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Research Article

Advance in Environmental Waste Management & Recycling

Composting Technology for Municipal Solid Waste Management and Production of Organic Fertilizer

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Abstract

As a population number is increasing in high rate from time to time agriculture is need to be improved in order to feed the world population. Farmers including high investment farm land uses artificial fertilizer for increasing productivity. Despite increasing the productivity of crops it has a limitation in causing environmental pollution including eutrophication, effects on aquatic animals, soil nutrient deprivation and etc. This problem can be mitigated by using organic fertilizer with long lasting soil fertility. Composting technology plays a great role in producing organic fertilizer through microbial degradation of organic matter. The technology has become a solution for reduction for the municipal waste by recycling in to compost. There has been reported many types of composting technologies with distinguishable processes of fermenting organic materials. Compost became commercially produced and economically important in developed countries. Compost can be produced from environmentally available organic raw materials and it is environmentally friendly and suitable for sustainable soil enrichment. This paper is focused on reviewing different composting technologies, composting processes, benefits of composting technology in contrast to synthetic fertilizers.

Keywords: Organic Fertilizer, Compost, Municipal Solid Waste, Recycling

1. Introduction

Composting is the controlled aerobic or anaerobic biological decomposition of organic matter into a stable, humus like product called compost. Composting is a natural process that turns organic material into a dark rich substance, which is known to be a wonderful conditioner for soil. It is essentially similar to natural decomposition process except for enhanced and accelerated by mixing organic wastes with other ingredients to optimize microbial growth [1]. The composting process transforms waste organic materials into a nutrient rich, soil like material that can be used to improve garden and farm soils suitable for agriculture. Compost was confirmed to be superior for its agricultural application when compared to raw manure or synthetic chemical fertilizers over a long term as a means of solid waste management, water contamination reduction and soil health improvement [2]. During composting process various microorganisms are involved in the complex metabolic processes to break down complex organic compounds and produce microbial biomass in the presence of oxygen (O), nitrogen (N) and carbon (C) [3]. C and N compounds are easily transformed and used as energy and protein sources of the microorganisms, thereby producing heat, CO2, NH3, H2O, organic acids, and mature compost product at the end of the process [4].

Composting technology became the most promising technology to treat municipal solid wastes in a more economical way. For many centuries composting has been used as a means of recycling organic waste back into the soil to improve soil structure and fertility [5]. The production of quality compost from waste and other organic materials treated locally, at the source, has become an important objective for the sustainable and efficient management of municipal solid waste and the conservation of soils. Moreover, Local composting promotes better environmental conditions in the area, the creation of local jobs related to circular economy, and citizen awareness about waste reduction and recycling [6].

Composting is one means of organic waste management will not only support the development of the agricultural sector, but also reduce the waste pollution. Compost production technology is generally through conventional composting systems or composting using earthworms as an agent that can accelerate the composting rate called vermicomposting [7]. Organic raw materials used for composting could be crop residues, animal manure and agro industrial processing residues. Those residues are selected due to the highest degradability, nutritional value and fertilizing properties. Moreover, less-compressible material with beneficial structuring function such as pruning residues, wood chips, straw called bulking materials should always be added for a precise composting process. Those materials can give porosity to the mass and ensure the opportune oxygen passage for aerobic microorganism's activity which is suitable for aerobic fermentation [1]. Huge amount of municipal solid waste is produced and different waste management techniques has been practiced in the world. Landfill, incineration and recycling are the common once. Composting is the most preferred method for managing organic waste, as it applies to the masses, does not require significant areas, and capable of reducing the rate of the production of waste and producing valuable by-products in the form of compost [8].

The population size of the world needs a large amount of fertilizer for increasing world agricultural activity for rapid production of crops to feed the world. In fact, the world most agricultural production is assisted by artificial inorganic fertilizer. However, it has several influences on the fertility of the land soil and overall environmental health. This problem can be solved by replacing inorganic fertilizers by organic fertilizers through composting technology [9]. This review is aimed to assess composting technology as a means of organic waste management and compost (organic fertilizer) production.

2. Historical Background of Composting Technology

In fact compost utilization by farmers was an old experience. The results of controlled studies on both compost making and compost use to increase crop productivity were first published early in the 20th century. During the 20th century, numerous research projects were conducted and results published that firmly established the usefulness of compost in improving production of horticultural crops. The earliest composting systems did not employ mechanization, but rather relied on hand labor [10]. One of the first documented efforts on the application of composting in the management of organic residues began in India in 1933 composting has been used since the ancient times when Greeks, Romans, and Egyptians discovered agriculture production and improved the methods by using organic wastes that had decayed for a long time. In ancient times, humans disposed food wastes in piles near their tents and found that seeds of many food plants grew there. This discovery likely led to the idea that organic piles are good places for food crops to grow [4]. Indore process composting procedures were developed and it was used only animal manure. Initially, the composting process lasted 6 months or longer, during which the material was aerated only two times. It is possible that the composting piles were aerobic for only a short period of time at the beginning of the process and after each turn, and were anaerobic during most of the remainder of the composting process [11]. In Malaysia, South Africa, and others in various parts of the world conducted several studies of the Indore method with some modifications and evaluated the use of the finished compost as a fertilizer. The modifications were concerning more frequent turning in order to maintain aerobic conditions, thus achieving more rapid degradation and shortening the composting period. The investigations found at the University of California from 1950 to 1955 by Golueke and his associates, made significant contributions to the knowledge of modern composting. Europeans made a great effort for mechanizing compost as a method for the treatment and sanitary disposal of MSW [12].

3. Benefits of Composting Technology

Application of composting technology has a significant role in increasing and stabilizing the yield of agricultural products. Compost can make the soil develop in a healthy direction and keep the soil acid-base environment stable to reduce crop disease occurrence to a certain extent. This provides a theoretical basis for organic fertilizer in the prevention and control of soil-borne diseases. The application of composting technology is an inevitable choice for agriculture to move forward in playing an irreplaceable role in both agricultural production and promoting the process of sustainable agricultural development [9].

Composting helps to optimize nutrient management and the land application of compost may contribute to combat soil organic matter decline and soil erosion [13]. The recycling of compost to land is considered as a way of maintaining or restoring the quality of soils, mainly because of the fertilizing or improving properties of the organic matter contained in them. Furthermore, it may contribute to the carbon sequestration and may partially replace synthetic fertilizers [14]. Compost application to agricultural land needs to be carried out in a manner that ensures sustainable development. Management systems have to be developed to enable to maximize agronomics benefit, whilst ensuring the protection of environmental quality. The main determinant for efficient agronomics use is nitrogen availability, high nitrogen utilization in agriculture from mineral fertilizers is well established and understood, whereas increasing the nitrogen use efficiency of organic fertilizers requires further investigation [5].

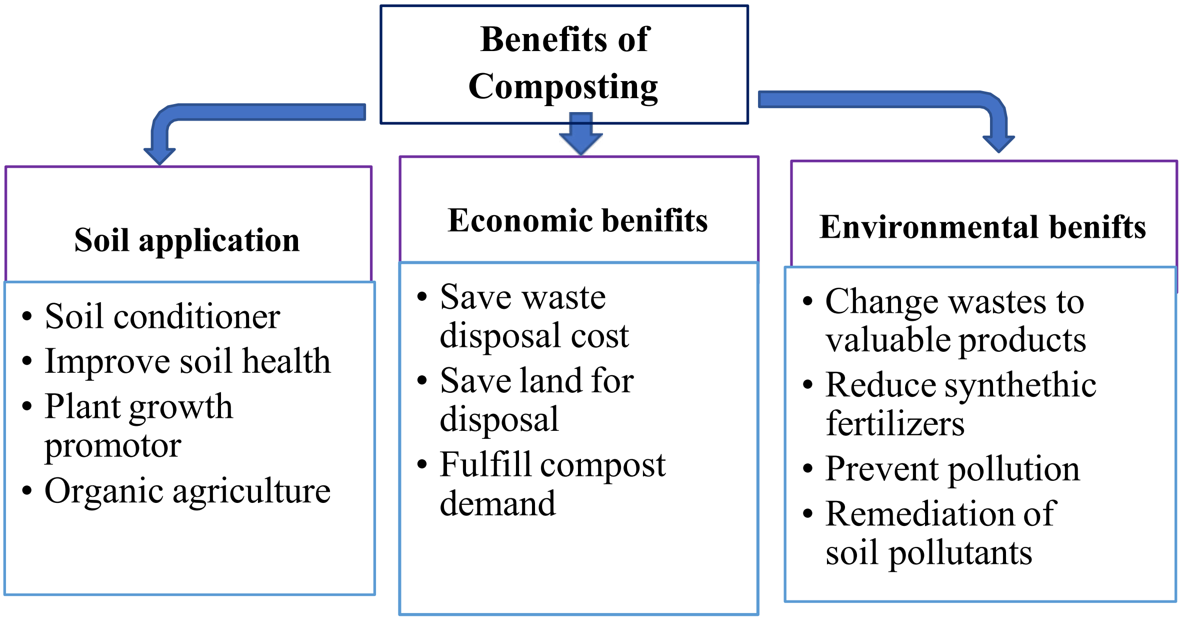

Figure 1: *Benefits of Composting* (Aburiazaiza et al., 2018) [15].

4. Conventional Composting vs Vermicomposting

The conventional composting refers to the decomposition process under natural conditions by monitoring environmental factors, without adding any types of microbes or additive materials [16]. Conventional composting is biological decomposition of biodegradable waste driven by the microorganism (bacteria, fungi, actinomycetes), in which organic matter is converted to CO_2, H_2O, NH_3, inorganic nutrients, and stabilized product (i.e., compost) [17]. It is a biological decomposition of organic waste either in an aerobic or anaerobic environment with the former being more common. The organic matters in the waste are consumed by aerobic thermophilic and mesophilic microorganisms as substrates and converted into mineralized products such as CO_2, H_2O, NH_4+ or stabilized organic matters [18]. The resultant compost is a stable, humus-rich, complex mixture that can improve physical properties of the soil. During composting process, these parameters are regulated and controlled to provide an optimum environment for the microorganisms to degrade the organic waste [19]. The conventional composting techniques require high preparation, maintenance, and equipment costs as well as occupying large areas, thus it is unsuitable for urban period of time. Moreover, it takes long-term period of 16 to 32 weeks to complete the composting process. Conventional techniques are not sustainable, since it will produce an unpleasant odour and smells, and toxic gas emissions [20].

Vermicomposting process is also a biological decomposition of organic waste to produce stabilized organic fertilizer, namely vermicompost. Unlike conventional composting, vermicomposting process involves interactions between earthworms and microorganisms to biodegrade organic waste at a faster rate. Earthworms act as the main drivers in the decomposition of organic waste by fragmenting and conditioning the substrate. In doing so, earthworms increase the surface area of the organic waste that is exposed to the microorganisms. Thus, the microbial activity and decomposition process of solid waste are enhanced. Vermicomposting results in the production of vermicompost or earthworm biomass that has low C/N ratio, high porosity, water-holding capacity and available nutrients [21].

Vermicompost is a nutrient rich, microbiologically active organic amendment that results from the interactions between earthworms and microorganisms during the breakdown of organic matter. Earthworms are the crucial drivers of the process as they accelerate and fragment the substrate, thus drastically altering the microbial activity. Earthworms act as mechanical mixers, and by fragmenting the organic matter they modify its physical and chemical status by gradually reducing the ratio of C/N and increasing the surface area exposed to microorganisms. This makes the environment much more favorable for microbial activity for further decomposition [22]. Earthworms' intestine contains a wide range of microorganisms, enzymes and hormones which aid in rapid decomposition of half-digested material and transforming into vermicompost in a short time. The vermiculture provides for the use of earthworms as natural bioreactors for cost effective and ecofriendly waste management. The following earthworm species are commonly used for preparation of vermicompost. These are *Eisenia foetida* (red worm), *Eudrilus eugeniae* (night crawler) and *Perionyx excavates* [23].

Like composting, efficiency of vermicomposting process is also influenced by several factors such as initial C/N ratio, moisture content, pH and nature of the organic waste. In comparison with the composting process, all the factors influencing vermicomposting process are also inextricably linked to the earthworm species which are used during the biodegradation process. In addition to the vermicompost, earthworm biomass is also produced during vermicomposting. After the completion of vermicomposting process, earthworms can easily be removed from the vermicompost via light, vertical or sideways separation or addition of fresh organic material to the site. The excess earthworms after the vermicomposting process ends could be used to biotransform other organic waste [24].

	Composting	Vermicomposting
Definition	The biological oxidation and stabilization process of organic matter degradation by microorganisms.	The biological degradation and stabilization of organic waste by earthworms and microorganisms to form vermicompost.
Active agent	Microorganisms	Earthworms + microorganisms
Type of process	Thermophilic (40–70°C) + Mesophilic	Mesophilic (25–40°C)
Major phases	1. Mesophilic phase 2. Thermophilic phase (45–65°C) 3. Cooling phase 4. Curing	1. Acclimatization 2. Hydrolytic 3. Curing
Characteristics	Microorganisms; major drivers of broken down organic matter.	Earthworms; crucial drivers as aerators, grinders, and conditioners, finally increasing microbial activity.
End product	1. Compost 2. Stable, humus-rich, complex mixture	1. Vermicompost + earth-worm biomass 2. Stable, homogenous, humus-rich, and peat-like material 3. Disinfected and high nutrient content
Advantages	Sorting of waste and precomposting not required, applicable on large-scale waste decomposition	Fast, economical, ecofriendly, zero-waste technology

Table 1: ***Major Features of Composting and Vermicomposting*** **(K. Sharma and K. Vinod, 2018) [25].**

5. Types of Composting Process Based on Oxygen Requirement

There are two types of composting processes based on the need for oxygen. These are aerobic and anaerobic composting processes.

5.1. Aerobic Composting

Aerobic composting is the decomposition of organic wastes in the presence of oxygen which will produce CO_2, NH_3, water and heat. This process requires moisture contents of around 60-70% and carbon to nitrogen ratios (C/N) of 30:1. Any significant variation inhibits the degradation process. Generally, wood and paper provide a significant source of carbon while sewage sludge and food waste provide nitrogen. An adequate supply of oxygen through ventilation of the waste should be required following active or passive process [26]. Aerobic microbes utilize oxygen to feed upon organic matter to develop their cell protoplasm from nutrients (mainly nitrogen, phosphorus, some of the carbon) present into the raw material of compost. Organic matter generally broken down more efficiently and completely in conditions of ready oxygen availability, largely as a result of the energy produced from the aerobic respiration and heat generated through the process [27].

Aerobic composting involves the introduction of air to break down the materials, this compost needs to be turned regularly, whether daily, twice a week or thrice a week. This turning could be done with a tumbler composter for efficiency and reduced labor. However, plenty of green matter contains a significant amount of nitrogen. As the bacteria disintegrate the high nitrogen content materials, the temperature of the compost will increase resulting in increasing the rate of decomposition [28].

The first phase of aerobic composting is pile formation. Within the first couple of days of composting, temperature rises rapidly to 70-800C. Initially, mesophilic organisms (optimum growth temperature range 20- 45oC) multiply rapidly due to adequate presence of available sugars and amino acids. Some common mesophilic microbes include Pseudomonas, Bacillus, Flavobacterium, Clostridium, Alternaria, Cladosporium, Aspergillus, Streptomyces etc [29]. Due to availability of Oxygen and plenty amount of food source these microbes grow rapidly and generate heat by their own metabolism and raise the temperature of pile. Then several thermophilic fungi (Aspergillus, Mucor, Chaetomium, Humicola, Torula (yeast)), thermophilic bacteria (Bacillus and Thermus) and few Actinomycetes (Streptomyces, Thermoactinomyces and Thermomonospora) are involved and continue the process of raising pile temperature up to 65 to 700 C or higher [30]. This necessity of this peak heating phase is that it can kill most of the pathogens and weed seeds that can contaminate the compost and later on soil and crop which are in contact of this compost [31].

5.2. Anaerobic Composting

Anaerobic composting process takes place without or little of oxygen supply. The anaerobic decomposition results the breakdown of organic compounds by the application of anaerobic microorganisms and produces intermediate compounds including methane, organic acids, hydrogen sulphide and other substances. Similar to aerobic process, anaerobic microbes also utilize nitrogen, phosphorus, and other nutrients to develop their cell protoplasm. The major difference is between decomposition of organic and inorganic compounds present into the compost pile like breakdown of organic nitrogen to organic acids and ammonia. Major portion of carbon is released in the form of methane gas (CH_4) and a small portion of carbon can be respired as CO_2 [32]. Since the major part of anaerobic composting is breakdown of organic matter through reduction process but the final product is subject to have some aerobic oxidation. There are no consequences of this oxidation process on utilization of material as it is there for only short duration [33].

Anaerobic composting follows four major stages during the composting process: hydrolysis, acidogenesis, acetogenesis and methanogenesis. The first stage is hydrolysis where the fermentative microbes breakdown the insoluble complex organic matter, such as cellulose into soluble molecules as fatty acids, amino acids and sugars. The hydrolytic activity is a rate limiting factor as it is having a significant impact on raw material with high organic content [34]. The second stage is acidogenesis, involving further breakdown of remaining complex molecules by acidogenic bacteria. In the third phase simple molecules created through the acidogenesis phase are further digested up to acetic acid, as well as carbon dioxide and hydrogen by acetogenesis. The major bacteria of this phase are Clostridium aceticum, Acetobacter woodii and Clostridium termoautotrophicum. The final phase is methanogenesis, methane is produced by bacteria called methane formers (e.g. Methanosarcina) [35].

Generally, both aerobic and anaerobic composting techniques utilize microorganisms for the decomposition of organic matter and release unpleasant gases. Many studies reviled that anaerobic composting is preferred as it has ability minimize nitrogen loss over aerobic composting. However aerobic composting has its own advantages over anaerobic composting. These are the raised temperature during aerobic process helps in killing of weed seeds and pathogens; aeration increase the decomposition rate of the organic material; shorter period of time requires for compost preparation and the intensity and number of objectionable emissions are distinctly reduced [36].

6. Phases of Composting Process

During composting process various microorganisms performed the complex metabolic processes to produce their own microbial biomass in the presence of oxygen, nitrogen and carbon. In this process additionally, the microorganisms generate heat and a solid substrate, with less carbon and nitrogen, but more stable, which is called compost [37]. During the decomposition process of initial complex organic C, N and organic matter a measurable heat is generated due to metabolic activities of microorganisms which causes temperature variations over the time period of decomposition process. The three main phases of composting have been identified based on the temperature variations besides a phase of maturation. Generally different phases of composting have been classified according to their temperature as: Hot Phase (Mesophilic Phase I), Thermophilic, Cooling or Mesophilic Phase II and Maturation Phase [3].

6.1. Hot Phase (Mesophilic Phase) (15–40oC)

The composting process starts at ambient temperature and in a few days (or even hours), the temperature rises to 45°C. Metabolic activity of various heterogeneous group of microorganisms results in an increased temperature as these microbes utilizes the N and C of the organic matter for their body assimilation. Decomposition of soluble compounds, such as sugars, produces organic acids and hence, pH can drop (to about 4.0 or 4.5). The hot phase lasts for two to eight days [3].

The first phase also called starting phase of composting in which energy rich and easily degradable compounds like sugars and proteins are abundant and are degraded by fungi, actinobacteria, and bacteria, generally referred to as primary decomposers. Depending on the composting method, the contribution of these animals is either negligible or, as in the special case of vermicomposting. It has been demonstrated that the number of mesophilic organisms in the original substrate is three orders of magnitude higher than the number of thermophilic organisms, but the activity of primary decomposers induces a temperature rise [38].

6.2. Thermophilic Phase (45–65°C)

When the temperature of the parent organic material attains temperature higher than 45°C, the mesophilic microorganisms are replaced by the thermophilic microorganisms. Thermophilic bacteria are the most common ones which has capacity to grow at higher temperature. These thermophilic microorganisms facilitate the degradation of complex organic matter i.e., cellulose and lignin. Conversion of nitrogen into ammonia by the thermophilic microbes results in pH rise of the compost pile during this stage [37]. In particular, over 60°C, bacteria producing spores and actinobacteria which are responsible for breaking down waxes, hemicellulose and other compounds of C complex, begin to develop. High temperature of compost pile during this phase helps in killing of contaminants and bacteria of faecal origin i.e., Escherichia coli, Salmonella sp. Helminth's cysts and eggs, phytopathogen fungi spores and weed seeds etc. Thus this phase is also known as hygienization phase [31].

6.3. Cooling or Mesophilic Phase II

After the exhaust of carbon and nitrogen sources from the composting material, temperature of the pile decreases again to about 40-45ºC. During mesophilic phase, polymers degradation as cellulose continues and some fungi visible to the naked eye appear. As temperature goes below 40ºC, activity of mesophilic microorganisms resumes and pH of the compost pile decrease slightly, whereas in general pH of the compost pile remain slightly alkaline. Some fungi can develop and even produce visible structures. This cooling phase requires several weeks and may be confused with the maturation phase [3].

6.4. Maturation Phase

During maturation phase the temperature of the compost pile drops to the ambient temperature level (20-30ºC) and during this phase condensation of carbonaceous compounds and polymerization occurs, which further helps in formulation of fulvic and humic acids [39]. During maturity phase the quality evaluation of compost is basically done for its maturity and stability. Compost undergo analysis of certain physical, chemical, or biological parameters quality of compost. Maturity is the indication of the degree or the level up to which a composting process is complete [40]. The evaluation of maturity of a compost can't be done by just assessing a single property, rather two or more than two parameters need to be assessed for evaluation of maturity. Plant growth potential or phytotoxicity is one of the criterion for evaluating the maturity and stability of the compost. Some of the on-site parameters that help in testing the maturity and stability of a compost are phytotoxicity, temperature, colour, odour and moisture [41].

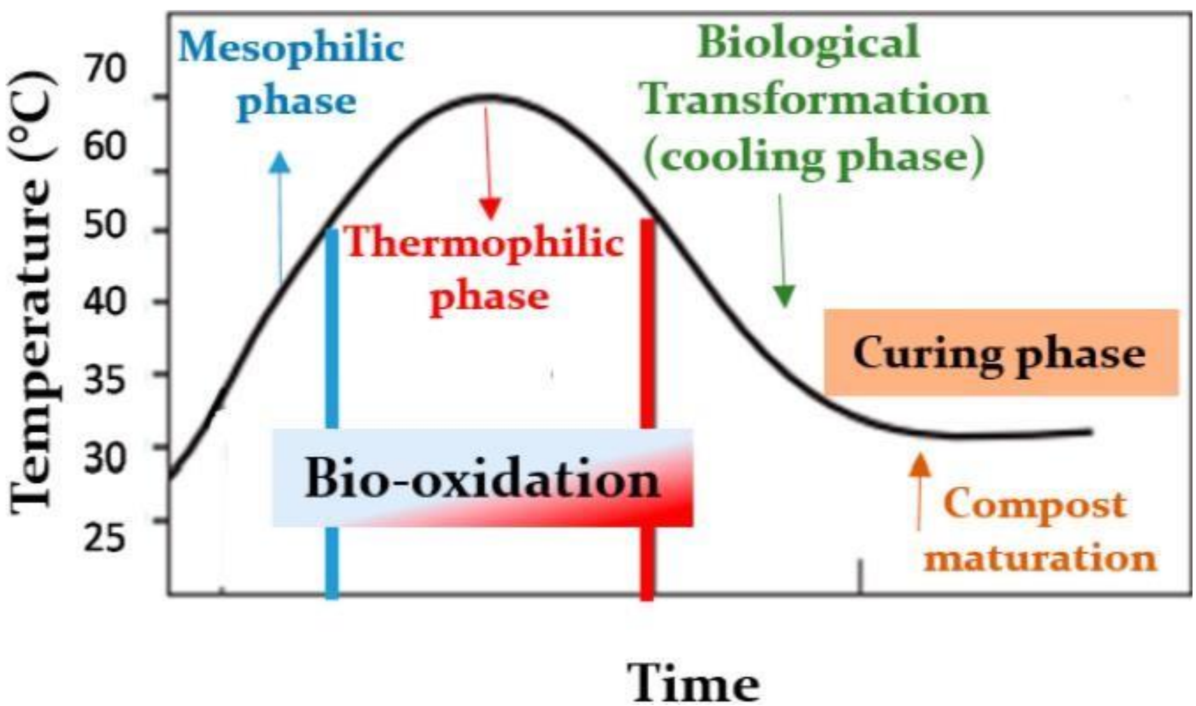

Figure 2: *Temperature Changes in Composting* (Papale et al., 2021) [42]

7. Hyper Thermophilic Composting Technology

Conventional thermophilic composting (TC) can be applied to organic solid waste treatment to achieve waste reduction, mineralization, and humification simultaneously. However, its wide application is always limited by poor efficiency, a long processing period and low compost quality [16]. Moreover, compost products from conventional composting often contain high amount of antibiotic resistance genes and mobile genetic elements that can easily be transferred to other living things reduce the efficacy of antibiotic therapies when transmitted to humans. Fermentation of organic materials under elevated temperature will suppress this problem. During the hyperthermophilic composting fermentation process temperatures reach up to 90°C which is 20- 30 °C higher compared to conventional composting has high bioconversion efficiency [43]. HTC accelerated the humification process by decreasing protein like and increasing humus substances more quickly compared to conventional thermophilic composting [44].

There are four stages for HTC, These are the temperature rising stage, the hyperthermophilic phase, the thermophilic phase and the maturation stage. Due to the development of a hyperthermophilic microbial community during HTC, this can lead to an improvement in organic biodegradation efficiency, composting efficiency, sanitation situations and pathogen killing efficiency. For the same reason, nitrification and denitrification processes can hardly take place, and organic nitrogen is either converted to ammonium or an undigested form, leading to less loss of nitrogen [45]. Compared with the TC process, the shorter composting period and higher temperature and treatment efficiency, as well as more desirable compost quality, can be achieved during HTC by inoculating the waste with hyperthermophilic microbes. Additionally, HTC can reduce greenhouse gas emission, increase the removal rate of microplastics and antibiotic residues, and achieve in-situ remediation of heavy metal-polluted soils, which greatly improve its application potential for organic solid waste treatment [16].

The other studies verified that the potential of hyperthermophilic pretreatment composting (HPC) with hyper pretreatment at 120◦C for 30 min improved sludge stabilization and explore the key mechanism for enhancing sludge humification and improved organic nitrogen retention [46].

Characteristic	HTC	TC
Maximum temperature (°C)	>80	50–70
Average temperature (°C)	70	40
Thermophilic period (d)	≥80 °C, 5–7 d	≥50 °C, 5–7 d
Composting period (d)	15–25	30–50
Low C/N (<10) for start-up	Easy	Hard
Compost maturity	GI [a] ≥ 95%	GI ≥ 65%
Pathogens inactivation rate	High	Low
Waste weight reduction (%)	52.4	45.9
Moisture loss (%)	58.9	53.4
Organic matter loss (%)	66.8	63.8
Nitrogen loss (%)	26.2	31.0
	26.1	44.2
Odor	NH_3, less	NH_3, H_2S, SO_2, more
Operation cost	Low	High

Figure 3: *Comparison of Hyperthermophilic and Thermophilic Composting* (Wang Shaofeng and Wu Yuqi, 2021) [16].

8. Factors Affecting Composting

8.1. Temperature

Rate of organic matter decomposition depends on the temperature of the raw material. The decomposition starts in a temperature range (40-65°C). Temperatures higher than 50°C should be maintained for at least 3-4 days to destruct the harmful organisms such as plant pathogens, weed seeds and fly larvae. It is reported that temperature as high as 85°C doubles the decomposition rate than at 55°C. However, this high temperature is fatal for a certain microbial population. Hence, most of the modern composting plants are operating in thermophilic temperature range (55-65°C) [47].

8.2. Carbon to Nitrogen (C:N) ratio

To perform effective composting process, C:N ratio must be in the range of 20:1- 40:1 (on dry weight basis). Carbon and nitrogen are the source of energy and protein production, respectively. A C: N ratio lower than 20:1 leads to the formation of NH3 due to the fully utilization of available carbon that will cause odour nuisance. If C:N ratio exceeds 40:1, decomposition of organic compounds retarded due to insufficient nitrogen. The most preferred range of C:N ratio is 25:1 to 30:1 [48]. In case, raw material has insufficient or excessive ratio, supplement material is added to fulfill the requirement. For instance, saw dust can be added to enhance the C:N ratio of the feed stock having vegetable waste as raw material. Similarly, poultry manure can be added to wood or paper waste to bring the ratio within prescribed limits [49].

8.3. Moisture Content

The raw material should contain sufficient moisture for adequate microbes functioning. The prescribed limit of moisture content is 40-65% (preferred range 50-60%). Moisture content below 40% hinders microbial activity and thus makes the aerobic decomposition of solid waste difficult. On the other hand, moisture content more than 65% will reduce the air concentration in the pores and pose danger of establishing the anaerobic conditions [49].

8.4. Particle Size

Nevertheless, aerobic decomposition of fine or dense particles occurs at faster rate, it may cause obstruction in oxygen movement through the raw material. Hence, a bulking agent like straw, paper and cardboard is added to the raw material to facilitate free aeration. In general, preferred particle size range depends on the particular feedstock, pile, size and weather conditions. However, it is suggested that the average particle diameter should be in the range of 0.3-5.0 cm [50].

8.5. Aeration

Aeration refers to the amount of oxygen in the system, and it is the key environmental factor. Organisms present in the compost pile can degrade organic materials either aerobically or anaerobically. Many organisms including aerobic bacteria need oxygen to produce energy, grow and reproduce. The types of organisms active in the pile and the metabolic process used to degrade organic compounds are related to the oxygen content of the system. Aerobic degradation is preferred for rapid composting [48]. Sufficient oxygen supply must be ensured for aerobic decomposition of raw material. Anaerobic conditions can be developed in oxygen deficit environment that will cause bad odour and production of $CH4$ gas. Oxygen can be replenished in the waste material either by turning or through perforated pipes [32].

8.6. Time

Total organic matter decomposition period depends on a number of factors such as nature of the contaminants, temperature, oxygen availability, particle size, moisture content etc. For example, generally period of active composting for dairy cattle waste is around 10-14 weeks. This stage is followed by 3-4 weeks curing period [51].

8.7. PH

The pH of most of the composting substrate is slightly acidic. At the early stage organic acid is going to be produced and hence pH goes again acidic 4.5-5.0. As the decomposition process get over and temperature reduces and pH of the composted mass start increasing. It gets converted into alkaline pH 7.5-8.5 from acidic pH. The pH of the mature compost is therefore assumed to be 7.5-8.5 [52].

9. Types of Composting Technologies

Compost can be produced by applying different composting technologies. These are windrow composting, aerated static composting and vessel enclosed composting.

9.1. Windrow Composting (Agitated Pile)

Windrow composting is the most widely used composting technology in which different food wastes, municipal solid wastes, plant parts and manures of animals are decomposed into humus (soil conditioner) through the microbial activity. Primarily the required waste is collected from any source and dumped until the required amount of raw material is obtained. Windrow composting requires frequent turning by specialized equipment. The elongated piles, called windrows, are naturally ventilated as a result of diffusion and convection. Despite the simplicity of this technology, it presents major constrains that should be emphasized, such as high labor cost, long lead time and taking up of valuable land space [53].

Appropriate site area should be selected and cleaned properly from the grass, weeds and stones and ready for the required amounts of windrow composting piles. The size of the site is depending on the amount of the solid waste obtained. Then the corresponding windrow composting piles have to be prepared of defined dimensions. After preparing the windrow composting pads, they need to cover with plastic sheets. The main purpose to place plastic sheets into composting piles is to avoid the leaching and percolation of applied water, nutrients and filling waste. Food waste has to be shredded to gain minimum size which is necessary for the rapid and quick decomposition of food waste during composting operation [54].

9.2. Aerated Static Pile

Unlike turned windrows, the static piles are not turned or agitated. In the aerated static pile composting technology, the aeration system is formed by a network of perforated pipes connected to timer-controlled blowers. The blowers provide direct control of the process, maintain an oxygen level of 5-15%, and allow working with larger piles without turning. In order to prevent heat loss from the upper layers and deliver a minimum odor management, the piles are frequently covered with a layer of matured compost. Once the pile is properly formed and the air is supplied in sufficient quantity, the active composting period may be completed in three to five weeks [53].

9.3. Enclosed or in Vessel Composting

This is the novel and well-advanced technology which is gaining the interest of many researchers and composters. The whole system is closed inside a container or a tank. There is an outlet exhaust for emission of harmful gases and odor which get filtered through biofilters fitted at the exhaust unit. The aeration is provided either by rotation of the container or through aeration pumps, to maintain steady air flow rate. Since the whole system is enclosed, moisture is conserved within itself thus reducing the dependency on water. The ideal moisture content of 40-60% can be maintained easily. A thermophilic condition which is favorable for aerobic thermophilic bacteria can be achieved due to the prevention of heat loss. Since the inside environment is not affected by the exterior conditions in-vessel composting can be taken up in any part of the world, irrespective of the climate of the place [55]. In-vessel composting can process large amounts of waste without taking much space or cost as other solid waste management methods in short time for maturity. In this technology there is a control system for temperature, exhaust air, moisture and aeration system when compared to other systems of composting [56].

10. Microorganisms in Composting

Composting process is established through the decomposition of organic materials by the involvement of efficient microbes. Efficient microbial strains produce enzymes that are critically important for the degradation of organic materials, including cellulose and lignin. Few known potent cellulose producing bacteria include; Cellulomonas, Pseudomonas, Bacillus spp. and Thermoactionmycetes. Similarly, fungal species Aspergillus, Trichoderma, Sclerotium and white- rot fungi, produce extracellular enzymes accountable for cellulose and lignin degradation during composting [57]. Addition of efficient microbes to composting process will reduce the time of compost maturity, reduced the odorous emissions and plays role for production of pathogen free compost. Furthermore the application of microbes will minimize nitrogen loss and increase the overall quality of compost. The results showed that actinomycetes inoculation also accelerated production of the key enzymes, including CMCase, Xylanase, lignin peroxidase etc. and increased the rate of organic matter degradation [58].

The compost environment consists of complex organic materials that form a suitable habitat for a diverse microbial community. Along the process, variations produced in a microbiome depend extremely on composition of the raw materials and nutrient supplements, environmental conditions (ambient or trial) and interactions among all these factors. The substrates utilized and the microbiota involved within the process have a great influence on the quality of the formed compost [57]. Few studies successfully assessed the impact of EM inoculation on the humification of lignocellulosic and cellulosic waste. Biodegradation of organic matter and lignocellulosic waste with optimized inoculation strategy, resulted in enhanced mineralization of organic carbon and accelerated lignocellulose degradation, achieving a good humification in waste [59].

11. Volatile Greenhouse Gas Emissions from Composting

Composting is an environmentally friendly waste treatment process where organic matter is biologically degraded. Although compost has agricultural and environmental benefits, it is considered to be the sources of GHG emissions to the atmosphere during the composting process contributing to global warming. GHG emissions are highly dependent on the waste type and composition. The composition and characteristics of the feedstock are key parameters for the design and operation of the composting facilities and for the final quality of the compost [60].

In both aerobic and anaerobic composting processes some unpleasant odours emitted from the composting materials which are generated due to rapid microbial degradation of complex organic matter into simple compounds. The extent and intensity of odours emission are high in aerobic composting as compare to anaerobic composting but rapid turning and frequent supply of oxygen in aerobic composting decrease the chances of evolution and emission of unpleasant gases whereas, because of closed systems and low level of oxygen causes higher formation and emission of unpleasant gases in anaerobic composting [61].

During composting and vermicomposting processes greenhouse gases like CO_2, N_2O, and CH4 and NH3 emissions will be resulted in different phases of composting. Many researchers have reported that most of the CH_4, CO_2 and NH3 emissions are recorded during the start of the thermophilic process [62]. CO2 is among the primary heat-trapping greenhouse gas that contribute the most to global warming. The rate of CO2 emissions is a sign of rapid total organic matter breakdown and high microbial activity. The CO2 released during composting is created from the decomposition of plant material and it is regarded as neutral in terms of its GWP [63].

Methane is the second-largest produced GHGs next to CO_2 and it has GWP with 28 times greater than CO_2. CH_4 generation will be enhanced by low aeration rate and it will be minimized by increasing the aeration rate through oxygen supply [64]. N_2O is another common GHG produced during composting process. Denitrification is a primary source of N_2O emissions from composting. It has been reported that as the composting duration is prolonged, N_2O emissions during the cooling phase might be exceeded during the second mesophilic phase [65]. When the organic material is being decomposed, carbon is provided as a source of energy for denitrification and affects the Oxygen (O_2) availability and promoting N_2O production [66]. The higher emission of N_2O in thermophilic compost is due to the arrangement of the pile. Meanwhile, in vermicompost, the earthworms destroy the arrangement or stratification and homogenized the material resulting in a 53 % lower emission of N_2O [67].

Generally, the emission of GHGs is affected by the factors aeration, temperature, C/N ratio, moisture content and pH. GHG emission will have the following greenhouse effects on environment, including global warming, acidification of the ocean, melting of glaciers and ice sheets and rise in sea level [62].

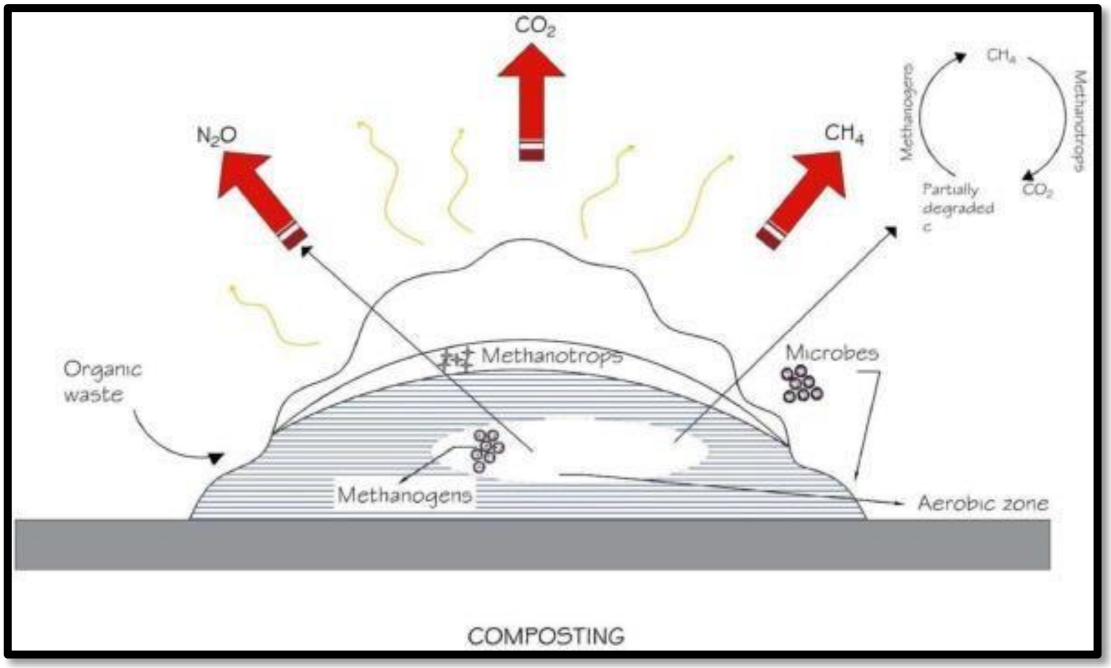

Figure 1: *Emission of GHGs During Composting.* N.Yasmin et al., 2022 [62].

12. International Marketing of Compost

Despite the obvious advantages, the marketing of compost is in many cases challenging. Potential users may not be familiar with the properties of the compost product, or simply not trust its composition and effects. Also, competition with alternative soil improvers/fertilizers is a critical issue [68]. A key to the success of a composting operation is a marketing or distribution program for compost products. To develop long term markets, the products must be of consistently high quality. Other essential marketing factors include planning, knowledge about end users, following basic marketing principles and overcoming possible regulatory barriers. Compost characteristics desired by end users vary with intended uses, but most compost users look for the following elements (in order of importance).

• Quality (moisture, odor, feel, particle size, stability, nutrient concentration, product consistency, and a lack of weed seeds, phototoxic compounds and other contaminants).
• Price (should be competitive with other composts, although high quality and performance can justify a higher price).
• Appearance (uniform texture, relatively dry, earthy color).
• Information (products benefits, nutrient and pH analysis, and application rates and procedures).
• Reliable Supply [5]

In compost marketing there are typical competing products for compost including: fertile topsoils, animal waste, human faecal sludge, nutrient-rich waste from industrial processing and mined decomposed landfill material. Compost in some parts of the world has got a great attention and become an intensive area for research. It could be prepared based on the demand of the users either for green houses or farm lands. For long distance transport it can easily be bagged and sold with a unit price [69]. Farmers producing compost will choose to use it on their own land to improve soil health and provide nutrients. Other farmers will establish markets for the compost they produce, generating income, or offsetting manure management expenses. Marketing compost can be a formidable challenge for many farm managers, in the context of already busy schedules. Often, a producer does not have enough time, lacks marketing knowledge [70].

13. Conclusion

Composting technology plays a major role in mitigating environmental pollution through utilization of wastes from household and agricultural industries. It is irreplaceable process for recycling solid organic wastes in to environmentally friendly organic fertilizer through different composting processes. Microorganisms like bacteria, fungus, actinomycetes and earth worms play a great role for fermentation of organic material in to compost either aerobically or an aerobically.

Compost is an important soil conditioner having many environmental benefits than inorganic fertilizer. Such as, preventing soil erosion, increases soil fertility with long lasting effect, reduce environmental pollution, remade the degraded land and others. Compost can easily be produced from environmentally available raw materials including municipal solid waste, animal manure, residues from human and animal feeds with simple technique in small space. Composting technology should be the future focus of research for commercial production and international marketing. Because the land we live is highly degraded and aquatic biomes are highly affected through eutrophication due to the utilization of inorganic fertilizer. Furthermore inorganic fertilizer is not affordable for farmers in properly ways. These problems could be solved when future world is targeting on the utilization of organic fertilizer.

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