

Review

# Waste Management through Composting: Challenges and Potentials

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**Abstract:** Composting is the controlled conversion of degradable organic products and wastes into stable products with the aid of microorganisms. Composting is a long-used technology, though it has some shortcomings that have reduced its extensive usage and efficiency. The shortcomings include pathogen detection, low nutrient status, long duration of composting, long mineralization duration, and odor production. These challenges have publicized the use of chemical fertilizers produced through the Haber–Bosch process as an alternative to compost over time. Chemical fertilizers make nutrients readily available to plants, but their disadvantages outweigh their advantages. For example, chemical fertilizers contribute to greenhouse effects, environmental pollution, death of soil organisms and marine inhabitants, ozone layer depletion, and human diseases. These have resulted in farmers reverting to the application of composts as a means of restoring soil fertility. Composting is a fundamental process in agriculture and helps in the recycling of farm wastes. The long duration of composting is a challenge; this is due to the presence of materials that take a longer time to compost, especially during co-composting. This review discusses the proper management of wastes through composting, different composting methods, the factors affecting composting, long-duration composting, the mechanism behind it, the present trends in composting and prospects. The extraction of mono-fertilizers from compost, development of strips to test for the availability of heavy metals and pathogens as well as an odor-trapping technique can go a long way in enhancing composting techniques. The addition of activators to raw materials can help to improve the nutritional quality of compost. This review further recommends that degradable organic material in which composts slowly should be assessed for their ability to mineralize slowly, which could make them advantageous to perennial or biennial crops. Viricides, fungicides, anti-nematodes, and anti-bacterial of plant or organic sources could as well be added to improve compost quality. The enhancement of composting duration will also be useful.

**Keywords:** composting; organic fertilizer; biodegradability; decomposition; waste management

## 1. Introduction

Improper waste management is detrimental to human health. Apart from being unsightly, it causes air pollution, affects water bodies when dumped into the water, as well as depletes the ozone layer when burnt, thereby increasing the impact of climate change. Wastes are often improperly managed [1,2] using conventional methods. Wastes are burnt, disposed into oceans, waterways, and dumped by the roadsides [3]. These practices breed insects and pests, release offensive odors, are unsightly and contribute to global warming (during combustion). Organic (degradable) wastes transformation

is either aerobic or anaerobic. When transformed under aerobic conditions, compost is formed [4]. When treated anaerobically, biogas—as well as effluents that can be used as biofertilizers—are formed [5]. Composting is a safe method of waste management. Composting is an aerobic process where complex degradable materials are degraded and transformed by microorganisms into organic and inorganic byproducts [6]. The byproducts contain ‘humic-like’ compounds that differentiate them from those found in native soil, coals, and peats. Composting is a means of transforming different degradable wastes into products that can be used safely and beneficially as biofertilizers and soil amendments [7–9].

The composting process helps to protect underground water from becoming polluted compared to the landfilling method of waste disposal, which could pose a pollution threat to underground water. This is because there is a reduction of the microbes and chemical pollutants during composting. These are the pathogenic microbes present in waste which are harmful to humans. The beneficial microbes absorb chemicals such as POPs and EDRs left in the soil during composting. An elaborate explanation on this is made later in this review. The application of composting increases agricultural productivity and organic matter content of the soil [10], owing to the sufficient nutrient in the composted materials and the presence of plant growth-promoting organisms [11]. This helps to ensure food security to a great extent. Aside usage as fertilizer, compost is useful in bioremediation [12], plant disease control [13], weed control [14], pollution prevention [15], erosion control, landscaping and wetland restoration. Composting also increases soil biodiversity and reduces environmental risks associated with synthetic fertilizer [16]. Composting is started and managed under a controlled environmental condition rather than a process that is natural and uncontrolled [17]. The controlling process differentiates composting from decomposition (a naturally occurring process) [18]. As beneficial as composting is, it takes a longer time to be ready, produces offensive odor, has long mineralization time, may contain some pathogens that can withstand high temperature to some extent, i.e., thermotolerant pathogens and insufficient nutrient content. All these have discouraged farmers from incorporating them as a means of sustainable agriculture. This made the synthetic counterpart (chemical fertilizers), which is readily available, preferred to the organic source, i.e., composting. Compost should be appreciated after the comparison of the advantages and disadvantages of the two sources of nutrients. More information on how to trap odor, a rapid method of pathogen and heavy metal detection will make composting more utilized. Several works have focused majorly on the agronomic evaluation, microbial contamination, and nutrient composition of compost [19–22], leaving out the causes of long duration in composting and prospects to alleviate odor, pathogen and heavy metals. This review evaluates the challenges associated with composting and the prospects which can make composting to ensure sustainable agriculture. Therefore, this review recommends that mono-nutrients could be extracted from compost, rapid methods should be developed to detect pathogens and heavy metals, odor-trapping techniques should be sorted. In addition, the concept of slowly composting organic materials should be well explored to ascertain if they contain specific nutrients and if they could be sustainable in biennial and perennial farming, composts should also be enriched with nutrient-rich activators, antibacterial, antifungal, antiviral and anti-nematode agents.

Although composting has many reported benefits that have been mentioned above, various challenges are posed by this method of waste management, from its effects on climate change to its release of carbon dioxide into the atmosphere and the depletion of oxygen, as well as the production of offensive smells from the release of hydrogen sulfide produced from anaerobic activity. As a result of these health impacts, various regulations have been put in place by different bodies in different countries concerning the use of the method. These limitations show that this method should still be improved to address various concerns mentioned. Two major areas of improvement are the temperature regulation and the control of oxygen flow. These are key to the function of the microbes carrying out the composting process. The various microbes at each stage have the temperature at which they function, so these must be well-monitored, and they need oxygen so that the anaerobes will function less. Increased activity of the anaerobes increases the production of more carbon dioxide

and the release of hydrogen sulfide, which can cause various health issues. If these can be sorted, then opportunities abound for this process to be effective in proper waste management.

## 2. Wastes: How Are We Affected and How Should We Treat Them?

Waste is any unwanted solid, liquid, or gaseous substance [23]. Poorly managed wastes have adverse effects on humans, animals, plants, and the environment [24]. About 50% of wastes generated is organic [25–27]; thus, the proper management of organic wastes will drastically reduce the volume of pollution arising from improper waste management.

### 2.1. Effects of Wastes

Wastes affect the environment leading to severe hazardous impact on lives. Humans and animals alike are affected by these adverse effects, which can cause disease outbreak, reduction in life expectancy, and unsafe environment. Some wastes may rot, but those that do not will smell and generate methane gas, which significantly contributes to the greenhouse effect. The environmental and health impacts of wastes will be described subsequently. Wastes pollute the air, water, and soil. Air pollution includes odor, smoke, and dust. When solid wastes are burnt, greenhouse gases such as carbon dioxide and nitrous oxide are released, these lead to ozone layer depletion and greenhouse effect [28]. Hydrogen sulfide and methane are also released into the air. These substances are toxic to human lives.

Another environmental effect of waste is water pollution. It is reported that approximately 1400 people die daily due to water and water-related problems/disease [29]. Wastes that find their way into water bodies such as rivers, streams, and oceans can have a disruptive influence on the water bodies by lowering the pH and causing toxicity to the aquatic inhabitants and humans that use the water. Some of these pollutants are less soluble in water and are highly lipophilic [30]. Reports have shown the presence of toxic metals [31–33] in water bodies. Water polluted with wastes from a location could serve as receiving water in another place. Soil pollution, too can result from improper waste management. Wastes dumped indiscriminately are unfriendly to the sight, breeding disease vectors. Metals from iron, radioactive wastes, etc. are toxic to soil organisms and plants, thereby reducing crop productivity [34].

Human diseases result from improperly treated wastes that harbor disease vectors. Mosquitoes breed in stagnant water bodies, in blocked drainages, in tires that collect rainwater, in empty food cans, plastics, etc. The refuse workers as well face some hazards which include tissue damage, respiratory infection, injuries from glass, razor blades and syringes, as well as parasite infections caused by skin contact with refuse [2]. Though workers use protective measures such as gloves and nose masks, advanced automated means should be encouraged to prevent refuse workers from casualties associated with waste treatment.

In Australia, Langdon, et al. [35] studied the risk assessment for organic contaminants in composted solid municipal waste. In their study, they were able to categorize the risk levels into low, medium, and high priority, based on the health implications. From this, measures can be put in place on how the individual toxicants from these wastes can be properly and efficiently disposed of. In another study by Gangwar, et al. [36], they studied the impact of electronic waste on human health and reported the release of various toxic metals into the air, as a result, causing air pollution. Other studies have also reported the impact of these wastes on human health and the environment [37–40].

### 2.2. Classification of Wastes According to Biodegradability

Based on the biodegradability, wastes can be classified into biodegradable, moderately degradable, and non-biodegradable. Aerobic and anaerobic organisms act on biodegradable wastes as a result of speeding up their degradability rate. Some agricultural wastes such as cow dungs, poultry droppings, etc. are examples of biodegradable wastes [28]. While moderately degradable wastes are slowly degrading wastes. They have tough textured components. Examples of such wastes are wood and cardboards [28]. This is discussed extensively in the latter part of this review. Non-Biodegradable

Wastes, on the other hand, cannot be broken down biologically [2]. Examples of non-biodegradable wastes are wastes from mines, mineral materials, polythene bags, leathers, plastics.

### 2.3. Methods of Waste Disposal

Wastes could be composted or disposed of using conventional methods. Below is the classification of the waste disposal methods comprising of the conventional and composting methods.

#### 2.3.1. Refuse Disposal by Open Dump

This is a refuse disposal method where wastes are dumped indiscriminately in any available space. Waste could be disposed of on the street or the highway. This method of waste disposal should be discouraged. The wastes disposed of through this means to serve as breeding grounds for houseflies and rodents, which are vectors of certain diseases (cholera and Lassa fever). They also cause an offensive odor [2].

#### 2.3.2. Refuse Disposal by Animal Feeding

Domestic animals such as goats, dogs, and sheep are fed with wastes like yam peels, cassava peels, leaves, and leftover foods. The food wastes could be infected and thus, lead to infection of animals directly feeding on the wastes or humans that feed on those animals [41]. Some human diseases have been traced to the consumption of animals that have been previously fed with contaminated feeds [41]. For instance, trichinosis in humans has been traced to the contamination of raw garbage used in feeding animals [41].

#### 2.3.3. Refuse Disposal by River and Ocean Dumping

Wastes containing numerous chemical substances are discharged into water bodies and could render the water toxic to aquatic life as well as humans [3]. There could be biomagnification of toxic wastes in humans, which is transferred from the consumption of animals living in water bodies [42]. Some industries are located close to rivers or oceans for natural discharge of their effluents into the water bodies. They do this in a bid to save the cost of waste disposal. In some developing and underdeveloped countries, houses are built on top of water such that their feces drop directly into water bodies, which eventually carry it away. The water which flows from this source can be receiving water in another location and may serve as a source of water-borne pathogens, which could cause infection for people using the water for various domestic purposes. Such water-borne pathogens include *Vibrio* sp., *Salmonella* sp., and *Shigella* sp. [43].

#### 2.3.4. Refuse Dump by Incineration

This is the process of burning combustible wastes at high temperatures. This method reduces the volume of such wastes by 90%. The leftover from the burning of materials like ashes, glass, and metals are then disposed of in a sanitary landfill [2]. This method only reduces the size of wastes, it is not a total means of waste disposal, and it is also associated with fire disaster and the release of greenhouse gases [44]. Energy can be produced from incineration. This energy is preferable to energy produced from coal. This method could save about 2–2.6 Mt of CO<sub>2</sub> eq per year [45].

#### 2.3.5. Refuse Disposal by Deep-Well Injection

The deep-well injection method involves the deposition of wastes into the subsurface, impermeable rock layers. This method is used for toxic fluid wastes from industries [2]. Wastes such as acidic and caustic chemicals, oil field brine, and radioactive wastes from uranium processing plants are disposed of using this method. Before wastes can be disposed of using this method, the local subsurface geology of the area should be considered to prevent pollution of underground water. The disadvantage associated with this method is that it can lead to groundwater contamination.

### 2.3.6. Refuse Disposal by Sanitary Landfills

This method of waste disposal involves the use of waste as landfills. This method is also known as controlled tipping [46]. The process is carried out by spreading wastes in thin layers and compressing with a heavy bulldozer when each layer is added. When the refuse is about 3 m high, it is covered by a thin layer of clean soil and compressed again. This process is repeated until the pit is filled [2]. Wastes disposed of through this method could host pathogenic microbes or toxic chemicals that are harmful to the soil and soil organisms, as well as humans (through inhalation of polluted air or consumption of contaminated water). These adverse effects have made this method of waste disposal to be discouraged by the EU members states [47], thereby promoting other methods of waste disposal such as anaerobic waste treatment and incineration with energy recovery [48]. A landfill directive was proposed in 2001 that the EU member state should reduce waste management by landfill to 35% by July 16, 2016, and that landfill is eliminated by 2020 [49].

### 2.3.7. Refuse Disposal by Composting

Composting can eradicate degradable organic wastes. Degradable organic wastes are otherwise known as biodegradable wastes [41]. Composting is a workable means of transforming various organic wastes into products that can be safely used and beneficially employed as biofertilizers. Recalcitrant substances, polythene bags, and plastics, among others, cannot be composted. Composting is a safe way of managing organic wastes, but it is associated with odor production and release of greenhouse gases (CO<sub>2</sub>, SO<sub>2</sub>, and NO<sub>2</sub>).

The comparison between conventional and composting methods of waste management are further represented in Table 1.

**Table 1.** Comparison between composting and conventional waste management

Composting	Conventional	References
Composting helps to ensure environmental sustainability, as it helps to hold the soil particles together, thereby preventing erosion. It helps to keep wastes in a controlled environment and recycled to a useful product. They help in the bioremediation of polluted soil. They also increase biodiversity in the soil by attracting different insects, bacteria, fungi, etc. that are beneficial to the crop. They are treated in a controlled environment where they do not stay forever	Conventional waste management methods (open dump, river and ocean dumping, sanitary landfills, and incineration) pollutes the soil, air, and water bodies. They release odors and create bad sights. In addition, they cause contamination of underground water when wastes are buried.	[50–52]
They also help to suppress diseases in plants and enrich the soil	They (animal feeding, incineration, open dump, river and ocean dumping) host pest, pathogens and insects, which have a bad impact on human and animal health	[53]
They help to reduce greenhouse effects by mitigating the production of gases like methane. Though CO <sub>2</sub> is release during composting, lesser compared to other (combustion) modes of waste management	They contribute majorly to the greenhouse effect. This is as a result of the combustion of wastes	[54,55]
Reduces the volume of wastes drastically	Wastes (open dump, river and ocean dumping,) are usually piled and therefore increasing in volume of wastes	
Recalcitrant substances, such as polythene bags, plastics among others cannot be composted	It (incineration) can treat plastics, polythene bags, etc., though they pose an environmental pollution threat	[56]

## 3. Fertilizer–Environment Impact: An Overview

Fertilizer is defined as any substance of natural or synthetic origin that is added to soil to supply certain elements crucial for plant growth [57]. Fertilizer is required to be applied to the soil to replace



the nutrients taken up by crop from the land with the primary goal of maximizing productivity and economic returns [58,59].

Fertilizers may be made up of one or more essential nutrients, and this serves as a means of fertilizer classification. The fertilizers that contain only one of the major elements are called single, simple or straight fertilizers. Those that contain two or more of the major elements and trace elements are categorized as mixed or compound fertilizers [60]. Nitrogen, phosphorus, and potassium (NPK) are the major nutrients required by plants. Although micronutrients are also necessary for normal development in plants, higher concentration leads to toxicity. According to Rai, Ashiya, and Rathore [59], chemical fertilizers have been said to be toxic to soil organisms such as earthworms, which are well known to promote soil fertility as a case study. Fertilizers can be grouped into organic or inorganic fertilizer according to their source of production [61]. Organic fertilizer is a fertilizer that is produced from organic substances or materials which could be biofertilizers or composts, e.g., plants and animals remain, while inorganic fertilizer is made from synthetic or inorganic raw materials. The deleterious effect caused by the chemical fertilizers on the environment through chemical toxicity and leaching into the waterways thereby affecting aquatic life directly or indirectly has necessitated the need for safer alternatives. Some alternatives have been proposed such as the use of microorganisms, composting, among others. We try to focus on composting and how it can help in maintaining a safer environment.

### *3.1. Composting Methods*

There are different composting methods, with each method having its advantages and disadvantages. Therefore, the method that best suits the goal of the researcher and the type of material to be composted dictates the composting method to be adopted. Some of the composting methods are enumerated below.

#### *3.1.1. Indian Bangalore Composting*

The Indian Bangalore composting method was developed at Bangalore in India [62]. The method is majorly recommended for the composting of night soil and refuse. The composting is carried out by digging trenches or pits about one meter deep where organic residues and night soil are put in alternate layers [62]. The pit is finally covered with a 15–20 cm thick layer of refuse. The materials are left in the pit without turning or watering for three months. During this period, there is a reduction in the volume of the materials, and more night soil and refuse are placed on top in alternate layers and covered with mud or earth to prevent loss of moisture and breeding of flies. This type of composting takes about six to eight months to obtain the finished product [62]. This method is laborious and expensive to support.

#### *3.1.2. Vessel Composting*

In-vessel composting refers to any type of composting conducted in an enclosed area such as a container, building, or vessel. In-vessel methods depend on a variety of forced aeration and mechanical turning techniques to enhance the composting process [63]. This method is labor-intensive and expensive.

#### *3.1.3. Windrow Composting*

Windrow composting is conducted by placing raw materials in long narrow piles or windrows, which are turned regularly. The mixing of the materials allows aeration into the setup. A typical windrow composting set up should start from 3 feet in height for dense materials like manures and 12 feet high for fluffy materials like leaves [63]. It is difficult, and costly to support, but it is rapid and retains heat.

#### 3.1.4. Vermicomposting

The term refers to the use of earthworms for composting degradable organic matters [64]. Earthworms can degrade practically all kinds of organic matter by feeding on them. They can eat their body weight per day. For example, earthworms that weigh 0.1 kilogram can eat 0.1 kilogram of residue per day. The excreta of the worms—termed “castings”—are rich in nitrate, as well as available forms of phosphorus, potassium, calcium, and magnesium, which improve soil fertility [28]. The existence of earthworms in the soil promotes bacterial and actinomycetes growth.

#### 3.1.5. Static Composting

This is a traditional method of composting where wastes are composted aerobically using passive aeration (little and infrequent turnings or static aerations like perforated poles or pipes). This method is time-consuming, though it is a simple way of composting, which has low operational and capital costs compared to vermicomposting, windrow, vessel, and Indian Bangalore composting. This method simply involves the formation of a pile of raw materials and has a low requirement of labor and equipment. Aeration is based mainly on the passive movement of air through the pile, thereby degrading the organic matter slowly [63].

#### 3.1.6. Sheet Composting

Sheet composting release the benefit of decayed organic material without building a composting pile. In this method, organic matters such as leaves, garden debris, grass clippings, weeds, and vegetative food are thinly spread directly onto the soil as a mulch. The organic materials are then tilled in with a hoe, spade or garden fork and left to decay there, rather than in a heap or container. One or more layers of organic material(s) are spreads over the growing area, watered thoroughly and left to decompose until planting time. More layers of organic materials are placed at the bottom layers decompose thoroughly [62]. The method is cheap and straightforward.

#### 3.1.7. Indian Indore Composting

Indian Indore method involves a mixture of raw materials such as plant residues, animal dung, and urine, earth, wood ash, and water. All organic wastes available on a farm such as weeds, stalks, stems, fallen leaves, pruning, chaff, fodder leftovers are made into a layer about 15-cm-thick until the heap is about one and a half meters high. The heap is cut into vertical slices of about 20–25 kg for the night rest. The bedding is taken to the composting pits and filled layer by layer within a week. Enough quantity of water is sprinkled over the materials in the pit to wet them. Moisturizing of the compost is done only three times throughout the whole period of composting. The moisturizing is done on the fifteenth day after stacking the compost pit, on the next 15 days after the first moisturizing and finally after one month after the first moisturizing. This method is labor-intensive and time-consuming. It is also prone to flies, and pest disturbances and wind can lead to loss of nutrients [62].

#### 3.1.8. Berkley Rapid Composting

This is a fast composting method. Here, materials compost faster if the size is between 0.5–1.5 inches in size. Soft, succulent tissues do not need to be chopped in very small pieces because they decompose rapidly. The harder the tissues, the smaller they need to be chopped to enhance decomposition. Once a pile is started, nothing should be added because it takes a certain length of time for the initial materials to break down, and anything added has to start from the initial breakdown stage—thus lengthening the decomposition time for the whole pile [62].

### 3.2. Uses of Compost

#### 3.2.1. Increase in Soil Fertility, Crop Yield, Erosion Control, and Soil Amendment

The compound fertilizer form of compost is a welcome idea at present because of the recent campaign against the use of synthetic fertilizers. According to Majbar, et al. [65], compost helps to improve soil fertility and plant yield. Supplement of compost with synthetic fertilizer can be another route of application of compost for plant growth. Literature showed synthetic fertilizer might be more effective than compost in plant growth promotion [66]; therefore, we suggest the combined application of the two in appropriate proportions. Composts also host plant-growth-promoting bacteria, which help to increase soil fertility and plant growth.

Erosion causes the soil to lose its fertility. An appreciable amount of nitrogen, phosphorous, and potassium are lost to erosion. The use of surface-applied organic amendments has been reported to be very successful in combating erosion. Compost increases the water holding capacity, soil structure, and aggregate stability of the soil [63]. This is due to the presence of humus (stable residue resulting from a high degree of organic matter decomposition) that binds to the soil and can be said to act as soil 'glue' holding the soil constituents together [67].

#### 3.2.2. Biocontrol of Diseases, Bioremediation and Safe Waste Management

Compost serves as a biologic control for plant diseases. The microorganisms present in compost use different mechanisms in combating their pathogenic counterparts. These include competition for nutrients, parasitism, predation, antibiotic production, production of lytic, and other extracellular enzymes or compounds [68]. For instance, the control of plant wilt and damping-off diseases was reported to be countered by *Bacillus* sp. in compost [69].

Soil polluted with heavy metals can be remediated with compost. Compost has been useful in degrading chlorinated and non-chlorinated hydrocarbons, wood preserving chemicals, solvents, heavy metals, pesticides, petroleum products, and explosives in soil. Compost can reduce the toxicity of some chemical pollutants by absorbing or degrading such elements [70]. Heavy metals can be made unavailable by precipitation [71], adsorption [72], complexation [73] and redox reactions [74].

Composting is a safe way of managing degradable organic wastes. Wastes that could be dumped into water bodies, roadsides or even burned can be composted. The products from such composted wastes are used for different beneficial purposes [63,75].

### 3.3. Major Elements in Compost

For compost to be useful, it must have some elements in an optimum quantity which will supply adequate nutrients to plants. Though these elements may not be necessary if the compost is meant for landfills.

#### 3.3.1. Nitrogen

Nitrogen is one of the most important elements for plant growth when there is a deficiency of it plant growth and development is impaired. Nitrogen is a significant constituent of chlorophyll and responsible for the green color in plants. Compost has been reported to contain optimum N content required for plant growth [75]. High accumulation of nitrogen in compost fertilizer is not a common occurrence because due to mineralization, nutrients in compost fertilizer is released gradually. Excess nitrogen in plants because of fertilizer over-application can result in rapid growth, brilliant green color, and a diminished root system. In extreme cases, excess nitrogen can cause the burning of the leaf tissue and the plant's death. Deficiency in nitrogen causes a loss in the green color of leaves, stunted growth, low protein content, and yellow coloration [76].



### 3.3.2. Phosphorus

Phosphorus is a constituent of the complex nucleic acid structure of plants, which regulates protein synthesis. Phosphorus is, therefore important in plant's cell division generation of new tissue and complex energy transformations in the plant. Adding phosphorus to soil low in phosphorus promotes root growth, winter hardiness, stimulates tillage, and often hastens maturity in plants. Deficiency in phosphorus can lead to stunted growth, poor seed and fruit development, delayed maturity, and there could be a change in the color of the matured leaves to characteristic dark blue to blue-green coloration in plants. Compost has been reported to contain optimum phosphorus concentration necessary for plant growth [75].

### 3.3.3. Potassium

Potassium is an element necessary for proper plant growth. It increases plant growth, carotene, and chlorophyll contents [77]. It promotes the vigor and color of plants. Potassium is needed for the plant to create sugars. It is also essential because it helps the plant to resist disease and survive adverse weather conditions such as drought and cold. The deficiency of potassium in plants can lead to scorching and browning of tips of older leaves, which progresses to the total leaves with time. Weak stalks could also be associated with potassium deficiency. According to Kammoun, et al. [78], composts are good sources of substantial phosphorus required for plant growth.

## 3.4. Microbiology of Composting

According to Hafeez, et al. [79], the major component responsible for the biodegradation and conversion process during composting is the resident microbial community. Composting occurs by the activity of a mixed microbial community. Of all the microorganisms that have been said to be present during composting, bacteria and fungi have the highest population [80]. Two different groups of aerobic microorganisms are involved in composting, the first group is the mesophilic organisms, while the second group is the thermophilic organisms. These organisms could be bacteria, actinomycetes, molds, and yeasts, and they dominate different phases of composting. The mesophilic stage, the thermophilic stage, and the second mesophilic stage, which is known as the cooling stage, are the important phases in the composting process. The composting process could start with a mesophilic stage where the temperature lies between 20–40 °C (Figure 1). The thermophilic stage comes in after the mesophilic stage. In the thermophilic stage (40–70 °C), active decomposition takes place compared with the mesophilic stage [79]. During this stage, mesophilic organisms are killed or inactivated and the population and diversity of thermophiles and/or thermotolerant bacteria, actinomycetes, and fungi increase [81]. The second mesophilic stage is also known as the curing phase, comes after the thermophile stage; at this stage, the compost is matured.

Actinomycetes have been observed to have biodegradative activity; they secrete a wide range of extracellular enzymes [82]. They as well have the capacity to metabolize recalcitrant molecules [82]. Some lignocellulose degrading microorganisms are involved in composting. Lignocellulose comprises polysaccharides (cellulose and hemicellulose), phenolic polymer, and lignin [83]. The ability of organisms to degrade organic matter depends on their ability to produce enzymes that are needed to degrade the substrate's components (cellulose, hemicellulose, and lignin). The more complex a substrate is, the more complex the enzyme required to biodegrade the organic matter [84]. Singh and Nain [85] revealed that hundreds of fungi are also capable of degrading lignocellulose. They said that three major types of fungi are known to reside in dead woods containing lignocellulose. They are soft rot fungi, brown rot fungi, and white-rot fungi. These organisms degrade the wood components. Soft rot fungi (*Chaetomium*, *Ceratocystis*, and *Kretzschmaria deusta*) are capable of decomposing cellulose but degrade lignin slowly and incompletely. Therefore, the regulation and control of these microorganisms can help to speed up the rate of composting.

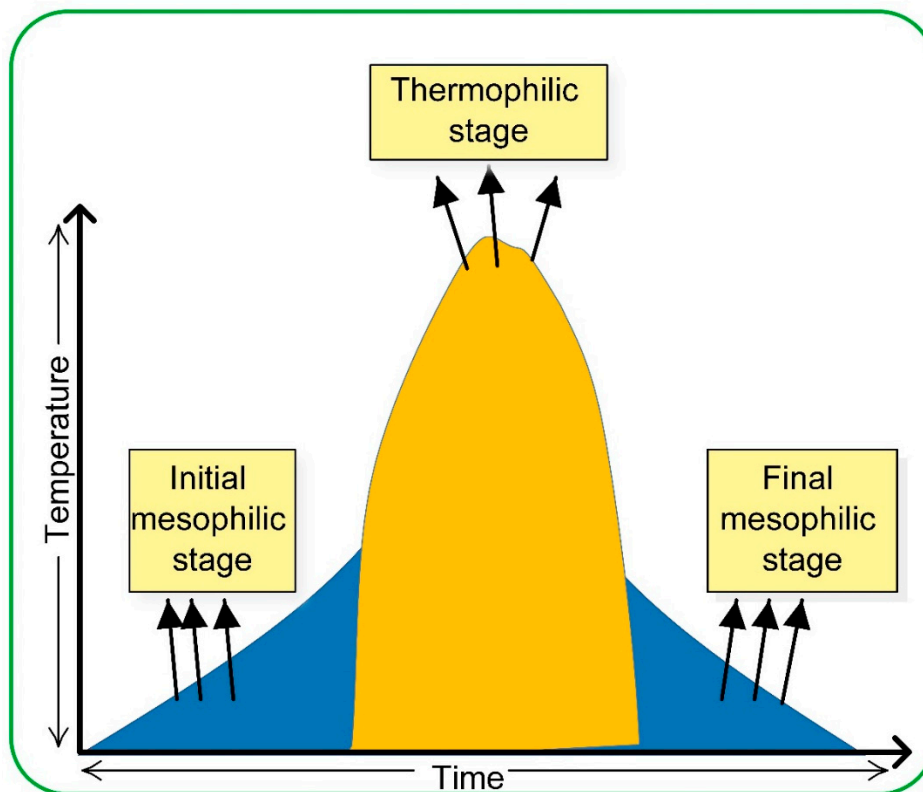


Figure 1. Temperature changes in composting.

### 3.5. Biochemistry of Composting

Compost is essentially a mineralization process during which an array of aerobic and facultative organisms degrades organic matters to inorganic compounds with a stabilized humic acid or humus as a major end product. The three major fractions of humus are fulvic acid, humin, and humic acid. Humus contains amino acids, purines, pyrimidines, aromatic substances, uronic acids, amino sugars, pentoses, hexoses, sugars, alcohols, methyl sugar, and aliphatic acids. In addition, during composting,  $\text{CO}_2$ ,  $\text{NO}_3$ ,  $\text{SO}_4$  and  $\text{PO}_4$  are released. These are released in gaseous forms in the presence of oxygen (aerobic conditions).

### 3.6. Insects in Composting

The role of insects in composting cannot be underestimated. They can either be present non-deliberately [86] or inoculated. Different insect species such as the Black Soldier Fly (BSF) [87], Japanese beetles [88], cricket [89], Milichiidae [90], and housefly larvae [91]. Of all these species, BSF is the most popular, due to its ability to degrade a wide range of substrate [92,93]. Insects degenerate large biomolecules of wastes into forms of nutrients that can be used to promote plant growth [93]. It is noteworthy to note that some insect species which have been tagged “problematic” could be of advantage during composting. For instance, stable fly (*S. calcitrans*) well known to induce weight loss, reduce milk production, and cause death in cattle and as well as infect animals and humans [90].

### 3.7. Factors Affecting Composting

The factors affecting composting include the texture of raw materials, composting temperature, moisture content, pH, oxygen, and C/N ratio.

### 3.7.1. Temperature and Carbon to Nitrogen (C:N) Ratio

Temperature is an essential factor in composting because it helps to hasten the composting process and eliminate pathogenic organisms that are harmful to soil organisms, plants, animals, and humans [79]. Microorganisms present during the composting process are classified according to the temperature at which they exist. Microorganisms growing at 20–40 °C are classified as mesophilic organisms, while those growing above 40–70 °C are thermophilic bacteria [81]. Mesophilic organisms start the composting process; they break down the readily degradable compounds of the waste. Their metabolism leads to a rapid increase in compost temperature. The volume of the wastes treated sometimes affects the temperature (heat generation); if the volume of waste is low, the high temperature may not be attained. Sometimes the temperature during composting does not rise to 45 °C, but pathogens could die when nutrients present in the composting materials are exhausted and when competitive organism excrete enzymes which are capable of destroying the pathogens.

An ideal C:N of 30 is optimum for a composting process [63,94]. When composting materials are low in C:N, air will fail to penetrate the pile, which results in anaerobic conditions and causes odor production in addition to nitrogen loss in the form of ammonia gas. In addition, if the C/N ratio is too high, the activities of microorganisms will be reduced, and the rate of decomposition will be slow [95].

### 3.7.2. Oxygen and pH

The presence of oxygen is important during the composting process. When organisms oxidize carbon for energy formation, the oxygen present is used up, and gases are produced. Without adequate oxygen, the composting process will become anaerobic, and gases (methane, carbon dioxide, and ammonia) will be produced, leading to the production of undesirable odors [63].

The pH of the materials that are composted affects the composting rate. Alkaline pH has been reported to be best for composting. When pH is acidic, composting is very slow because the microorganisms are destroyed [96].

### 3.7.3. Moisture Content, Particle Size, and Raw Material Texture

Moisture is a key factor that supports the metabolic activities of microbes. The moisture content for composting materials should be maintained between 40% to 60% [96]. The presence of moisture in compost was reported to come from either the initial water added or the metabolic water produced by the actions of the microorganism. Excess water leads to a reduction in the diffusion of oxygen, and this, in turn, reduces the metabolic activities of the organisms. Microbial cells fully depend on water for their metabolic activities. Thus the metabolism of organic molecules by microorganisms is only possible when such organic molecules have been dissolved in water. Moisture decreases as the composting process proceeds [81].

Best composting conditions are usually attained when the material's particle size ranges from 1 to 2 inches in diameter [62]. This size brings about a higher surface area, which helps to increase microbial activity as well as the composting process. The rate at which aerobic decomposition takes place increases as the particle size decreases. However, extremely small particles may reduce the oxygen movement within the pile, thereby reducing the composting rate [97]. Besides, tiny particle size encourages moisture retention and reduces airspace thus leading to a decrease in the composting process.

Degradable organic materials with hard texture, high lignin or tough texture generally composts slowly [98]. For instance, hard, textured leaves have a high tendency to compost slower than soft textured leaves. Leaves that have thorns also may take a longer time to compost because of their physical barrier. Leaves with leathery or hard texture may be due to high lignin content.

## 3.8. Waste Management: Recent Trends, Challenges, and Potentials of Composting

Technological advances have made separation processes easier, driving the methods and materials used in composting through important changes. Many primary separation tools have evolved for

better waste management through composting. The composting process has been improved with the addition of biochar as a co-compost material. This reduces the time of composting, and suggestions have been made that seed germination improves when directly placed in finished compost. The surface area of biochar is reduced by the clogging of the pores. Among the activities affected by the presence of biochar in composting are those of the microbial communities. It increases the presence of some microorganisms [99]. It influences and enhances their efficiency in fast decomposition. Properties such as high stability, high nutrient sorption, porosity, good water holding capacity, low bulk density make biochar useful in composting [100]. Biochar also balances pH and acts as a catalyst in speeding up composting [101]. The control of odor and bioaerosols released during composting will go a long way in improving the efficiency of composting. Odor release can be prevented by improving aeration in compost piles, using oxygen feedback control and aeration process with a switch [102]. The addition of bulking agents such as rice straws, sawdust, wheat straws will remove moisture from the compost pile and increase air porosity [103]. Toxic gases released during composting can as well be trapped using modern bioreactors such as the airbag bioreactors [104] and spray towels [105]. The airbag bioreactors trap and recycle ammonia, thereby increasing the nitrate content of the compost [104].

Techniques such as culture-based and culture-independent methods were used for decades to check the microbial diversity in composting. However, some limitations occur in the use of culture-dependent techniques, which prioritizes the use of culture-independent techniques. This was also found to be limited in community evaluation giving rise to the recent use of molecular methods. Molecular methods make evaluations and characterizations easier and affordable. Different outcomes from these methods have led to questions arising as to the authenticity of these methods [106]. For comprehensive reviews and research on methods in identifying microbial diversity in compost, studies of Awasthi, Sarsaiya, Awasthi, Liu, Zhao, Kumar, and Zhang [55], Yamamoto and Nakai [107], Qiu, et al. [108], Hou, et al. [109] and Ishii and Takii [106].

### 3.8.1. Long Composting Duration

Agricultural wastes such as leaves, plant part remains, and dead plants occupy a large percentage of wastes produced on the farm. Some of them hold recalcitrant compounds and low nutrients, which make their composting difficult. When such wastes are added in a composting pile, they slow down the composting rate of other materials. The different taxa of plants vary in toughness (sclerophylly) due to quantities and varieties of chemical compounds (e.g., lignin, suberin, cellulose, phenolics, tannins, irritants, and allergens) [110]. High-quality leaves (like nutrient-rich alder leaves) will decompose faster than low-quality leaves (like nutrient-poor conifer needles). High nicotine content in leaves, such as tobacco, also contributes to their elongated composting time [97]. High lignin, cutin, polyphenol, and suberin content in plant wastes elongates the composting time in a composting pile. Lignin are produced by phenylpropanoids (coniferyl, p-Coumaryl and sinapyl alcohols). Lignin is very complex to compost due to its recalcitrant nature. Highly crystalline lignocellulose is more recalcitrant when compared to the amorphous portion of the lignocellulose. Though certain bacteria and fungi (for instance, Basidiomycetes and Actinomycetes, respectively) degrade lignin over time. These species produce complex enzymes. The enzymes they produce include manganese, versatile, laccase, lignin, and dye-decolorizing peroxidase. Actinomycetes are also capable of degrading lignin [111].

Highly phenolic compounds take a longer time to compost due to their complex chemical structure [110]. Two groups of bacteria can degrade phenol. The first group of bacteria (e.g., *Arthrobacter*, *Micrococcus*, *Alcaligenes*, *Acinetobacter*, *Corynebacterium*, and *Staphylococcus*), use phenol as a carbon source while the other group utilizes other forms of carbon as their energy source. *Penicillium*, *Fusarium*, white-rot fungi, and some algae are also capable of degrading phenol.

Co-composting is the addition of materials together during composting. This is done majorly to bring about an optimum C:N, to hasten the composting process and also to improve the fertilizer quality [81,112,113]. While the co-composting, a combination of different materials may hasten or slow down the composting rate. When highly nutritious substrates are added to composts, microorganisms

become more available, and the composting process is hastened. When materials with low nutrients, high cellulose, or high lignin contents are added to a compost pile, the composting process is slowed down.

High C:N in organic materials makes them unsuitable for the microorganism to utilize, making them difficult to compost. Reduction of the C:N of such substrates using activators will be necessary to ensure a hastened composting process. Activators are sources of microorganisms that are expected to degrade the raw materials that are being composted [114]. Examples are sewage, poultry droppings, cow dung, pig dung, goat dung, etc. They are known to have a low C:N ratio, which makes composting them alone very difficult because of the odor problem associated with them [70]. Therefore, co-composting them with degradable materials having a high C:N ratio helps to attain the proper C:N ratio. Furthermore, materials that take longer time to compost can be composted separately to prevent it from slowing down the composting process of other materials. The composts made from such materials could as well be evaluated for their ability to release nutrients over a long period to a biennial or perennial crops.

### 3.8.2. Low Nutrient and Agronomic Value

The agronomic evaluation of compost is conducted to observe the effect of the composts on the growth of certain plants by assessing the yield of plants cultivated with the compost, and the results observed are used to determine the quality of the compost. Compost has been reported to increase the yield of crops due to the nutrient present in them [115–117]. In a similar manner, there have also been reports of low nutrient status in compost, which did not increase plant growth. It is, therefore very important to evaluate the nutritional value of composts and as well add nutrient-rich substrate to improve its nutritive and agronomic value.

Chemical analysis is conducted on compost to examine the quality and concentration of the elements present in them. According to the Food and Agricultural Organization of the United Nations (FAO, 2001) supported by the work of {Brinton, 2000 #764} Brinton (2000), the standards of nitrogen(N), phosphorous(P) and potassium(K) in organic fertilizer are stated that N content should not be less than 1%, while the P and K content should not be less than 1.5%. In addition, the fertilizer must supply calcium, zinc, copper, and other essential micronutrients in concentrations that range from 0.01%–0.05%.

### 3.8.3. Detection of Pathogenic Microbes in Composts

The source of the degradable materials and activators (which could be animal dung or sewage) determines the diversity and population of the microorganisms as well as the pathogens that could exist in the compost produced [118]. Pathogenic organisms like *Escherichia coli* and *Salmonella* sp. are present in composts [67,119]. According to Wu, et al. [120], *Thermoactinomyces* was also reported from mushroom compost. *Thermoactinomyces* are thermophiles that can cause “farmer’s lung”; an allergy disease of the respiratory system in agriculture workers. Composts should be properly evaluated for the microbial and chemical constituent to ensure the safety of plants, soil organisms, animals, and humans.

### 3.8.4. Composting on Persistent Organic Pollutants (POPs) and Endocrine Disruptors (EDRs)

POPs and EDRs are hazardous chemicals that are leftover in soils, water, etc., and are not easily degraded by all means available. They include polycyclic aromatic hydrocarbons (PAHs) (fluoranthene, benzo(b)fluoranthene and benzo(a)pyrene) and nonylphenols (NP) among others. POPs and EDRs affect human health negatively, therefore, the need to take them seriously. Exposure to EDRs is mainly through inhalation, contact, and ingestion of contaminated products, air, water, and soil. Plants absorbed these hazardous chemicals from soils in contact with treated waters [121]. Contaminations from water and soil have been documented in Asia, the United States and Europe [122,123]. Ingesting these plants, therefore, leads to bioaccumulation of EDRs in humans, although quantities absorbed by plants may



be negligible. Finding a means of eradicating these hazardous groups of chemicals has not been easy. Although many methods have been employed in eradicating them no accepted level of success. However, compost methods have shown to be capable of eliminating these threats to human existence. A careful application can improve agricultural and environmental sustainability [124]. The presence of microbes in compost help to absorb POPs therefore bioavailability of these POPs is very critical for their absorption. To cope well, microbes go through various adjustments such as physiological, behavioral, and morphologic to be able to fully absorb (Figure 2).

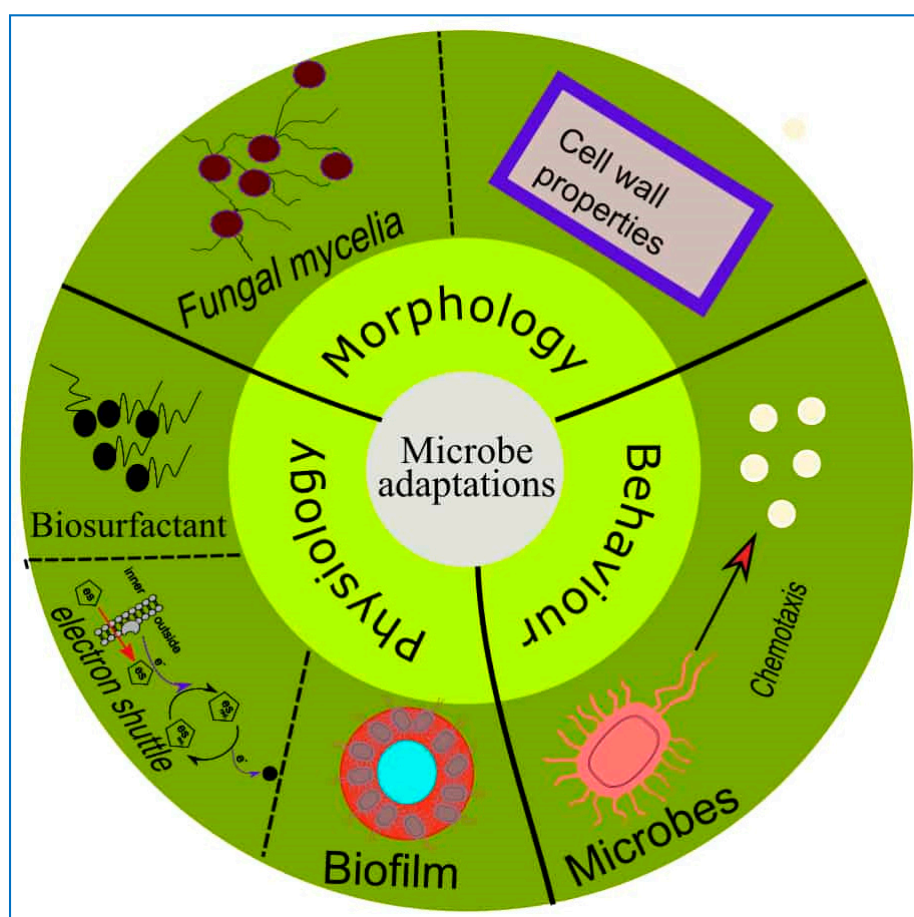


Figure 2. Morphologic, physiological and behavioral adaptations of microbes.

#### 4. Practical Implications and Future Perspectives

In the 1970 s, the aerated static pile system was developed in the United States to control temperature change due to the changing rate of aeration. Instead of the mechanical turning, a fan was used to either blow air into or suck air from it. The two main teams involved in this research were at the United States Department of Agriculture (USDA) facility at Beltsville in Maryland being run by Epstein and at Rutgers University run by Finstein [125,126]. Initially, mixtures of sludge and woodchips were considered, and in 1980, manual on the 'Beltsville aerated-pile method' was produced by the USDA and the United States Environmental Protection Agency (USEPA) [127]. Generally speaking, the system that sucks air was a good one for minimizing odors while the other one gave better control over temperature, thereby enhancing the processing time. The aerated static pile system made available a relatively low-cost controlled composting system that allowed for a range of control strategies [127,128]. This made it possible for researchers to build their controlled systems without relying on large scale commercial plants. Many researchers in the 1980 s and 1990 s used this system to test and validate their ideas. As research continues to evolve, the drive to improve the composting



process started increasing. Two important factors underlie these drives *viz* sanitization (ensuring that the material was safe to use from the point of view of pathogenic microorganisms) and stabilization (controlling the breakdown of the more readily biodegradable components in as controlled and rapid a manner as possible). Although these two factors were the basis of much research from the 1970s however, the ways in which they should be assessed were themselves subject of much research [128]. As of today, there is no common agreement on how to measure them, but, many national standards have incorporated assessment methods and limits in their regulations.

In the last 20 years, many factors have affected the increase of composting plants across the world. In Europe, however, the major forces have been the landfill directive [48], disposal costs, and financial penalties. Based on the amount of organic waste landfilled in 1995, each of the European Union states had to reduce the amount of biodegradable material in the landfill. From this, the only target date left to be met is this year 2020 [129], when it is expected that the amount of biodegradable waste in landfills should be 35% of that produced in 1995. We, therefore, suggest a few ways that composting can be improved upon for a sustainable environment and improved human health.

Insects can be involved in a controlled manner in composting. Some insects such as black soldier field larvae are capable of ingesting and degrading some organic wastes (e.g., catering wastes and manures). Composting using BSF has been documented to reduce the emission of greenhouse gases 47-fold compared to other methods of composting [130]. BSF, due to its ability to degrade a wide range of substrate, could be incorporated into the composting of recalcitrant organic wastes. Some insects, such as pill bugs and centipedes can be utilized in composting if the conditions are right [90]. The utilization of these insects in composting will help to serve as a means of conserving these important species and encourage biodiversity conservation. Perhaps, instead of them being destroyed, they can be captured and utilized in composting processes. Research can be expanded to know if insects can make specific micro or macronutrients available in compost, or they are capable of releasing enzymes that can lyse pathogens.

Besides, the odor is always a general problem in composting. The production of an odor trapping device which can be incorporated in-vessel composting or used in other types of composting methods.

Furthermore, compost majorly consists of mixed nutrients. Therefore, the ability to extract single nutrients (N, P, K, etc.) will tremendously contribute to the good health of the soil. For instance, trace elements are contained in matured compost within an acceptable limit, but when such composts are applied in the soil for bioremediation purposes, some trace elements can be added to the previously contained trace elements in the soil instead of reducing them.

Energy demand for forced aeration in composting piles and reactors is an important element in composting. The introduction of solar energy may help reduce the cost of energy. A solar composting pilot plant is already in use in San Joaquin Valley in California, USA, intending to reduce the total air emissions of the composting facility by replacing diesel generators and optimizing solar energy use to power aeration equipment [131].

Compost process management is another important factor to consider for future improvement. Indicators and sensors that can help in the understanding of the management process are necessary. The possibility of greenhouse gasses being formed during composting urges the need for proper management processes, hence, the need for more knowledge on handling of enzymes, microbial communities, substrates and processing conditions to effectively reduce the emission of methane and nitrous oxide.

For future research, in some areas where research is needed, the background of researchers will generally set their agenda in terms of the perceived importance of research in various particular areas. Albeit, there is a challenge to test at pilot-scale how easily measurable basic parameters can be used as indicators for more complex processes and to aid a proper control of composting operations. To solve this issue, there is a need for sensors that can measure gas phases, thereby reducing the need for time-consuming and tedious steps. This can increase the opportunities for compost plant improvement.

In this era of next-generation sequencing, DNA sequencing has been relatively affordable compared to what it used to be. Research should tap into this opportunity to apply sequencing techniques in enabling a proper and full understanding of the microbial communities and enzyme functions in composting. These enzyme functions include greenhouse gas production, organic waste production, and odor generation.

## 5. Conclusions and Recommendations

Improper waste management is a common practice which is not safe and can be replaced with safer waste management method such as composting. The world is tending towards improving environmental and human health. As a form of organic fertilizer, composting can play a significant role in achieving this goal. Focus on composting will cause a shift in the use of chemical fertilizer in favor of compost. This shift will invariably promote environmental and human health by reducing the number of toxic chemicals released into the environment. In the present state, a lot of awareness still needs to be done concerning the potentials of this technology for its full acceptance by farmers. Concerning the improvement technologies, some recommendations are hereby suggested to aid its improvement.

Due to the large nutrients contained in composts, it is recommended that mono nutrients should be extracted from composts. Many times, when pre-planting soil analysis is conducted, there may be a deficiency of one nutrient. The extraction of mono fertilizers from the compound fertilizer form of compost will go a long way in preventing the over-application of nutrients that are not needed. In addition, organisms that are capable of degrading complex degradable materials can be made available to farmers as inoculum to hasten slow composting processes. More researches should also be conducted to discover the odor trapping mechanism to solve the problem of air pollution associated with compost production. There should be provision for CO<sub>2</sub> trapping to prevent the release of greenhouse gases from composting.

For many years now, researchers and companies have envisaged the potential of municipal wastes as a source of raw materials. The organic components in the waste are of great interest. Over the past 15 years, we have moved from processing the organic fractions by composting majorly because of its usefulness in crop production to the use of anaerobic digestion, with the ability to provide methane as an energy source. Across Europe, for example, waste companies have moved their investments into anaerobic digestion systems as a result of government incentives made available to them. These government incentives could bring a new development such as integration of bioenergy processes (anaerobic digestion, biochar) to composting, and the byproducts of bioenergy processes could be composted to increase their value, agronomical and environmental benefits.

The ability of compost to improve soil structure and improve nutrient availability by adding to the nutrient already available has been the major factor driving its use in crop production. The nutrient focus has usually been on nitrogen, but we have recognized that mineral phosphate available for plant production is a limited resource, and its availability was reported to decline after 2035. With this in mind, using the phosphorous in compost combined with more effective and efficient use of phosphorous should be able, at the very least, to significantly extend the life of our sources of available mineral phosphate.

Furthermore, to make an effective compost, plant-derived anti-nematode, viricide, bactericide, and fungicide can be added to compost. This will help to encourage solely organic farming by preventing chemical applications. It is advisable to compost slowly degrading materials separately so that the slowly degrading materials will not elongate the composting period of other materials. More research should be conducted to know if materials that take longer time to compost also mineralize gradually. Slowly mineralizing materials could be helpful to biennial and perennial crops, as they serve as a long-term source of nutrients. Further research should be conducted on the potency of this hypothesis. Information on the nutritional content of different slowly composting leaves should be incorporated into research, as this will help in making decisions if they should be incorporated into compost or not. The high wastes from agriculture generated in developing countries (e.g., Nigeria) can

be composted instead of being combusted. Composts should always be assessed for maturity and pathogens before application to the field; this will prevent potential hazards to the environment and other living things.

Finally, more research should be carried out to discover how to enhance the duration of composting. Though the Berkley method was discovered in the past and is still the fastest composting method, the discovery of faster methods will help to sustain the composting process.

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