3 What happens during composting?

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3.1 Introduction

Composting is the science of converting organic matter to useful products by the action of various organisms. Decomposition as a process occurs in nature at various levels. To attain the goal of having quality end products, various modifications have been applied to this natural process with a careful monitoring of the process. Composting is associated with the reclamation, recycling, treatment, and disposal of wastes. Reclamation and recycling are means of saving and reusing natural resources. Disposal has become a less desirable option because of environmental concerns.

The composting process mainly involves a battery of actions carried out by the interplay of various organisms that form a web of life. Composting is generally defined as the biological oxidative decomposition of organic constituents in wastes of almost any nature under controlled conditions (Sharma *et al.* 1997). In this process, the organic substances are reduced from large volumes of rapidly decomposable materials to small volumes that continue to decompose slowly. The process brings the ratio of carbon to other elements into a balance, thus providing nutrients to plants in the absorbable state (Fig. 1).

To understand the science of composting, a basic understanding of the various organisms involved is necessary. Based on their functions, these organisms have been classified as first-order consumers, which feed directly on the dead plant or animal materials; second-order consumers, which feed primarily on the first-order consumers or on the produce of these consumers; and third-order consumers, which feed on the second-order consumers. This system keeps different populations in check and maintains a healthy and balanced system. Further, the vast array of organisms found in the compost pile can be classified based on their functions as chemical and physical decomposers. Microscopic organisms such as bacteria, fungi, actinomycetes, and protozoa are the chemical decomposers, while larger organisms such as worms, mites, snails, beetles, centipedes, and millipedes are mainly the physical decomposers. Bacteria and worms are the powerhouse of chemical decomposers and physical decomposers, respectively. Microbes and invertebrates carry out decomposition of organic litter by utilizing its carbon and nitrogen contents as the energy source with oxygen and water, resulting in the production of carbon dioxide, heat, water, and soil-enriching compost (Fig. 1).

Most organisms preferred for composting are aerobic (requiring oxygen) as they provide rapid and complete composting (Figs. 2 and 3). Other organisms can operate without oxygen (anaerobic conditions), and this process is sometimes called fermentation and usually occurs more slowly. They utilize nitrate, sulfate, carbonate, and ferric ions to oxidize organic compounds (Fig. 4). However, the greatest disadvantage of anaerobic process is the offensive odors produced during the process. It also produces organic acids, alcohols, methane and other gases, which may be harmful to the plants.

3.2 Composting principles

As stated earlier, composting is essentially a mass of interdependent bioprocesses carried out by an array of micro- and macroorganisms resulting in the decomposition of organic matter. Soil microbes oxidize organic compounds, and release essential minerals such as nitrogen, phosphorus, and sulfur, which plants need. This oxidation process is also called respiration, wherein carbon dioxide, water, and energy are produced followed by the release of minerals that are essential for the growth of plant and other soil organisms (Figs. 2-4). Carbon dioxide escapes to the atmosphere.

The breakdown of organic matter is a dynamic process accomplished by a succession of microorganisms, with each group reaching its peak population when conditions have become optimum for its activity. Mesofauna such as mites, sow bugs, worms, springtails, ants, nematodes, and beetles do

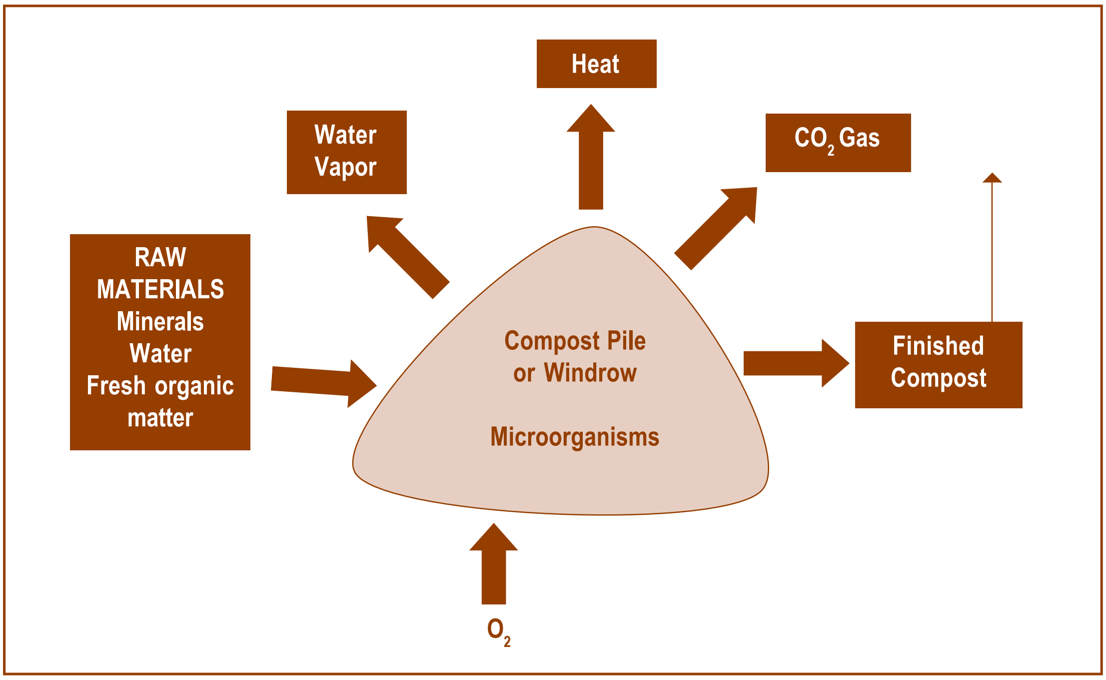

Fig. 1. Generalized representation of the composting process.

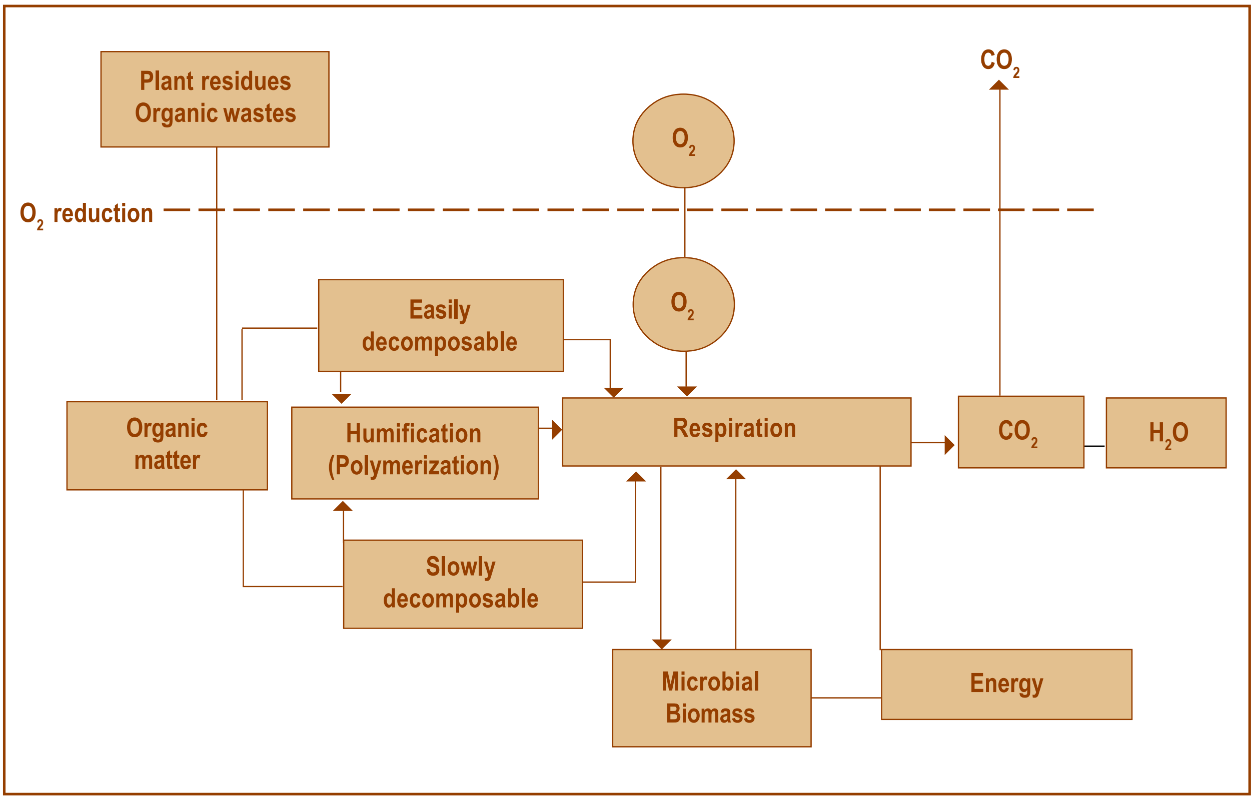

Fig. 2. Organic matter decomposition pathways for aerobic respiration. (Adapted from Reddy *et al.* 1986, with modifications)

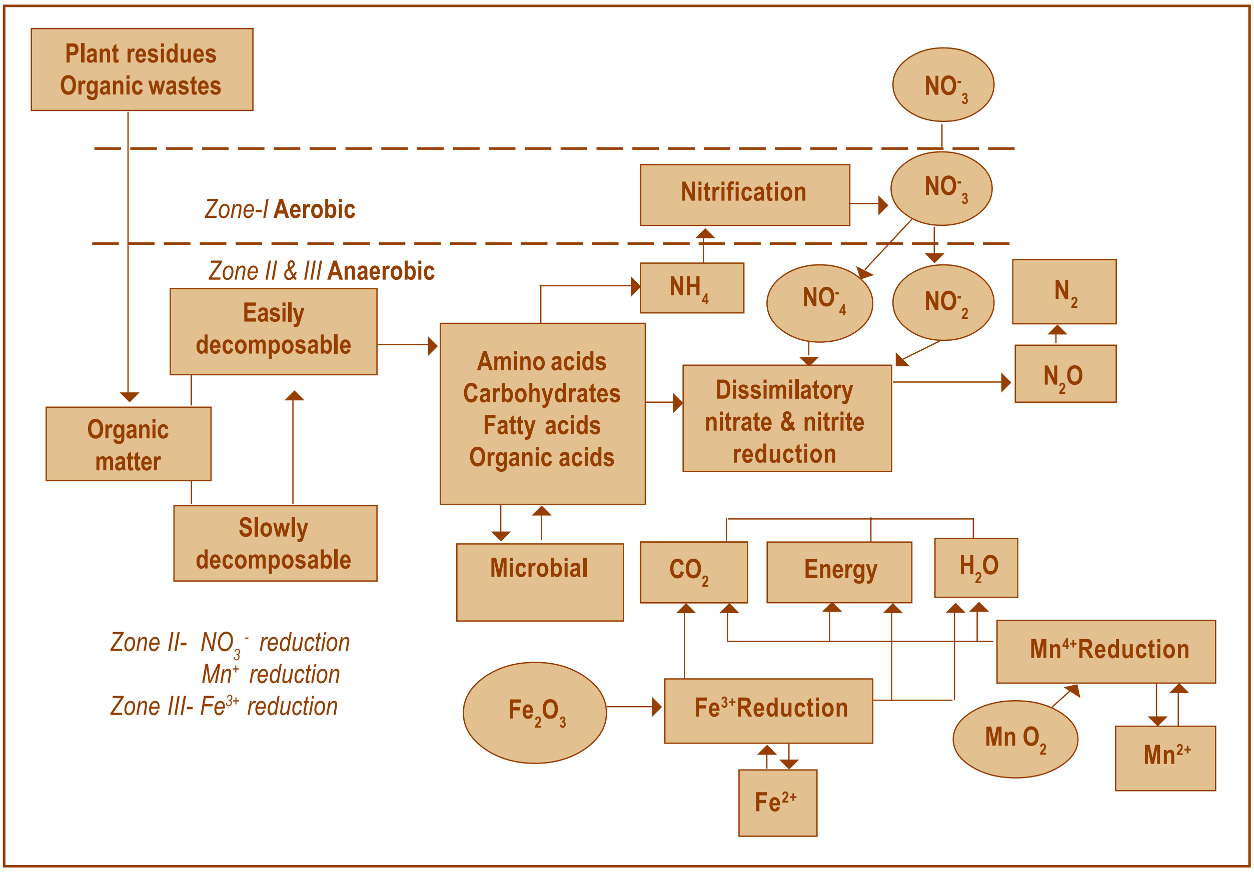

Fig. 3. Organic matter decomposition pathways for facultative respiration. (Adapted from Reddy *et al.* 1986, with modifications)

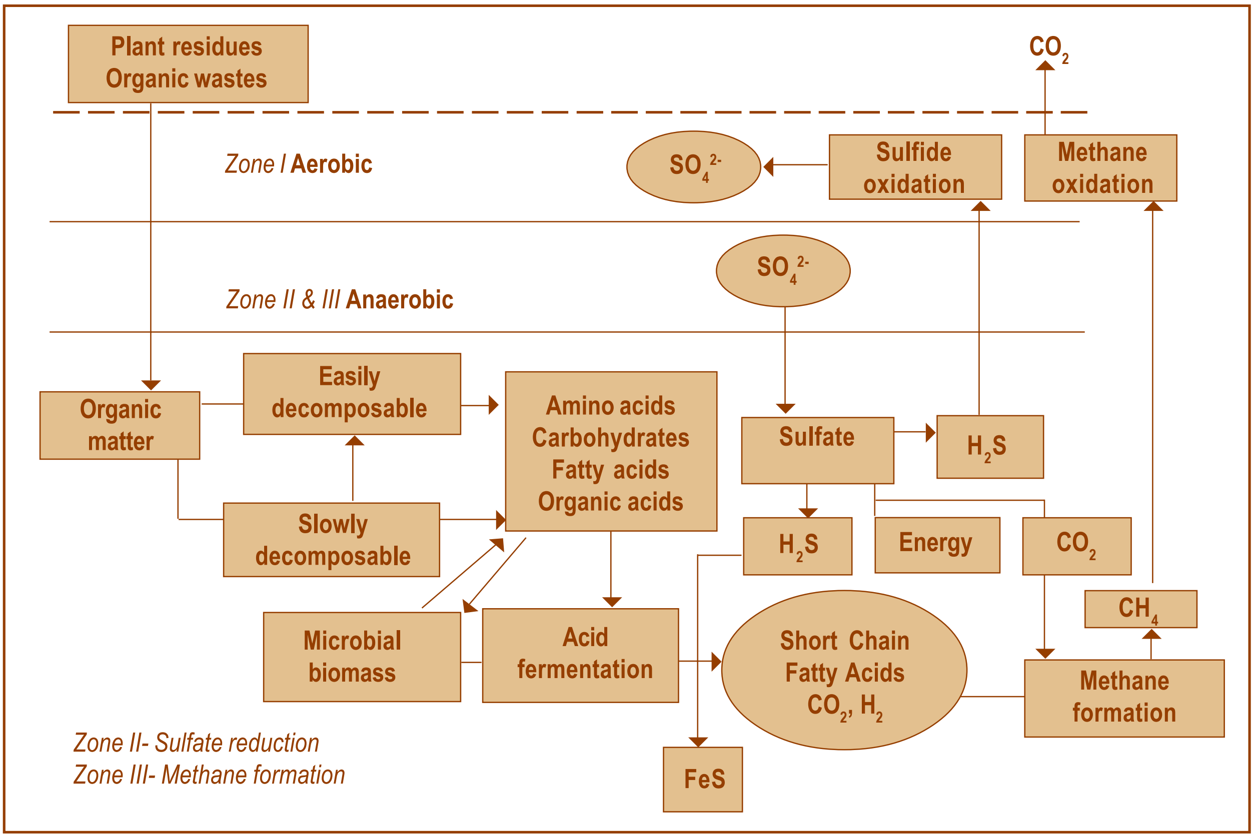

Fig. 4. Organic matter decomposition pathways for anaerobic respiration. (Adapted from Reddy *et al.* 1986, with modifications)

most of the initial mechanical breakdown of the materials into smaller particles. Mesophilic bacteria, fungi, actinomycetes, and protozoa (microorganisms that function at temperatures between 10° and 45°C) initiate the composting process. As temperature increases as a result of oxidation of carbon compounds, thermophiles (microorganisms that function at temperatures between 45° and 70°C) take over. Temperature in a compost pile typically follows a pattern of rapid increase to 49°-60°C within 24-72 hours of pile formation and is maintained for several weeks. This is the active phase of composting. The process involves the degradation of easily degradable compounds under aerobic conditions. The increased temperature kills pathogens, weed seeds, and phytotoxins. During this phase, oxygen must be supplied by either mixing, forced aeration, or turning the compost pile. As the active composting phase subsides, temperature gradually declines to around 38°C. Mesophilic organisms recolonize and the curing phase begins. During curing, organic materials continue to decompose and are converted to biologically stable humic substances (mature or finished composts). The maturing phase requires minimum oxygen and the biological processes/ activities become very slow. Considering the various stages of compost formation, the bio-oxidation phase used for the degradation of organic substances can be identified. In contrast, the synthesis phase of humic substances, started during the first phase of composting, develops and finally will be completed in the mature phase of the compost.

Curing is a very critical stage and should be kept for 1-4 months. Compost is considered finished or stable after the temperature of the pile core reaches near-ambient levels.

The processes are accomplished by different phases and are discussed below.

- Initial phase, during which readily degradable components are decomposed;
- Thermophilic phase, during which cellulose and similar materials are degraded by the high bio-oxidative activity of microorganisms;
- Maturation and stabilization phase.

The processes can also be explained in terms of two well-defined phases, namely, mineralization and humification. The former is an intensive process involving the degradation of readily fermentable organic substances like carbohydrates, amino acids, proteins, and lipids. The degradation involves high microbial activities and generates heat, carbon dioxide, and water in addition to a partially transformed and stable organic residue. When the assimilable organic fraction is utilized, some of the cells undergo decay by auto-oxidation, which provides energy for the remaining cells (Fig. 5).

The transformation process of the organic substances is completed in the second phase under less oxidative conditions, thus allowing the formation of the humic-character substance and eliminating the dense toxic compost, eventually formed during the first phase. The humification phase is carried out by specific microbes, which synthesize the complex polymers that create the energy substratum for future microbial activities.

3.3 Conditions and components of the process

The following components are necessary for the process to progress smoothly and to obtain good quality compost as the end product. Under controlled conditions, natural decomposition progresses faster and yields a quality product. The rate of composting, like the rate of plant or animal growth, can be affected by many factors. The key factors are nutrient balance (C:N ratio), moisture content, temperature, and aeration. In addition, the organic substance selected for composting should be free of any toxic compounds such as detergents, surfactants, phenolics, and pharmaceutics, which will pose health risks either directly or through their metabolic, degraded products. It is therefore very important to minimize such materials in the input source.

3.3.1 Temperature

Temperature is an important parameter affecting microbial activity, and variations in temperature affect the various phases of composting (Epstein 1997; McKinley *et al*. 1985). Temperature is produced during the composting process, resulting from the breakdown of organic materials by microbes. The organisms in composting systems can be divided into three classes: cryophiles or psychrophiles (0°-25°C); mesophiles (25°-45°C); and thermophiles (>45°C).

Cryophiles are found only during winter composting. Mesophiles, in association with thermophiles, generally predominate commercial composting systems. The temperature can range from near freezing to 70°C. Starting at ambient temperature when the components are mixed, the compost can reach 40°-60°C in less than two days depending on the composition and environmental conditions. Hence, heat is generated from within the compost medium, and applying external temperature is not necessary unless ambient temperature is far below freezing. Temperature is also a good indicator of the various stages of the composting process. The process is divided into four phases based on temperature. The first stage is the mesophilic stage, where mesophilic organisms generate large quantities of metabolic heat and energy due to availability of abundant nutrients, but gradually this will pave the way for the dominance of thermophiles. With depletion of food sources, overall microbial activity decreases and temperature falls to ambient, leading to the second mesophilic stage, where microbial growth will be slower as readily available food is consumed. Finally, compost material enters the maturation stage, which might take some months.

3.3.2 Composting microorganisms

The degradation of organic wastes is a natural process and begins almost as soon as the wastes are generated. Composting is a means of controlling and accelerating the decomposition process. Compost is normally populated by three general categories of microorganisms, namely, bacteria, actinomycetes, and fungi (Table 1). Although considered bacteria, actinomycetes are effectively intermediate between bacteria and fungi because they look similar to fungi and have similar nutritional preferences and growth habits. They tend to be more commonly found in the later stages of the composting process, and are generally thought to follow the thermophilic bacteria in succession. They, in turn, are followed predominantly by fungi during the last stages of the composting process (Fig. 5). The typical composting process is explained below.

Initial degradation involves endophytes and epiphytes associated with the plant, and microbes from the air and within raw materials. These are rapidly followed by heat-tolerant bacteria and yeasts, which probably come from airborne sources. The bacteria and other organisms take up soluble sugars and amino acids from the plant materials first. Starch is then broken down and absorbed. Subsequently, pectin and cellulose are digested. Finally, fungi digest lignin and the waxes. The most common complex carbohydrate available in the environment is cellulose. In the absence of glucose, fungi specifically target the breakdown of the cellulose in their environment, and do not waste energy on the unnecessary formation of enzymes for degradation of molecules that may not be present. Cellulose is a polymer of glucose, which is digested by a variety of enzymes. In simple terms, the enzymes may either cleave glucose molecules from the end of the polymer (exocellulase), or fragment the cellulose polymer into smaller molecules by internal digestion (endocellulase). Cellulases are especially common in soil- and plant-inhabiting fungi. Many fungi in the *Ascomycotina* and *Basidiomycotina* are able to digest cellulose. The necessary enzymes are less common in members of the *Zygomycotina*.

Lignin is commonly found in plants. Lignin is a polymer of phenyl-propanoid units (C_6C_3), with a variety of carbon-carbon and carbon-oxygen linkages resulting in a complex chemistry and structure. Various enzymes are needed to completely degrade lignin. These can be classified into two functional groups: lignin peroxidases and manganese peroxidases. The enzymes are only induced in the absence of readily available nutrients. Thus, degradation of lignin is delayed and slow. Lignin molecules are commonly found associated with cellulose. Fungi with ligninases usually digest cellulose. Fungi with ligninolytic potential are more common in the *Basidiomycotina* than in any other group. Generally, lignin is broken down slowly because only few uncommon fungi are able to degrade the organic material when the environment is highly competitive.

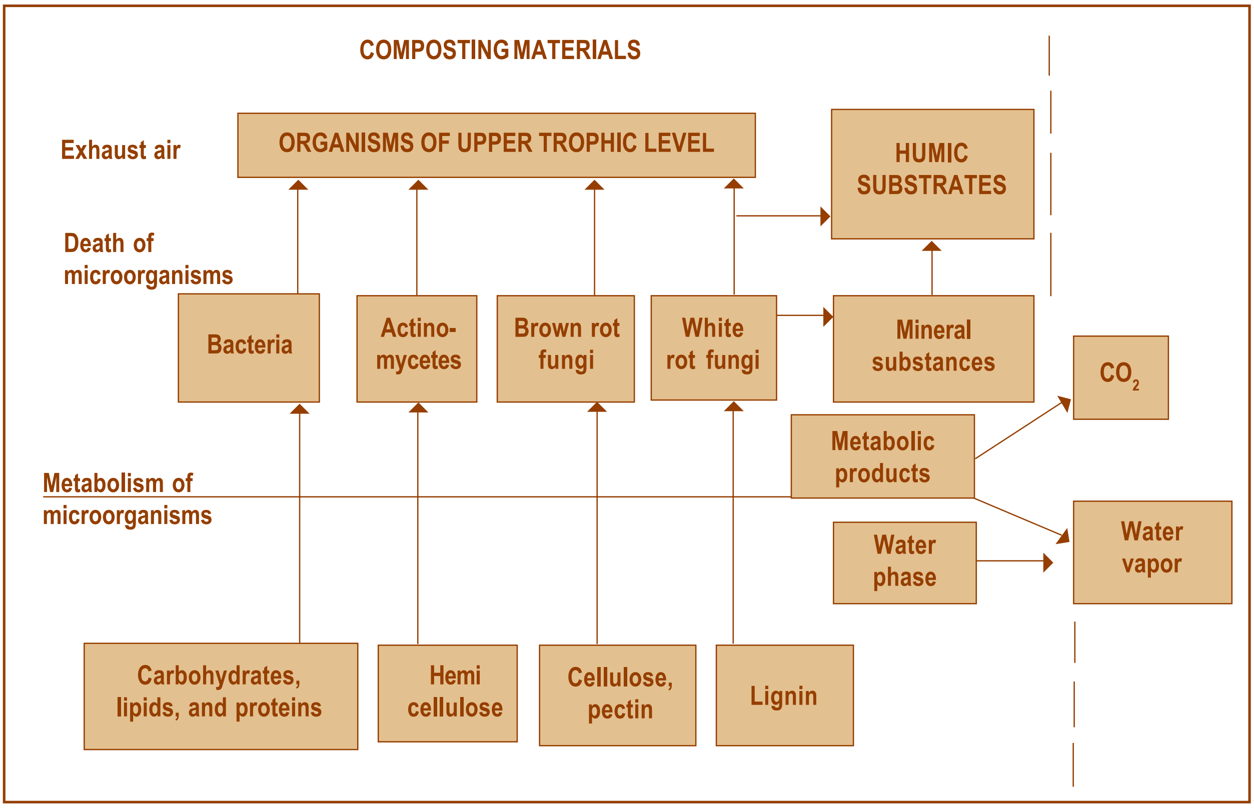

Fig. 5. Generalized food-web scheme of the composting ecosystem. (Adapted from Kaiser 1996, with modifications)

Table 1. List of major microorganisms present in compost.

Actinomycetes	Fungi	Bacteria
Actinobifida ahromogena	*Aspergillus fumigatus*	*Alcaligenes faecalis*
Microbispora bispora	*Humicola grisea*	*Bacillus brevis*
Micorpolyspora faeni	*H. insolens*	*B. circulans* complex
Nocardia sp.	*H. lanuginosa*	*B. coagulans* type A
Pseudocardia thermophilia	*Malbranchea pulchella*	*B. coagulans* type B
Streptomyces rectus	*Myriococcum thermophilum*	*B. licheniformis*
S. thermofuscus	*Paecilomyces variotti*	*B. megaterium*
S. theromviolaceus	*Papulospora thermophilia*	*B. pumilus*
S. thermovulgaris	*Scytalidium thermophilim*	*B. sphaericus*
S. violaceus-ruber	*Sporotrichum thermophile*	*B. stearothermphilus*
Thermoactinomyces sacchari		*B. subtilis*
T. vulgaris		*Clostridium thermocellum*
Thermomonospora curvata		*Escherichia coli*
T. viridis		*Flavobacterium* sp.
		Pseudomonas sp.
		Serratia sp.
		Thermus sp.

Source: Palmisano, A.C. and Bartaz, M.A. (1996) *Microbiology of solid waste,* pp. 125-127. CRC Press, Inc. 2000. Corporate Bld. N.W. Boca Raton. FL 33431 USA.

3.4 Chemical processes

3.4.1 Nutrient balance–carbon/nitrogen ratio

Nutrient balance is very much dependent on the type of feed materials being processed. Carbon provides the preliminary energy source and nitrogen quantity determines the microbial population growth. Hence, maintaining the correct C:N ratio is important to obtain good quality compost. Bacteria, actinomycetes, and fungi require carbon and nitrogen for growth. These microbes use 30 parts of carbon to 1 part of nitrogen. Composting is usually successful when the mixture of organic materials consists of 20-40 parts of carbon to 1 part of nitrogen. However, as the ratio exceeds 30, the rate of composting decreases. Further, as the ratio decreases below 25, excess nitrogen is converted to ammonia. This is released into the atmosphere and results in undesirable odor (Pace *et al.* 1995).

During bioconversion of the materials, concentration of carbon will be reduced while that of nitrogen will be increased, resulting in the reduction of C:N ratio at the end of the composting process. The reduction can be attributed to the loss in total dry mass due to losses of C as CO_2 (Hamoda *et al.* 1998). Ammonium-N (NH_4-N) and nitrate-N (NO_3-N) will also undergo some changes. NH_3 levels were increasing in the initial stages but declining towards the end (Liao *et al.* 1995). In several instances, NO_3 concentrations were less during the initial phases but gradually increased towards the end (Neto *et al.* 1987) and, in some instances, remained unchanged (Palmisano *et al.* 1993). Maintaining NH_3 concentration is important to avoid excess nitrogen losses and production of bad odor. Maintaining C:N ratio after composting is also important to determine the value of finished compost as soil amendment for crops. The final C:N ratio of 15 to 20 will be expected and the value of more than 20 might have a negative impact and will damage the crop and seed germination. The value of 10 has been suggested as ideal.

3.4.2 Phosphorus

Levels of P along with N and K will be important to determine the quality of compost, as P is also one of the essential nutrients for plant growth. A C:P ratio of 100 to 200 is desirable (Howe and Coker 1992). Phosphorus is not lost by volatilization or lixiviation during the composting process, but P concentration might increase as composting proceeds (Warman and Termeer 1996).

3.4.3 Sulfur

Presence of S in sufficient quantities can lead to the production of volatile, odorous compounds (Day *et al.* 1998). The major sources of S are two amino acids, namely, cysteine and methionine. Under well-aerated conditions, the sulfides are oxidized to sulfates, but under anaerobic conditions, they are converted to volatile organic sulfides or to H_2S, leading to a bad odor. Some compounds like carbon disulfide, carbonyl sulfide, methyl mercaptum, diethyl sulfide, dimethyl sulfide, and dimethyl disulfide might also lead to bad odors.

3.5 Physical processes

3.5.1 Moisture content

Moisture in compost comes from either the initial feedstock or the metabolic water produced by microbial action (0.6-0.8 g/g), but, during aerobic composting, 1 g of organic matter releases about 25 kJ of heat energy, which is enough to vaporize 10.2 g of water (Finstein *et al.* 1986). This will be further coupled with losses due to aeration (Naylor 1996), resulting in water loss during composting. Hence, moisture is an important factor to be controlled during composting as it influences the structural and thermal properties of the material, as well as the rate of biodegradation and metabolic process of the microbes.

The moisture content of compost should be 60% after organic wastes have been mixed. Depending on the components of the mixture, initial moisture content can range from 55%-70%. However, if this exceeds 60%, the structural strength of the compost deteriorates, oxygen movement is inhibited, and the process tends to be anaerobic. Low C:N ratio materials (e.g., meat wastes) putrefy when anaerobic, while high ratio materials ferment. Both these processes produce odor, leach nutrients, increase pathogens, and block air passages in the pile, hence they must be avoided. As the moisture content decreases below 50%, the rate of decomposition decreases rapidly. Excessive moisture in the compost will prevent O_2 diffusion to the organisms. Reduction in the moisture content below 30%-35% must be avoided since it causes a marked reduction in the microbiological activity. Moisture can be controlled either directly by adding water or indirectly by changing the operating temperature or the aeration regime. Feedstock with different moisture-holding capacities can be blended to achieve an ideal moisture content.

3.5.2 Oxygen and aeration

Aeration is a key element in composting, especially in aerobic composting, as a large amount of oxygen is consumed during initial stages. Aeration provides oxygen to the aerobic organisms necessary for composting. Proper aeration is needed to control the environment required for biological processes to thrive with optimum efficiency. Oxygen is not only necessary for aerobic metabolism of microorganisms, but also for oxidizing various organic molecules present in the composting mass. It also has the important function of controlling temperature as well as of removing excess moisture and gases. If the oxygen supply is limited, the composting process might turn anaerobic, which is a much slower and odorous process. A minimum oxygen concentration of 5% is necessary to avoid an anaerobic situation. Turning the pile regularly or by mechanical agitation will ensure sufficient oxygen supply.

3.5.3 Particle size

Decomposition and microbial activity will be rapid near the surfaces as oxygen diffusion is very high. Small particles have more surface area and can degrade more quickly. Haug (1993) suggested that, for particles larger than 1 mm, oxygen diffusion would limit in the central part of the particles, thus the interior parts of the larger particles will be anaerobic with a slower rate of decomposition. Particle size also affects moisture retention as well as free air space and porosity of the compost mixture (Nalyor 1996). Smaller particle size results in reduced air space and less porosity. Aerobic decomposition increases with smaller particle size; however, smaller particle size reduces the effectiveness of the oxygen supply. By turning regularly, this problem can be solved. The preferable size is 3 mm-50 mm diameter. Compaction can also influence the free air space. By employing grinding and sieving equipment, such problems can be avoided. At the end of the process, the bulk density of the compost would be expected to increase due to breakdown in the particle size of the material, resulting in more compact compost. But in some composting systems, where water evaporation and water loss are high, the bulk density might decrease as the materials will be dried during the composting period (Day *et al.* 1998).

3.6 Biological changes

3.6.1 Fate of pathogens during composting

In addition to the already discussed microbes, there will be many human, animal, and plant pathogens. It is not only the heat of the compost that destroys all these pathogens; it is a combination of factors including:

- competition for food from compost microorganisms;
- inhibition and antagonism by compost microorganisms;
- consumption by compost microorganisms;
- biological heat generated by compost microorganisms; and
- antibiotics produced by compost microorganisms.

There is no doubt that the heat produced by thermophilic bacteria kills pathogenic microorganisms, viruses, bacteria, protozoa, worms, and eggs that may inhabit humans. A temperature of 50°C (122°F), if maintained for 24 h, is sufficient to kill all the pathogens, according to some sources. A lower temperature will take longer to kill the pathogens. A temperature of 46°C (115°F) may take nearly a week to kill the pathogens completely; a higher temperature may take only minutes. What we have yet to determine is how low those temperatures can be and still achieve satisfactory pathogen elimination.

A compost pile that is too hot can destroy its own biological community. It can also leave a mass of organic material that must be repopulated to continue the necessary conversion of organic matter into humus. Such sterilized compost is more likely to be colonized by unwanted microorganisms, such as *Salmonella*. Researchers have shown that the biodiversity of compost acts as a barrier to colonization by such unwanted microorganisms as *Salmonella*. Without a biodiverse "indigenous flora," such as what happens through sterilization, *Salmonella* are able to regrow.

The microbial biodiversity of compost is also important because it aids in the breakdown of the organic material. For example, in high-temperature compost (80°C), only about 10% of sewage sludge solids could be decomposed in three weeks, whereas at 50°-60°C, 40% of the sludge solids were decomposed in only seven days. The lower temperatures apparently allowed for a richer diversity of living things, which, in turn, had a greater effect on the degradation of the organic matter.

Even if every speck of the composting material is not subjected to the high internal temperatures of the compost pile, the process of thermophilic composting nevertheless contributes immensely to the creation of a sanitary organic material. Or, in the words of one group of composting professionals: "The high temperatures achieved during composting, assisted by the competition and antagonism among the microorganisms (i.e., biodiversity), considerably reduce the number of plant and animal pathogens. While some resistant pathogenic organisms may survive and others may persist in cooler sections of the pile, the disease risk is, nevertheless, greatly reduced."

3.7 Chemical changes

During composting, around 50% of the organic matter will be fully mineralized, producing CO_2 and water. Protein, cellulose, and hemicelluloses are easily degradable. Many of these compounds produce organic residues, referred to as humic matter. A great deal of work has been recently conducted on humic matter from various sources. The amount of humic acid increases during the process. Increase in aromatic structures, phenolic structures, and carboxylic structures was also evidenced, whereas decrease in O-alkyl structures, polysaccharides, and amino acids was recorded with no changes in alkyl structures and carbohydrates (Chefetz *et al.* 1998).

3.7.1 Toxic intermediates

Many phytotoxic chemicals will also be produced during composting that might significantly impact on germination, plant growth, and also plant pathogens (Young and Chou 2003). In many instances, composting can also be a source of zenobiotic and hazardous volatile organic compounds. Recently, more than 20 different types of volatile organic compounds and their intermediates were recovered from the municipal solid waste composting facility (Komilis *et al.* 2004). The major phytotoxic compounds include either phenolic compounds or short chain fatty acids (Young and Chou 2003). Some of the phenolics are vanillic, *trans-p*-coumaric, *cis-p*-coumaric, *p*-hydroxybenzoic, ferulic, and *o*-hydroxyphenylacetic acids; short chain fatty acids include acetic acid, propionic acid, and butyric acid. The amount of these compounds varies with the composting method and feedstock.

3.7.2 Process control

Composting, being a microbial process, can be proceeded with a desired efficiency when the environmental requirements for decomposition are met at their optimal levels. To attain this, it is necessary to control the treat process. The important control parameters such as pH, humidity, and C:N ratio can serve as indicators for expected process failure. It is necessary to monitor the pH and maintain it between 6 and 7.5, which is an optimum range. It is well understood that during the process, this parameter undergoes considerable change from an initial pH of 5-6 due to the formation of carbon dioxide and organic acids. As the process progresses, the value will rise to 8-8.5, which is due to the decomposition of proteins and elimination of carbon dioxide. In a practical operation, very little evidence exists that pH should be artificially adjusted. The microorganisms that produce the acids can also utilize them as food after higher oxygen concentrations are established. This typically occurs within a few days after the most readily biodegradable substances have been destroyed. The net effect is that the pH begins to rise after a few days. The rise continues until a level of 7.5-9.0 is reached, and the mass becomes alkaline. Attempts to control pH with sulphur compounds are often difficult to justify because of the cost involved.

As discussed earlier, the temperature change during the process has a profound influence on the efficiency of the process. As microorganisms decompose (oxidize) organic matter, heat is generated and the temperature of the compost is raised a few degrees as a result. The temperature is increased to 60°-65°C in the second phase and the thermophilic digestion takes over. Thermophilic treatment has advantage because of the increased organic removal efficiency, improved solid-liquid separation, and destruction of pathogens. Above 60°C, the thermophilic fungus flora dies while continuing the actinomycetes' activities. The process stops when readily biodegradable material is fully consumed. The temperature then gradually decreases, which activates the reinvasion of the thermophilic fungus flora, which attacks the cellulose materials. On the completion of the digestion, the temperature returns to the ambient. The increase in the temperature favors saprophytic activities that cause the transformation of the material in composting.

Most composting should include temperature in the thermophilic range. At these temperatures, the rate of organic matter decomposition is maximum, and weed seeds and most pathogenic microbes cannot survive. It is also very important to mix the composting substances so as to ensure that all parts are exposed to high temperatures.

3.8 Mineralization

The end products of any composting process are water, organic and inorganic matter that can be used as soil amendment to supply essential nutrients to the plants, in addition to the buffering action and to increase water-holding capacity (Fig. 6).

During the composting process, the ash or inorganic component increases due to the loss of organic fraction or volatile solids as CO^2. Values of volatile solids present in feedstock are between 65% and 99%. About one-third (20%) of the organic material is decomposed into water and CO^2, but this will be dependent on the feedstock, influenced by aeration, temperature control, and nutrient levels.

3.8.1 Respiratory rates (O_2 uptake and CO_2 formation)

To ensure sufficient aeration in the compost pile, levels of oxygen consumption and carbon dioxide formation should be monitored regularly during the entire process. A 1:1 ratio (oxygen/ carbon dioxide) will be an indication of a good composting process. Usually during the process, the oxygen concentration will reflect the changes in the CO_2 evolution and temperature curves. The oxygen will decrease from its initial value of 21% to a value of 10% over the first few days as the temperature increases and the CO_2 evolution increases, but gradually the oxygen level increases and returns to the 21% level as the temperature reaches ambient. The relation between CO_2 evolution and oxygen consumption is called respiratory quotient (RQ). The RQ value of a good composting process will be about 0.9 (Atkinson *et al.* 1996).

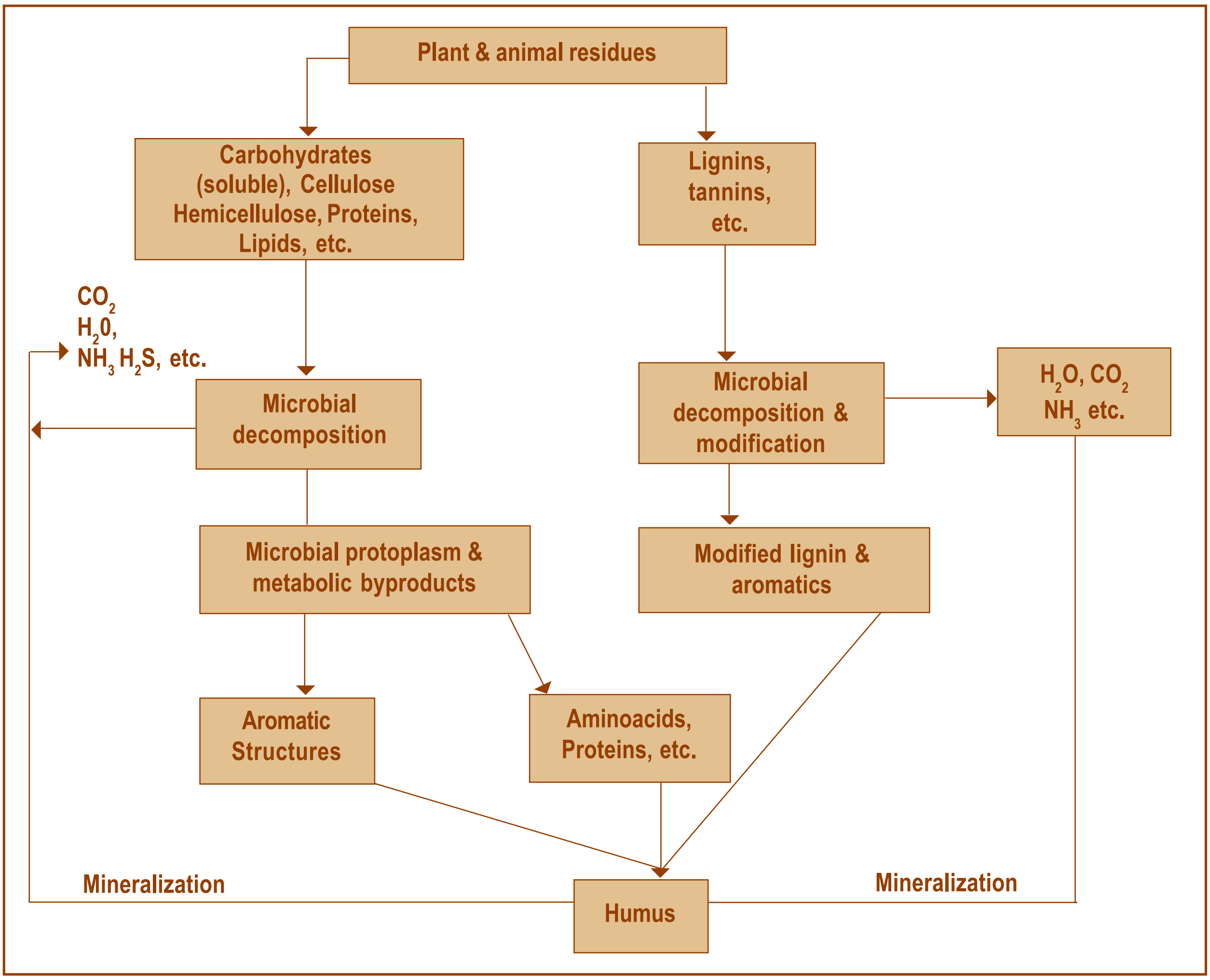

Fig. 6. Organic matter decomposition and the formation of humic substances. (Adapted from Bear 1964, with modifications)

3.9 Addition of bulking agents, shredding the substrates, and mixing

Generally, mixing of bulking agents such as woodchips, yard trimmings, bark, rice hulls, municipal solid wastes or previously composted materials is used to add a source of carbon, lower the moisture content, provide structural support, increase porosity, and favor aeration. The composting method involves the use of substrates that are fairly coarsely shredded to obtain biomasses with interstitial spaces (homogeneous empty spaces) that account for more than 25% of the total volume of the biomass to be bio-oxidized. This is done in an attempt to overcome the problem, commonly encountered with agglomerated biomasses, of anaerobic fermentation occurring during the bio-oxidation stage.

If the substrates per se are extremely fragmented and/or have a tendency to agglomerate, it is common practice to mix them with materials comprising large pieces (bulking agents). This is to create the interstitial spaces necessary to enable the air to flow and diffuse uniformly during the bio-oxidation stage. Another solution is to use systems that enable the biomass to be turned fairly frequently so as to break up the lumps and expose the resulting fragments to the air. In all these cases, the substrates to be biotransformed are prepared in such a way as to prevent the formation of agglomerates, since damaging anaerobic fermentation would inevitably occur within these.

The principal limitations of all composting systems currently in use are the following:

- Poor, uneven aeration of the biomass;
- Fluctuation of the temperature of the biomass during the bio-oxidation stage;
- Unsuitability of the system to the use of mycelial microorganisms;
- Few active contacts between microorganisms/enzymes and substrate;
- Little, if any, protection of the enzymes/microorganisms from external agents;
- Limited use of the capacity of the bioreactors.

The reasons for these limitations have been identified and studied, as follows:

1. The poor and uneven aeration of the biomass is due mainly to the fact that during the bio-oxidative process, the “structure” of the solid substrates loses its original characteristics. As a result, the substrates tend to collapse and fall in on themselves or, in the case of rigid substrates, tend to become compacted. Consequently, areas develop where the substrates become compacted, reducing and/or eliminating the interstitial spaces. The airflow is then reduced or blocked in these areas.
2. The temperature fluctuations during the bio-oxidative stage are due to the moisture initially present in the biomass evaporating during turning (designed to break up the aggregated mass and aerate it at the same time) and to conductive and convective phenomena developing in the biomass.
3. The unsuitability of the system to the use of mycelial microorganisms is due to the fact that the mycelium is damaged when the biomass is turned and so prevented from developing to the optimal degree on the surface of the substrate to be used and converted to useful biomass and/or to a particular product.
4. The low number of active contacts between microorganisms/enzymes and substrate is due mainly to the limited surface area of the substrate.
5. The lack of protection for the enzymes/microorganisms from external agents is due mainly to the virtually non-existent porosity of the solid substrates.
6. The limited use of the capacity of the bioreactors is linked to the need to mix the biomass with bulking agents and/or to turn or stir the biomass.

3.10 Odor management

Odor is the major problem associated with composting. Adopting proper management options can solve this problem. Odor is usually produced because of anaerobic conditions. Sources of anaerobic odors include a wide range of compounds, mainly ammonia, hydrogen sulphide, dimethyl disulphide, methanethiol, volatile fatty acids, amines, and several aromatic compounds.

Odor usually originates from the site where it is stored and its storage condition prior to composting. Once the ingredients are incorporated into the composting system, subsequent odor problems are associated with the anaerobic conditions. Hence, it will be very essential to bring them back to aerobic conditions. The best way is to combine ingredients with coarse, dry bulking agents to increase porosity and to allow sufficient oxygen penetration. Subsequent turning and forced aeration systems can also provide sufficient oxygen. In addition to these conventional systems, oxidizing chemicals like hydrogen peroxide, potassium permanganate, and chlorine can be used to control the odor, but care should be taken not to kill the composting microorganisms. *In situ* biological oxidation or biofilteration is also an effective method of controlling the bad odors. Commercial enzyme catalysts and different biofiltering units, which can effectively reduce the odors, are available in the market.

3.11 Composting accelerants

There are several commercially available accelerants, which are added to the composting pile with anticipated results. Here are examples of such commercially available accelerants:

CBCT is a proprietary blend of beneficial microorganisms (BM), macro- and micronutrients, amino acids, enzymes, proteins, vitamins, and minerals. The microorganisms in CBCT are selected both for their effectiveness in degrading organic matter and for their ability to grow synergistically to high concentrations. They are among the most effective decomposers in the composting process. CBCT produces odorless, hygienic, mature compost that can be safely applied to the land for improved soil structure, moisture retention, and addition of a wide range of nutrients.

CBCT initiates and accelerates the composting process. When CBCT is activated in an environment in which essential nutrients (organic materials) are present, the CBCT microbes rapidly grow to high concentrations and become the dominant organisms. These microbes provide optimized degradation for the biodegradable component in organic wastes. The end product of the process is a 100% organic fertilizer containing primary nutrients as well as trace minerals, humus, and humic acids. The by-products of the process are carbon dioxide and water.

CBCT microorganisms are unaltered microbes originally derived from the soil, which utilize organic matter as a food source. The cultures are safe for the environment and are not harmful to animals, plants, and humans. Their other benefits are the following:

- They control composting.
- They are convenient to use.
- CBCT is safe for the environment.
- CBCT is non-toxic to animals, plants and humans.
- They control flies and insects by creating a poor breeding substrate.
- The resulting compost is odorless and hygienic and can be safely applied to any soil.

Compost Treat is a scientifically developed combination of selected microbials and nutrients designed to initiate and accelerate the composting process. Compost Treat assists natural composting of organic matter and produces a more consistent, mature compost. The bacteria in Compost Treat are a selected mixture of mesophiles and thermophiles. Mesophiles grow and metabolize well at medium temperatures (70°-115°F); thermophiles do well at higher temperatures (95°-140°F). These types of bacteria are the most effective decomposers in the composting process. The viable bacteria in Compost Treat also produce several enzymes. The highly active enzymes assist in the decomposition of plant cell walls and other organic materials. Protease, amylase, xylanase, and pectinase all work on hard-to-digest components of the plant cell wall. Benefits from these include more rapid heat production; controlled, optimum composting; and convenient to use.

3.12 Conclusion

The process of composting is complex and can also happen naturally. The human wit has been successfully put in use in order to apply this technique of decomposition to convert the organic litter to useful compost, which in turn is eco-friendly. As the types of wastes utilized for the process vary in their qualities, modifications are incorporated day by day in order to achieve quality product. Further, to meet the complex nature of wastes, which contain toxic, hazardous substances that affect the end product, composting needs to be handled carefully. Since compost products vary significantly in terms of biological, chemical, or physical contaminants, the quality level of a compost product must be suited to the intended use of the product. When the process is managed efficiently, composting ensures that the finished product can be safely returned to the environment.

3.13 References

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