CHAPTER 2

Relationships between Composting and Vermicomposting

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CONTENTS

I INTRODUCTION

Many environmental problems of current concern are due to the high production and local accumulations of organic wastes that are too great for the basic degradation processes inherent in nature. Until recent years the utilization of organic wastes and manures in agricultural soils was not problematic because the production was small enough to be used in limited quantities. With adequate application rates, organic wastes are a valuable resource as a soil fertilizer, providing a high content of macro- and micronutrients for crop growth, and they represent a low cost alternative to inorganic fertilizers. Environmental problems arise when the local production and accumulation of manures through intensive strategies is too great, resulting in difficulties in finding sufficient land areas for disposing of the enormous amounts of organic wastes produced. Indiscriminate spreading of large quantities of such organic wastes can damage soil fertility, can cause water pollution and odors, and may present a health risk. The potentially adverse effects of such indiscriminate applications include overfertilization, particularly with N, P, and K; ammonia toxicity for the soil biota; accumulation and concentration of heavy metals in the soil surface and soil biota; gradual increases in soil alkalinity; salt accumulation in dry conditions; establishment of anaerobiosis and anoxic decomposition pathways; input and dispersal of human pathogens; and ground water pollution.

These important environmental problems can be avoided if organic wastes are treated appropriately before their disposal or use. In this way, aerobic biodegradation can be involved to produce either a high-quality final product or simply to reduce environmental problems through a rapid processing of the waste without increased costs. Through the end of the aerobic degradation process the oxygen demand is low, the organic materials are converted to more stable products, carbon dioxide, and water are released, and heat is evolved. Under field conditions, the degradation process takes place slowly at the soil surface, without reaching high temperatures and mainly under aerobic conditions. This natural process of breakdown can be accelerated by heaping the material into windrows to avoid heat losses and thus allowing temperature increases (thermophilic composting) or by using specific species of earthworms as agents for turning, fragmentation, and aeration (vermicomposting).

The humified composts and vermicomposts rapidly attain equilibrium with the soil ecosystem without causing some of the major disruptions commonly associated with raw organic wastes. These products are valuable in agriculture as nutrient sources and in soil improvement. Currently, the science of thermophilic composting is well known and applied widely to organic-waste management.

The cultivation of earthworms in organic wastes has been termed *vermiculture*, and *vermicomposting*, the managed processing of organic wastes by earthworms to produce vermicompost, has progressed considerably in recent years. Vermicomposting has been shown to be successful for processing sewage sludge and solids from wastewater (Domínguez et al. 2000; Clark et al. 2007; Pramanik et al. 2007; Suthar 2007), paper industry waste (Elvira et al. 1996, 1998; Kaushik and Garg 2003; Gajalakshmi and Abbasi 2004), urban residues, and food and animal waste (Edwards et al. 1985; Edwards 1988; Domínguez and Edwards 1997; Atiyeh et al. 2000; Triphati and Bhardwaj 2004; Garg et al. 2006; Aira et al. 2006a, 2006b; Suthar 2007; Lazcano et al. 2008), as well as horticultural residues from plants (Gajalakshmi et al. 2005; Gupta et al. 2007; Pramanik et al. 2007; Suthar 2007) and food industry waste (Edwards 1983; Butt 1993; Nogales et al. 1999a, 1999b, 2005).

II COMPOSTING AND VERMICOMPOSTING PROCESSES

Composting and vermicomposting are two of the best-known processes for the biological stabilization of solid organic wastes. Composting involves the accelerated degradation of organic matter by microorganisms under controlled conditions, during which the organic material undergoes a characteristic thermophilic stage 45°C–65°C (113°F– 149°F) that allows sanitization of the waste by the elimination of pathogenic microorganisms. Two phases can be distinguished in composting: (a) the thermophilic stage, where decomposition takes place more intensively and which therefore constitutes the active phase of composting; (b) a maturing stage, which is marked by decreases in the temperature to the mesophilic range and where the remaining organic compounds are degraded at a slower rate. The duration of the active phase depends on the characteristics of the waste (amounts of easily decomposable substances) and on the management of the controlling parameters (aeration and watering). The extent of the maturation phase is also variable, and it is marked normally by the disappearance of phytotoxic compounds. Thermophilic composting is well established on the industrial scale for solid organic-waste treatment, although the loss of nitrogen through volatilization of NH_3 during the thermophilic stage of the process is one of the major drawbacks of the process. Through composting, the heterogeneous fresh organic material is transformed into a homogeneous and well-stabilized humuslike product (Gootas 1956; Golueke 1972; Poincelot 1975; Haug 1979; De Bertoldi et al. 1983; Zucconi and de Bertoldi 1987).

Vermicomposting involves the bio oxidation and stabilization of organic material by the joint action of earthworms and microorganisms. Although it is the microorganisms that biochemically degrade the organic matter, earthworms are the crucial drivers of the process, as they aerate, condition, and fragment the substrate, thereby drastically increasing the microbial activity. Earthworms act as mechanical blenders and by comminuting the organic matter they modify its physical and chemical status, by gradually reducing the C:N ratio and increasing the surface area exposed to microorganisms—thus making it much more favorable for microbial activity and further decomposition (Domínguez et al. 1997). Therefore two phases can also be distinguished here, (a) an active phase where the earthworms process the waste, modifying its physical state and microbial composition (Lores et al. 2006), and (b) a maturation-like phase marked by the displacement of the earthworms toward fresher layers of undigested waste, where the microorganisms take over in the decomposition of the waste. As in composting, the duration of the active phase is not fixed and will depend on the species and population density of earthworms and their ability to ingest the waste (ingestion rate). Vermicomposting is not yet adapted fully to the larger industrial scale (Domínguez et al. 1997), and since the temperature is always in the mesophilic range, pathogen removal is not completely ensured, although some studies have provided good evidence of suppression of human pathogens (Monroy et al. 2008, 2009; see Chapter 16). In some cases, organic residues require pretreatment before being vermicomposted as they may contain substances that are toxic to earthworms, such as acidic compounds (Nair et al. 2006), NH_3, and salts.

A combination of composting and vermicomposting has recently been considered as a way of achieving stabilized substrates (Tognetti et al. 2007). Composting enables sanitization of the waste and elimination of toxic compounds, and the subsequent vermicomposting reduces particle size and increases nutrient availability; in addition, inoculation of the material resulting from the thermophilic phase of composting with earthworms reduces the expense and duration of the treatment process (Ndegwa and Thompson 2001).

Both composting and vermicomposting are aerobic biodegradation processes of organic wastes that involve complex interactions between the organic waste, microorganisms, moisture, and oxygen contents. The waste material normally contains indigenous mixed populations and communities of microorganisms. When the moisture content and oxygen concentration are brought to a suitable level, microbial activity increases. In addition to oxygen and water, microorganisms require a source of carbon, macronutrients such as N, P, and K, micronutrients, and certain amounts of trace elements for their normal growth and reproduction. These requirements are provided by the organic waste materials. By using the organic matter as a food source the microorganisms reproduce rapidly and release carbon dioxide, water, some organic products, and energy. Some of this energy produced is consumed during the metabolism processes with the remainder released as heat.

Thermophilic composting is a biological process in which the active agents are microorganisms; consequently, the successful outcome of the composting process depends on the presence of the appropriate microbial population—preferably indigenous—and on the provision for suitable conditions for microbial activity (Zucconi and de Bertoldi 1987). Several aspects related to nutrition and microbial succession characterize the composting process. The primary effect of the microbial succession is the establishment of a pattern in such way that one group of organisms paves the way for a succeeding group. A parallel well-known feature, syntrophy, sometimes referred also as synergy, has been recognized in microbiological terminology and refers to nutritional and metabolic interactions between two or more groups of bacteria when growing as a mixed culture. Through syntrophy or synergy, metabolic end products produced by one group of organisms may be used as nutrients by the following ones. Thus, the combined activities of two or more different types of organisms growing together may result in final products that are quantitatively or qualitatively very different from the total sum of the activities of each individual organism.

Collaborative or syntrophic decomposition of organic matter is the normal course of events in both composting and vermicomposting of organic wastes. However, in both natural decay and vermicomposting systems, a huge variety of microorganisms and soil invertebrates grow and interact, contributing to the "cycle of matter." The vermicomposting system sustains complex food webs, and different chemical forms of several nutrient elements become modified into long-lived organic compounds that are important for nutrient dynamics as well as plant growth regulators.

Vermicomposting is a mesophilic, completely aerobic decomposition process and, as such, is almost entirely the result of microbial activities. Earthworms and other soil animals do not have cellulolitic systems developed enough to digest plant material and therefore much of the animal nutrition depends on the action of microbes, either free-living or associated with their guts. Although microoganisms are responsible for the biochemical degradation of organic matter in the vermicomposting process, earthworms are important in conditioning the substrate and promoting microbial activity. They can be considered as mechanical blenders because they break down organic material, increase the surface area exposed to microbes, and move fragments and bacteria-rich excrement through the waste profile, homogenizing the organic material. The vermicomposting process per se is due to microbial activities, with the earthworms having also a strong influence, but the whole soil fauna community also plays an important role in these processes through its interactions with soil microbes and therefore must be considered in a holistic perspective.

III OPEN COMPOSTING SYSTEMS

A Windrow Composting

This consists of placing the mixtures of different raw organic materials in long, narrow piles or windrows that are turned mechanically on a regular basis to aerate them. Turning alone often does not ensure adequate and consistent oxygenation. Within an hour after turning, oxygen levels within a pile often drop drastically, and microbial activity is accordingly reduced. For this reason, the pile must be turned frequently, leading to technical and economic problems. In most modern systems there is recognition that the different phases of the process require different aeration rates. The results of this are turning programs that, for example, recommend turning every 3–4 days for the first 2–3 weeks and on a weekly basis thereafter. When a particular turning sequence does not cause local problems (e.g., odor) and the final product is “acceptable,” there is no reason to modify it (Stentiford 1996). On a more rational basis, systems using temperature as a turning indicator have been developed. Briefly, these work on the basis that as soon as a certain temperature 55°C–60°C (131°F–140°F) is achieved in the pile core, the material must to be turned.

B Forced Aerated Static Piles

Forced aeration systems are intended to supply air to the composting mass using pressurized air systems (typically using low head, <150 mm, high-volume fan units) rather than turning the mass. There are basically three ways to oxygenate the piles:

1. **Bottom Suction**
   The air is drawn through the pile by the imposition of negative pressure. In this kind of ventilation height is a critical factor. With piles higher than 2.5–3.0 m (8–9 ft) it is almost impossible to obtain uniform aeration. These piles must be blanketed with an insulating layer (usually cured compost) to ensure a uniform distribution of temperature (Finstein et al. 1983).
2. **Bottom Blowing**
   Aeration is provided by blowing air through the pile (positive pressure). This method tends to cool down and dry the bottom layers of the pile, leaving the outer layers warm and moist (Finstein et al. 1983).
3. **Alternative Ventilation**
   In these systems bottom blowing aeration is alternated with bottom suction aeration. The alternative flows of air movement lead to a homogenization of temperature and moisture gradients throughout the pile (Pereira Neto et al. 1991).

IV IN-VESSEL COMPOSTING

In-vessel composting refers to a group of methods that confine the mass to be composted inside a building, container, or vessel. In-vessel systems are designed to promote rapid digestion rates by careful monitoring and control of the composting process; although these systems can produce an end product more quickly, they are more complex and relatively costly to build, operate, and maintain. There are a variety of in-vessel methods with different combinations of vessels, aeration devices, and turning mechanisms. Among these, the most widely utilized are the following.

A Continuous Vertical Reactors

Usually the materials are loaded up from the top of the reactor and discharged from the bottom. Oxygenation is provided by forcing air up from the bottom through the composting mass. These reactors can process large amounts of material (as much as 2000 m^3 (2616 yd^3)) and may be as high as 9 m (28 ft); however, the height is extremely critical, and masses higher than 3 m (10 ft) lead to serious problems in ventilation, by hypo- or hyperventilation (Haug 1993).

B Horizontal Reactors

The materials are arranged along the length of the unit, and the height never exceeds 2–3 m (6–9 ft). The principal advantage of these systems is the feasibility for controlling the process, it being possible to shorten the thermophilic stage. Because the oxygen is supplied either by turning or by aeration the mass to be composted can be oxygenated uniformly and the temperature easily controlled (Haug 1993).

V OPEN VERMICOMPOSTING SYSTEMS

A Low-Cost Floor Beds

The traditional methods of vermicomposting have been based on beds or windrows on the ground containing materials up to 45 cm (1.5 ft) deep, but such methods have numerous drawbacks. They require large areas of land for large-scale production and are relatively labor-intensive, even when machinery is used for adding materials to the beds, watering, and harvesting the products. More important, such systems process organic wastes relatively slowly (Edwards 1988). Outdoor windrows or beds with simple walls are the simplest type of process. The size of such beds is flexible, but the width should not exceed 2.4 m (8 ft), which allows the entire bed to be inspected easily, without the need to walk on the bed, and is also compatible with the sizes of many suitable covering and construction materials. The length is less important and depends on the area available. The beds can be laid on soil that is freely draining and does not suffer waterlogging. Concrete areas are ideal for earthworm-processing systems since they provide a firm surface for tractor operations. However, it is essential for precautions to be taken to prevent too much water from entering the beds and to allow excess water to drain away from the bed. Usually, such floor beds are covered with permeable materials, and the covers are removed only for watering and addition of new waste materials. It is necessary to feed prepared organic wastes on top of the bed surface in thin layers of 5–10 cm (2–4 in) every week or so, depending on the type of waste. In addition, it is necessary to retain a light and open texture in the waste (Price 1987; Phillips 1988).

B Gantry-Fed Beds

An important principle to improve the efficiency of processing of organic wastes by earthworms is to add the wastes to the beds in thin layers of 2.5–5.0 cm (1–2 in) at frequent intervals. This can be done readily by adding the wastes by means of an overhead gantry running on wheels on the top of the walls of the beds.

This gradual addition of waste minimizes the generation of heat during composting and ensures that earthworms are continually processing the fresh wastes close to the surface.

C Raised Gantry-Fed Beds

Earthworms are usually confined to the top 10–15 cm (4–6 in) of the bed. The efficiency and rate of processing the wastes can be considerably increased by placing the bed above the ground. If the bed has a mesh underneath, the earthworm-processed organic matter can be sieved by mechanical action, such as a breaker bar, and can be collected using a moving belt or a slurry scraper. If the waste is added to the top of the bed in thin layers from a mobile gantry daily and collected at the base, a continuous waste-processing system can be obtained. Such systems can be relatively sophisticated by a complete mechanization and automation of the addition and collection systems of the waste. Such automated continuous-processing reactors have been operating successfully for as long as 3–4 years (Price 1987; Phillips 1988; see Chapter 8).

D Dorset Wedge-Style Beds

The design of this type of bed is quite different from the relatively shallow flat beds described previously. Waste is added to the angled leading edge in shallow layers. Because of the large amounts of waste added, the benefit of this type of bed is that the wedge tends to be more self-heating. It is particularly suitable for cattle waste, and separated pig solids. It is especially recommended for processing organic wastes in winter, and the depth of the wedge should not exceed 1 m (3.1 ft).

The floor of a Dorset wedge has the same requirements as the outdoor beds. It should be free-draining and firm enough to withstand quite heavy machinery. The only essential wall required is the removable rear wall, which should be sound enough to enable the front-end loader to dig the bed. Side walls can help to maintain the appropriate depth of the waste. Once the majority of the leading edge of the bed appears to be earthworm-worked, a new layer of fresh waste is added. This is usually done by adding wastes at the top of the leading edge and then raking the waste down onto the whole surface. Care should be taken to avoid unnecessary compaction of the bed; with long beds, a side-discharge muck spreader can be used. The amount of waste added to the wedge should be lower during the summer than in the winter months to prevent overheating.

Because of the shape of the Dorset wedge, it is not important to specify the dimensions or time to harvest the bed, and the best indicator is when there is at least a load of approximately 20 m^3 (26.2 yd^3) that can be harvested. Most earthworms are probably in the top 15 cm (6 in) of the leading edge, and therefore this material has to be removed in order to harvest the earthworm-worked material behind, which is collected and loaded up for transport. The remaining inoculum is used to form a new wedge as before (Price 1987; Phillips 1988; see Chapter 7).

VI IN-CONTAINER VERMICOMPOSTING

A Bins

Other systems refer to the use of bins or large containers, often stacked in racks. Although these and other small-scale systems are widely used, they have drawbacks when applied on a larger scale. They require considerable machinery for handling and lifting, and also there are several problems related to addition of water and additional layers of new material and to drainage. Edwards (1988) discussed batch vermicomposting in stacked boxes or containers and suggested that it is too labor-intensive, since the batches have to be moved in order to add more wastes or water.

B Batch Reactors

Much more promising techniques have used containers provided with legs. These allow adding the feedstock at the top from modified spreaders or mobile gantries and collecting the vermicompost mechanically at the bottom after being sieved through the mesh floors using breaker bars. Such methods were developed and tested at the National Institute for Agricultural Engineering (Silsoe, England) and are currently being used at several places in the United States and elsewhere, ranging from relatively low-technology systems using manual loading and collection to completely automated systems using hydraulically driven continuous-flow reactors. Such reactors process 1 m (3.1 ft) deep layers of suitable organic wastes in 30–60 days (Edwards and Bohlen 1996). Although these systems require more capital outlay, the cost of the reactor can usually be returned in 1–3 years (see Chapter 19), and they can be operated on a large scale with minimal labor requirements. An automated reactor processing 1000 tons of waste per year can be built for $35,000–$50,000, and the lower-technology systems cost much less. Detailed economic studies at Silsoe have shown that such reactors have a much greater economic potential to produce a high-quality plant growth media in a shorter time and more efficiently than windrows or ground beds. An even larger-scale system called the Sovadec was developed by Marcel Bouché in southern France and was based on similar principles, involving separation and sorting of the wastes followed by composting, vermicomposting, and sieving. This system can convert 27% of a total urban waste stream into a valuable vermicompost.

VII ORGANIC WASTE PROCESSING SYSTEMS

A summary of the recommended values for the important factors in composting and vermicomposting processes are given in Tables 2.1 and 2.2. The main task is to translate these factors into economic and reliable composting systems. The complexity of the composting and vermicomposting equipment and the problems of how to approach the optimum values of these factors may vary considerably from simple heap processes to large-scale mechanized reactors.

Table 2.1 Recommended Values of Process Factors

	Composting
Process Factor	**Values**
C:N ratio of wastes	25:1 to 30:1
Initial particle size	10–15 mm (0.4–0.6 in) for agitated systems and forced aeration
Moisture content	55%–60% (higher value possible when using bulking agents such as straw or wood chips)
Oxygenation	0.6–1.8 m^3.day.kg (0.78–2.4 yd^3.day.2.2 lb) volatile solids or maintain oxygen level at 10%–18%. Feedback temperature or oxygen control of air blower possible in forced aeration systems.
Temperature	55°C–60°C (131–140°F)
Agitation	No agitation to periodic turning in simple systems. Short bursts of vigorous agitation in mechanized systems.
Windrow size	Any length; 1.5 m high × 2.5 m wide (4.9 × 8.2 ft) wide for natural aeration heaps. Heap size can be increased for forced aeration.
Reactor size	Height is extremely critical, and masses higher than 3 m (3.1 yd) can lead to serious problems in ventilation.
Human pathogens	Killed after the thermophilic stage of the process
Time taken	The self-heating and the thermophilic phase (about a week) are followed by several months of “curing” at mesophilic temperatures

Table 2.2 Characteristics of Vermicomposting

Process Factor	**Values**
C:N ratio of wastes	25:1 to 30:1
Initial particle size	10–20 mm (0.4–0.8 in) (higher values slow down the process)
Moisture content	80%–85% (limits 60%–90%)
Oxygen	Earthworms maintain aerobic conditions
Temperature	15°C–25°C (limits 4°C–30°C) (59–77°F) (limits 39–86°F)
pH	>5 and <9
Ammonia content of wastes	Low: $<0.5\ mg \cdot g^{-1}$
Salt content of wastes	Low: <0.5%
Windrow size	Any length and width 50 cm high (higher values slow down the process or can even stop it long)
Reactor size	40 m long × 2.4 m wide (128 ft long × 8 ft wide) × lm deep. Wastes should be added in thin layers 5–10 cm (2–4 in.)
Human pathogens	Killed after 70 days of vermicomposting
Time taken	From 4 to 12 months in the windrows to 30–60 days in the continuous reactor systems

VIII CRITERIA OF COMPOST AND VERMICOMPOST MATURITY

Both composting and vermicomposting transform fresh organic wastes into useful products that are rich in available nutrients for plant growth, poor in readily biodegradable carbon, almost depleted in phytoinhibitory substances, and relatively free of plant and human pathogens. Subjectively, a mature compost should be dark brown or black, with a granular, spongy, or fibrous texture, and smell like mold or soil. A mature vermicompost should also be dark black, usually finely divided peat-like material with excellent structure, porosity, aeration, and drainage properties and high moisture-holding capacity (see Chapter 18).

IX ANALYTICAL METHODS TO EVALUATE COMPOST STABILITY

A Carbon:Nitrogen Ratio

The C:N ratio is one of the most widely utilized parameters to follow the development of material undergoing a composting or vermicomposting process, and it varies remarkably depending on the feedstocks and by itself can hardly give reliable indications of compost maturity. The C:N ratio of a mature compost or vermicompost should ideally be around 10, but this is hardly ever achieved due to the presence of recalcitrant organic compounds, or materials that decompose poorly. The most critical aspect related to the C:N ratio is whether further decomposition of the mature products in the soil will result in the release of mineral N or cause competition with plants for the N in the soil solution. C:N ratios ranging between 35.6–50.8 cm (14–20 in) in mature composts and vermicomposts are therefore acceptable as long as their further decomposition is slow and does not use up additional N from the soil.

B Humic Substances

The quantity and quality of compost and vermicompost humic substances have often been studied in the last 10 years (Roletto et al. 1985; Sequi et al. 1986; Saviozzi et al. 1988), suggesting possible parameters and evaluation indexes for compost maturity. During the maturation process, humic substances evolve qualitatively with an increasing predominance of humic acids over fulvic acids; the ratio between these two is considered an important index of compost maturity; and it is considered that it should be more than 1 in a mature compost.

C Absence of Plant Inhibitors

Perhaps the best indicator of a compost's or vermicompost's maturity is the absence of bio-inhibitory aliphatic acids and phenolics, which can be detected by chromatography or by using seed germination tests. In the latter test small seeds (*Lepidium sativum*) are placed in a Petri dish on filter paper that has been soaked in a water extract of the underlying final material, and they should germinate to the same percentage level as those placed on paper soaked in distilled water. Other methods have been devised: Zucconi, Pera, Forte, and De Bertoldi (1981) and Zucconi, Pera, Forte, Monaco, et al. (1981) evaluated phytotoxicity as a function of *L. sativum* seed germination and root growth; Wong (1985) used *Brassica parachinensis* seeds; and Kuboi and Fujii (1984) tested 20 plant species in liquid shaking culture.

D Absence of Human Pathogens

It has been proposed that a compost and vermicompost should be considered hygienic if 100 g (3.5 oz) of sample do not contain *Salmonella*, human viruses, infective parasitic helminthic eggs, and no more than 5×10^4 fecal coliforms and 5×10^5 fecal streptococci (see Chapter 16).

E Other Criteria

Organic nitrogen mineralization is a useful parameter to determine readily biodegradable nitrogen compounds, and therefore it can be correlated inversely with compost stability. The N mineralization assay evaluates organic matter stability as a function of the existing equilibrium between organic and mineral N during a 10-day incubation period. Respiration rates are related directly to the speed of microbial metabolism; therefore, they are related inversely to compost maturity. Consequently, in the early degradation stages, corresponding to a fast microbial activity due to the most readily fermentable organic fractions, respiration is very high. Later on, after a decrease in the biological activity, respiration decreases strongly until it reaches low values that remain constant in a stable final product.

X ADVANTAGES OF THERMOPHILIC COMPOSTING

The composting process typically reduces the pH of the end products, and the compost acts like a buffer in the soil. In-vessel composting allows collection of ammonia, which can be recycled as fertilizer to avoid atmospheric pollution. Compost can also provide a high content of available plant nutrients and improves soil physical properties such as water-holding capacity, cation-exchange capacity, soil aeration and permeability, and water infiltration, which all significantly contribute to reduce soil erosion and losses of nutrients by surface runoff. Composting produces a noticeable rapid volume and weight reduction as a consequence of organic matter mineralization, and water losses by evaporation; in addition, nutrient content per volume and unit of weight increases. Odor problems and proliferation of flies and rats can be minimized with effective management. Composting produces antagonists to plant pathogens and also weed seeds, and pathogenic organisms can be eliminated by the high temperatures occurring during the process. The composting process increases the amounts of humified compounds, and, although the total amount of heavy metals increases (as a consequence of the carbon losses by mineralization during the process), the amounts of bio-available heavy metals tend to decrease due to the formation of stable complexes with these polymerized substances (see Chapter 17).

Organic wastes recycled as composts also reduce the exploitation of limited resources such as inorganic fertilizers and peat and decrease the costs of disposal of the organic waste. Spreading compost on agricultural land can lead to a more uniform distribution of the nutrients, and unlike addition of raw organic wastes, no phytotoxic effects on seedlings and plant roots occur. For horticultural purposes, composts represent an economic alternative to peat and mosses. The duration of the composting process can vary depending on the characteristics of the final product to be obtained. In some cases simply removing pollution from the initial waste to obtain a "fresh compost" could be enough although the final compost may not be of agricultural value, and this process could then be completed in less than a week. When the objective is to obtain a high-quality compost it is necessary to continue the process until the maturation or curing of the compost is completed (the self-heating and the thermophilic phase, lasting about a week, are followed by several months of "curing" at mesophilic temperatures). Maturation is a passive stage that does not require any treatment and can take months.

XI ADVANTAGES OF VERMICOMPOSTING

Earthworms can break down organic matter very rapidly, resulting in stable, nontoxic vermicomposts with a better structure, microbial content, and available nutrient content than composts. These have a potentially high economic value as soil conditioners or media for plant growth. Although the best final products and the shortest residence times are obtained by high-technology systems, the low-technology ones can be easily adapted and managed in small farms or livestock operations. Vermicompost is a finely divided, peatlike material with a low C:N ratio, excellent structure, porosity, aeration, drainage, and moisture-holding capacity, and it supplies a suitable mineral balance, improves plant nutrient availability, and could act as complex-nutrient-source granules.

Similarly to composting processes, vermicomposting reduces waste bulk density, and recent research also showed that it greatly reduces populations of pathogenic microorganisms (see Chapter 16). It is generally accepted that the thermophilic stage during the composting process eliminates human pathogens, but it has been shown that human pathogens are also eliminated during vermicomposting, probably by means of an antagonism mechanism.

As an aerobic process, both composting and vermicomposting lead to N mineralization, but the presence of earthworms in vermicomposting increases and accelerates the N mineralization rate. Moreover, the humification rates that take place during the maturation stage are higher and faster during vermicomposting, resulting in a greater decrease of bio-available heavy metals. There is circumstantial evidence that the final product may contain hormone-like compounds or plant growth regulators that could accelerate plant growth and crop yields (see Chapter 9).

The main purpose when applying composting and vermicomposting technologies to organic-waste management has been to decrease landfill disposal and to obtain value-added products that can be suitable for commercialization. For this reason, many of the other applications of these processes have been disregarded and poorly studied. Therefore, we consider these two processes of utmost importance for stabilizing organic wastes, and at the same time solving or at least minimizing those environmental problems that could arise from their disposal. In many cases there is no need to complete the procedure, but, depending on the composition and characteristics of the initial waste to be treated, the processes could be extended, and then the end products would be of a much higher quality.

The thermophilic composting process seems suitable for the rapid treatment of large amounts of organic wastes, in order to eliminate contamination problems more quickly than the traditional low-technology vermicomposting systems. However, the newer vermicomposting continuous reactor systems seem to be equally applicable to rapid large-scale organic-waste processing. Traditional batch and bed vermicomposting systems may be an alternative, inexpensive way to avoid environmental problems and at the same time obtain a valuable organic fertilizer. Vermicomposting, whether low or high technology, may have an important role in organic-waste management, and it is possible to suggest that vermicomposting and composting are not necessarily mutually exclusive and could be used in sequence to take advantage of the unique and valuable features of each.

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