatively rich compost (1.8% of N, 0.4% P, 0.3% K) by adding extra mineral N and manure, together with 2% calcium phosphate. Taking local costs into account, they calculated that it was more economical to produce compost than to buy the equivalent amount of nutrients in mineral form. However, this result was obtained using mechanical aids (chopper and tractor with front loader).

Table 6.3. Fertilizer values of various composts made from organic refuse

	% N	% P	% K	C/N
1. Cotton stems and dung	0.40	0.13	1.4	-
2. Vegetable waste	0.49	0.12	0.9	-
3. Vegetable waste + dung	0.43	0.10	0.9	-
4. Weeds mixed with *Crotalaria*	0.41	0.11	1.7	-
5. Mixed weeds without *Crotalaria*	0.40	0.12	1.3	-
6. Garden compost	0.40	0.3	0.2	-
7. Chicken manure with sawdust	1.0	0.4	0.46	-
8. Pig manure and straw	0.53	0.37	0.33	-
9. Mixed farm refuse	0.44	0.13	0.92	14
10. Mixed dry residues (Indore)	0.45	0.11	0.8	11
11. Wheat straw*	0.62	-	-	26

* Produced using the Bangalore method

Sources: 1-8, DALZELL et al. (1979); 9-11, JAISWAL et al. (1971)

When comparing mineral fertilizers and composts, it must be borne in mind that composts also improve the soil. Trace element deficiencies, which often develop after several years of mineral fertilization (HEATHCOTE 1969; TANAKA 1974) are less likely when compost is used (DALZELL et al. 1979; KIEHL et al. 1978). Finally, as MILLER (1976) points out, economic as well as technical considerations should be taken into account when evaluating the pros and cons of different kinds of fertilizers. He calculated that a profit of some US $ 7 million was made in 4 years by using compost made from sugar cane trash on an area of 8000 ha in Barbados.

6.5.2 Compost on farms

Composting is particularly suitable if livestock, organic material, water and cheap labor are all available.[104]

Integrating livestock with arable cropping is a basic requirement for sustainable agriculture. The fact that draft animals can also be used for producing and transporting compost can be an additional incentive for keeping them.

Before resorting to hired labor, it should be remembered that a farm's own labor force is often underemployed at certain times of the year. Since it is not restricted to a particular season, composting can be done more cheaply at these times.

Little cash is needed to set up and maintain compost production, saving for other purposes money which would otherwise have been spent on mineral fertilizers.

Because compost production and application involves a considerable amount of transport of materials the composting site should be chosen with care. The three main factors to consider are the location of the fields, the stable(s), and the water source(s).

Farmers who produce their own compost are less dependent on external inputs, so their risk is lower. Furthermore, with a moderate level of technology and considerable labor, composting can substantially improve the yield capacity and long-term productivity of soils, while risk and running costs remain low.

6.5.3 Ways of introducing composting

Composting is not appropriate for every farm. Other methods of conserving soil fertility may be less costly or labor-intensive, technically simpler, or more firmly anchored in tradition. Composting may be uneconomic where large areas are exten-

[104] Full mechanization, as described by KIEHL et al. (1978), is usually not practicable for smallholders.

sively cultivated, where space is available for fallow regeneration or crop rotation with green manure crops, or where labor is very expensive.

Under other conditions, however, such as declining soil fertility combined with scarcity of land, composting may be highly appropriate. In such cases explanations and demonstrations may be enough to convince a farmer that composting makes sense.

Farmers' willingness to begin compost production is influenced not only by economic and technical considerations, but also by cultural and social attitudes. Thus in Southeast Asia composting is a long-standing farming tradition, whereas in large parts of India or in Bangladesh, other uses for materials such as rice straw make it difficult or impossible to introduce compost production.

It is almost always difficult to introduce something completely new. However, in some places it is already customary for farmers to heap weeds together in the fields, and it is only a short step from there to making compost.

The first step towards introducing composting can be the household or garden compost heap. Building on this, the second and considerably more difficult step of composting for field crops can follow. In places where agriculture and housework are strictly separated, however, it may be better to introduce field composting directly, as transferring gardening practices to field cropping may prove difficult.

Farmers tend to accept innovations only when these offer them a clearly visible improvement. For this reason it is better - at least at first - to concentrate the compost available on a small area. A small field of maize that produces double the yield after being heavily fertilized with compost will convince a farmer of the value of compost more readily than a 10-20% increase over a much larger area.

6.6 Zonal aspects of composting and compost application

6.6.1 Rainforest climates

Comparatively little has been reported on the use of compost in the humid tropical rainforest zone, where permanent crops in combination with mulches and live mulches predominate.

In Southeast Asia, compost is used very successfully in wetland rice cultivation. TANAKA (1974) mentions, however, that in systems without livestock compost fertilization quickly comes up against practical and economic limits. In Indonesia and the Philippines straw is therefore left to rot in the fields before being worked into the soil with simple implements.
Rice straw composts for mushroom cultivation are an exception. HONG KIM (1980) reports a yield of 16.9 kg of mushrooms per m^3 using these composts in Korea (see also NAS 1981).

In agroforestry systems, compost can be applied to great advantage on intensively farmed plots such as vegetable gardens with fruit trees. SUIZA (1979) mentions ways of using wood waste and branches for quick compost production (see also PAIN & PAIN 1977).

AGBOOLA et al. (1975) note that potassium fertilizers are often only effective in combination with organic fertilizers on acidic tropical soils. BANDY & NICHOLAIDES (1979, cited in SANCHEZ et al. 1982) used compost to achieve yields over four growing periods that were only 20% lower than when complete mineral fertilizer was used. This level could be maintained by the later addition of potassium.

In the mountains of Cameroon, LYONGA (1980) obtained greater economic efficiency by using 8-10 t/ha of compost than if the same yields had been achieved using mineral fertilizer. He confirmed KEEN et al.'s (1953) finding that root and tuber crops are particularly efficient users of compost.

6.6.2 Moist savannas

Moist savanna regions provide better conditions for composting. Materials lying on the ground break down only slowly during the dry season. However, effective mechanization for plowing crop residues back into the soil is usually lacking, so farmers often pile residues together for burning. Not only is organic matter thus lost, but also nitrogen and sulfur (BALASUBRAMANIAN & NNADI 1980).

After many years of research in the Nigerian savannas, JONES (1971) strongly advocated that at least the crop residues should be left on the fields, if adequate manure is not available.

RANGANATHAN et al. (1980) concluded from their studies in India that returning crop residues to the soil is not sufficient to restore the C balance in the lowland tropics. However, because livestock production is more common in this area and enough water is usually present, composting is possible.

Studies by RODEL et al. (1980) on acidic, sandy soils in Zimbabwe showed that, when manure was used directly, at least 4.5 tonnes per hectare were needed to obtain good crop yields. This would require a stocking density of 3.4 TLU/hectare. Making compost with the manure increased the efficiency with which it was used by crops, with the result that stocking densities could be reduced by 65% or more while still obtaining the same crop yields (PEAT & BROWN 1962). The effectiveness of mineral fertilizers in these studies was substantially improved by kraal compost.

CHARREAU (1975) cites pot experiments which showed that soils rich in iron oxides to which compost had been added exhibited a higher P content, and fixed far less phosphate after being fertilized with P.

The importance of livestock in moist savanna systems is confirmed by the practices observed at local level in many areas. The Wakara of Lake Victoria, for example, combine livestock stabling with the composting of crop residues. The addition of livestock manure enriches the compost, permitting continuous land use (LUDWIG 1967). NETTING (1968) describes similar practices in Nigeria.

Where rivers or canals provide water all year, water hyacinth, azolla and other water plants can be composted together with mud, as is frequently practised in Asia. According to SINGH & BALASUBRAMANIAN (1980), a compost made with water hyacinth (*Eichhornia sp.*) has a nutrient content up to four times higher than that of manure.

6.6.3 Dry savannas

In dry savanna regions, the scarcity of water makes composting more difficult. Plant materials for composting may also be scarce. Livestock raising is widespread in this zone, and is, in some areas of Africa, carried out by pure pastoralists who grow no crops.

In semi-arid areas, organic materials may be scarce only because of a shortage of fuel. Planting more fast-growing trees (eucalyptus, casuarina, margosa, etc) would alleviate the shortage of firewood, relieving the pressure on crop residues which could then be used for composting (BALASUBRAMANIAN & NNADI 1980). Surface mulching is often unpopular because the mulch provides a breeding ground for termites. The use of composting instead would help to prevent infestation.

Where water is available seasonally, it may be possible to use it on previously prepared compost pits. Particularly in semi-arid areas, better results can be obtained with compost than with mineral fertilizers. CHARREAU (1975) reports experiments in Senegal in which compost fertilizer clearly enhanced drought resistance. Even during intensive dry periods, compost fostered plant growth and delivered nitrogen to the plants, whereas mineral fertilizers had long been unavailable (see also FLAIG 1975) because they were associated with yield losses under such conditions. Nutrient losses from the system were lowest when crop residues were composted, and the soil structure was improved.

This finding was confirmed in laboratory experiments by GUIRAUD et al. (1980). They found that compost was the best type of organic fertilizer for savanna soils.

There was no drop in yield nor loss of N; the compost proved a stable source of organic matter. Its residual effect is 15-20%, according to JONES (1971).

FELLER & GANRY (1980) were able to markedly improve the humus content of sandy alfisols in Senegal over 4 years, using pit compost made from Pennisetum straw (11 t/ha). However, this effect was pronounced only in combination with mineral N fertilizer - which, used alone, showed no positive effect whatsoever.

SUIZA (1979) reports that arid and saline soils in Israel, Egypt, Pakistan and Thailand were made arable again by applying 10 t/ha of compost over 2-3 years.

6.7 References

AGBOOLA, A.A., G.O. OBIGBESAN & A.A.A. FAYEMI (1975): Interrelations between organic and mineral fertilizers in the tropical rainforest of Western Nigeria. FAO Soils Bulletin No. 27: 337-351.

ARAKERI, H.R., G.V. CHALAM, P. SATYARANAYANA & R.L. DONAHUE (Eds.) (1962): Soil Management in India. Bombay. 619pp.

BALASUBRAMANIAN, V. & L.A. NNADI (1980): Crop residue management and soil conservation in savanna areas. In: FAO Soils Bull. No. 43, Rome: 106-120.

BHARDWAJ, K.K.R. (1981): Barter farm wastes for crop feed. Co-Operative News Digest 32 (6): 114.

BRUCE, M.E. (no date): Gartenglück durch Schnellkompost. Mannheim, Waerland-Verlagsgenossenschaft, 4. Auflage, 96 pp.

CHARREAU, C. (1975): Organic matter and biochemical properties of soils in the dry tropical zone of West Africa. In: FAO (1975): 313-336.

DALZELL, H.W., K.R. GRAY & A.J. BIDDLESTONE (1979): Composting in tropical agriculture. Ipswich, The International Institute of Biological Husbandry. Review Paper Series No. 2, 33 pp.

EGAWA, T. (1975): Utilization of organic materials as fertilizers in Japan. In: FAO Soils Bull. No. 27: 253-271.

FAO (1975): Organic materials as fertilizers. Rome, FAO Soils Bulletin No. 27, 394 pp.

FAO (no date): Organic recycling - A practical manual. Rom, FAO Project Field Document No. 26, 71 pp.

FELLER, C. & F. GANRY (1980): Effect of nitrogen fertilizer (urea) and organic amendments (compost) on the stabilization of organic matter in a millet monoculture in semi-arid tropical conditions. Rome, FAO Soils Bull. No. 43: 160-167.

FLAIG, W. (1975): Specific effects of soil organic matter on the potential of soil productivity. Rome, FAO Soils Bulletin No. 27: 31-70.

GILBERT, R.G. & G.E. GRIEBEL (1969): Stimulation of soil respiration by volatiles from Alfalfa. Soil Sci. Soc. Amer. Proc. 33 (2): 270-273.

GUIRAUD, G., F. GANRY & GISELE LLIMOUS (1980): Action de différents résidus de recolte en sol sableux tropical. Estimation au moyen de N 15. Agron. Trop. 35 (3): 220-224.

HEATHCOTE, R.G. (1969): Soil fertility under continuous cultivation in Northern Nigeria. I: The role of organic manures. Experimental Agriculture 6: 229-237.

HONG KIM, B. (1980): Microbial conversion of agricultural wastes into useful products. Industry and Environment 3 (1): 4-6.

HOWARD, A. & WAD, Y.D. (1931): The Waste Products of Agriculture: their Utilization as Humus. Oxford University Press.

HOWARD, A., Sir (1943): Mein landwirtschaftliches Testament. (Übersetzung des englischen Originals von 1943 bei Edition Siebeneicher) München, Volkswirtschaftlicher Verlag 1979, 254 pp.

JAISWAL, P.L., A.M. WADHWANI, M.K. JAIN & N. CHHABRA (Eds.) (1971): Handbook of manures and fertilizers. New Delhi, Indian Council of Agricultural Research, 2nd ed., 396 pp.

JONES, M.J. (1971): The maintenance of soil organic matter under continuous cultivation at Samaru, Nigeria. J. of Agric. Sci. 77: 473-482.

KAMPF, MAAS & STRAUCHE, eds. (1964): Müll und Abfallbeseitigung, Handbuch über die Sammlung, Beseitigung und Verwertung von Abfällen. Erich Schmidt Verlag, Berlin.

KEEN, B. and D.W. DUTHIE (Eds.) (1953): Crop response to manures and fertilizers in East Africa. East Africa Agric. J. 19 (1): 19-57.

KIEHL, E.J., F. DE MELLO, J. KIEHL & C. DE ESCOLA (1978): Renova-se o interesse pelos adubos organicos. (Renewed interest in organic fertilizers) Dirigente Rural/Brasilien 17 (9/10): 16-23.

KING, F.H. (1911): Farmers of Forty Centuries. Madison/Wis. Democrat Printing Co., 441 pp.

KOEPF, H.H., B.D. PETTERSON & W. SCHAUMANN (1980): Biologisch-dynamische Landwirtschaft. 3. Aufl. Stuttgart, Ulmer, 303 pp.

LUDWIG, H.D. (1967): Ukara - Ein Sonderfall tropischer Bodennutzung im Raum des Viktoria-Sees. München, Institut für Wirtschaftsforschung Afrika-Studien Nr. 22, Weltforumverlag, 251 pp.

LYONGA, S.N. (1980): Some common farming systems in Cameroon. In: FAO (1980): 79-86.

MENGEL (1979): Ernährung und Stoffwechsel der Pflanze. Gustav Fischer Verlag Jena.

MILLER, L.G. (1976): Turning bagasse to organic matter. Barbados Sugar Industry Review 28: 18-19.

MINNICH, J. (1977): The Earthworm Book. Rodale Press, Emmaus, Pennsylvania, USA.

MINNICH, J. & M. HUNT (1979): The Rodale guide to composting. Emmaus, Rodale Press: 405 pp.

MÜCKENHAUSEN, E. (1956): Typologische Bodenentwicklung und Bodenfruchtbarkeit. Köln und Opladen, Arbeitsgemeinschaft für Forschung des Landes Nordrhein-Westfalen, Heft 60.

MÜLLER SÄMANN, K.M. (1986): Bodenfruchtbarkeit und Standortgerechte Landwirtschaft, Maßnahmen und Methoden im Tropischen Pflanzenbau. GTZ, Eschborn, Sonderpublikation SR 195. 559 pp.

NAS (1981): Food, fuel and fertilizer from organic wastes. Washington D.C. , Nat. Acad. Press, 155 pp.

NETTING, R.Mc.C (1968): Hill farmers of Nigeria. Seattle and London, Univ. of Washington Press, 259 p.

PAIN, I. & J. PAIN (1977): Another kind of garden. 5th ed., Villecroze/France, I. & J. PAIN, 58 pp.

PEAT, J. & K.J. BROWN (1962): The yield responses of rain-grown cotton, at Ukiriguru in the lake province of Tanganyika. 1. The use of organic manure, inorganic fertilizers, and cotton-seed ash. Empir. J. of Expl. Agric. 30 (119): 215-231.

RAABE, R.B. (1980): The rapid composting method. American Camellia Yearbook 1980: 80-84.

RALOFF, J. (1980): Vermicomposting. Science News 5, p. 13-14.

RANGANATHAN, V., M. GANESAN & S. NATESAN (1980): Organic matter flux in South Indian tea soils: a need for conservation. The Planters' Chronicle/Indian 75 (7-8): 309-312.

RODEL, M.G.W., J.D.H. HOPLEY & J.N. BOULTWOOD (1980): Effects of applied nitrogen, kraal compost and maize stover on the yields of maize grown on a poor granite soil. Zimbabwe Agric. J. 77 (5): 229-232.

SANCHEZ, P.A., D.A. BANDY, J.H. VILLACHICA & J.J. NICHOLAIDES (1982): Amazon basin soils: management for continuous crop production. Science 216: 821-827.

SAUERLANDT, W. (1948): Grundlagen der Bodenfruchtbarkeit. Humusdüngung und Bodengare. Lüneburg, Kinau, 127 pp.

SCHAERFENBERG, B. (1955): Beobachtungen am Coloradokäfer *(Leptinotarsa decemlineata Say)*. Zeitschr. f. Pfl.-krankh. u. Pfl.-schutz 62 (2): 67-75.

SINGH, A. & V. BALASUBRAMANIAN (1980): Organic recycling in Asian agriculture. In: FAO Soils Bull. No. 43: 235-278.

SUIZA, R.B. (1979): Agroforestry is recycling, too. Canopy 5 (7): 11.

TANAKA, A. (1974): Methods of handling of cereal crop residues in Asian countries and related problems. Extension Bulletin No. 43, (ASPAC), 29 pp.

WEBSTER, C.C. and P.N. WILSON (1980): Agriculture in the Tropics. Longman, London.