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Composting Unearthed: A Comprehensive Review Of Challenges, Historical Evolution, Prospects, Applications, And Processes.

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Abstract:

Composting is the biological degradation of protein, amino acid, lipids, carbohydrates, cellulose, and lignin through the presence of oxygen and an adequate supply of nutrients (N.P.K) for a microorganism that produces heat, CO_2, H_2O, NO_3, SO_4 as a byproduct of the exothermic reaction and having a final product of new cells generation and a stable soil-like substance called compost. New cells that are produced become part of the active biomass involved in the conversion of the organic matter, and when they die, they become part of the compost. This comprehensive look into the historical evolution of the composting process underlines the challenges in technology development and process modification. Market analysis and the challenges in developing nations cannot also be underestimated as they provide adequate motivation for functional industries and business expansion. The prospects and the demand for compost as the world moves toward sustainable development through greener activities that reduce the global footprint and environmental impact of agriculture activities and the lifestyle of the individual. As composting requires monitored stages, the necessary parameter and their challenges are further investigated and analyzed in this review.

Keywords: composting, environmental sustainability, degradation, food waste

1.0 Introduction

The global population reaches 9 billion, thus a need for industries and commercial activities to meet the daily demands of individuals. The provision of these demands' accounts for the generation of huge waste. Global trash creation is around 2.01 billion metric tons of domestic waste annually, with at least 33 percent of it highly conservative, which presents environmental concerns if not treated effectively and in an ecologically safe manner. With an ever-increasing population, Global trash creation is expected to raise to 3.40 billion tons by 2050, which will exceed the population growth during the same period. The daily per capita generation is expected to increase by 19 percent from 0.74 kg in 2050. With this growing generation rate, there is a need for a holistic and environmentally friendly approach to mitigate the many consequences attached. The emergence of new technologies and approaches in municipal waste management is crucial. Food waste (FW) are waste collected from the food industry supply system. Daily, approximately 1.13 million tons of food waste are discarded globally.[1]. At each step in the food distribution process, excess production of edible food should be prevented and reduced, with unusable or expired food being used as animal feed. [2] Due to a lack of adequate scientific disposal management, vast volumes of household and industrial food waste are frequently generated and stacked in an unhygienic way, releasing an unpleasant malodor, particularly in poor nations such as Liberia. In big cities, garbage generation per capita varies from 0.20 kg to 0.74 kg per day. [3] This urban rubbish may be composted and vermicompost into a possibly plant-nutrient-rich resource that can be utilized for long-term land restoration [4]. Compost are organic materials (plants and/or animal waste) that has been decomposed over time by microbes such as bacteria, fungi, actinomycetes, and others. Compost may be formed from a wide range of organic materials, like straw, leaves, vegetable and fruit peelings, and animals' manures. The deteriorated result is radically different from the initial organic elements, which are dark brown in color, crumbly in form, and have a nice odor. [5]

Compost is a vital resource for improving soil and crop quality because it is readily available, inexpensive, and simple to prepare." Compost increases the soil's structure. It increases drainage and lowers erosion by allowing more air into the soil. Compost prevents the soil from drying out during droughts by retaining more water. Compost aids in the enhancement of soil physicochemical qualities by adding nutrients to applied soils and acting like binding component for soil particles, boosting nutrient access for plants.[5].

Composting of the organic component of domestic solid waste alleviate many challenges posed by the decomposition of this waste such as groundwater pollution, odor problem, the spread of diseases, and air pollution through methane production (anaerobic decomposition of organic matter). Methane gases are 37 times more destructive than carbon dioxide in generating global warming. Composting deal with the decomposition of organic material by microbes in a controlled manner. The process produces a stable and nutritional product that is essential for agriculture and the soil stabilization process. The composting process requires consideration of different parameters to produce good compost rich in nutrients. The PH (6.5-9), moisture content, CN ratio based on the composition of the waste (normally 30:1), supply of seed (microbes), temperature (max 70-degree Celsius, particle size distribution, the bulk density is an important parameter to determine the porosity and aeration for microbial interaction. Based on the higher moisture content of food waste, To get the optimal moisture content in the feed stuck, effective bulking agents are used. Apart from optimizing moisture content, these bulking agents also increase aeration between the particles in the compost to avoid anaerobic conditions since composting is an aerobic process. Better air circulation and regular garbage shifting are required for successful composting. For optimum microbial activity, composting requires an ideal humidity level (40 - 60%) and C/N ratio (25) [6] Compost is an ever-ending resource

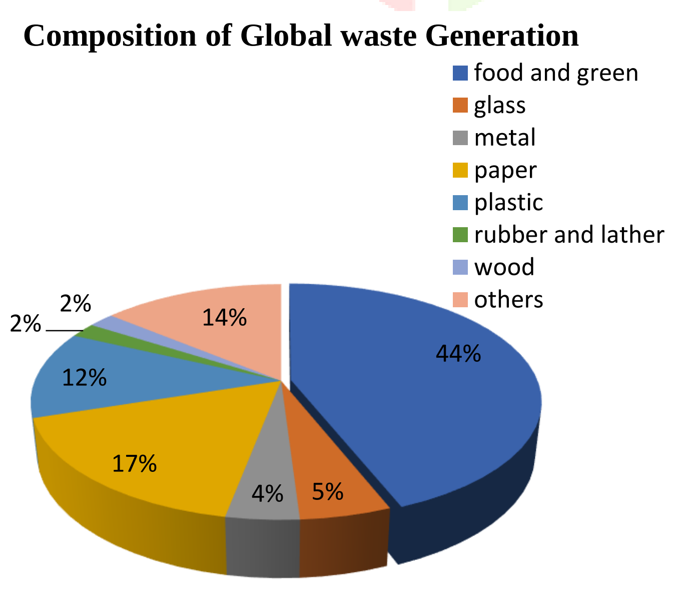

Figure 1. Global waste composition

2.0 Global Compost Market

"Composting has been favored as an important alternative for the treatment of organic waste" [6], [7]. The demand for user and business data drives the field of defining, measuring, and assuring compost product quality. [8]. The worldwide compost market is divided into the following segments:

1) Base on product type: the global compost business is expected to grow increasingly at a rate of 6.5% until 2027, with flower trimming, kitchen waste, animals' manure, mushroom, and vermicomposting being the main products. China holds highest percentages of global patents in the fields of compost technology, with specially focusing on novel composting devices.

2) By Use: Horticulture involves designing, constructing, and maintaining landscapes, while agriculture involves farming methods. Horticulture uses scientific principles and technologies to improve the yields produced by plants and it often uses intercropping or polycultures to cultivate the land sustainably. Home gardens represent a hopeful strategy to improve both household food security and overall well-being. Additionally, they offer a means to safeguard and transmit native crops and livestock varieties.

Market demand is anticipated to be $9.51 by 2027. The global compost market is predicted to grow at an 8.4% CAGR between 2022 and 2023, from $6.82 billion to $7.4 billion. In the short run, the Russia-Ukraine conflict has hindered efforts to recover from the COVID-19 pandemic. The conflicts between these nations have led to economic sanctions impacting numerous countries, a rise in commodity prices, and disruptions in supply chains. Inflationary pressures on products and services are hurting numerous markets throughout the world. "To ensure effective production of permanently sustainable development of agriculture systems, minimizing negative effects on the environment, especially on sources of water and soil fund is necessary" [9]. The worldwide compost market is estimated to increase at a 6.5% CAGR to $9.51 billion in 2027. Compost market growth is being driven by increased demand for organic agricultural products. Organic agricultural products are made without the use of chemical-based insecticides, growth hormones, antibiotics, synthetic fertilizers, or pesticides. During the COVID-19 outbreak, consumer appetite for organic food surged because Individuals are more inclined to consume meals that are more nourishing and immune-boosting. Furthermore, organic products are regarded to be of high quality and safer for both humans and the environment. Compost is often used to increase soil fertility in organic farming. The National Institute of Food and Agriculture (NIFA), which operates under the United States Department of Agriculture (USDA), declared a $30 million commitment through 33 grants In September 2021. These funds aim to assist farmers and ranchers in the development and marketing of premium organic food, fiber, and various other organic products. As a result of rising consumer appetite for organic agricultural commodities, compost consumption is expected to rise over the projected period.

3.0 Objective of composting

Due to the overuse of pesticides and artificial fertilizers in agriculture, compost, an organic fertilizer made from waste has gone unnoticed. Soil degradation, nutritional imbalances, insect outbreaks, and soil compaction have all been caused by this negligence. However, composting organic waste, particularly food waste, helps restore soil fertility. A significant portion of the world's 1.3 billion tons of agricultural output is wasted each year, and food waste adds to landfill methane emissions. Composting organic waste effectively lowers greenhouse gas emissions, eliminates environmental problems like odor, and improves soil quality. By substituting artificial fertilizers, compost acts as a vital soil conditioner and promotes sustainable agriculture. Composting improves soil quality and nutrient content by treating organic waste, neutralizing dangerous chemicals, and producing organic fertilizers [2]

4.0 Historical evolution of composting

4.1. Past: Composting history is a narrative of human progress and the growing realization of natural processes. Early people began to observe the link between the fertility of the soil and plant development when they transitioned from hunter-gatherers to farmers. In ancient Scotland (approximately 5000 BC), decomposed organic debris, such as decaying manure, was used, and agricultural production appeared to be tied to these practices. Manures and organic debris were used to enhance soil in ancient Chinese and Hindu literature, creating the groundwork for current composting and organic farming. Composting knowledge was passed down across centuries as civilizations developed and died. Writing became popular during the transition from BC to AD, allowing early man to record events such as composting. Among the oldest indications of "making" compost for agricultural use are clay tablets from the Akkadian Empire (2350 BC). The use of organic resources in agriculture is described in the Bible, Talmud, and works of characters such as Cato the Elder, a Roman commander. Agricultural knowledge declined throughout the Dark Ages, but it was kept and documented by monks and monasteries, helping future generations. As the globe evolved through the Dark Ages, authors from the Renaissance such as Shakespeare and Bacon incorporated composting allusions in their writings [10] Composting knowledge was brought to the Americas by European immigrants. They were startled to discover that indigenous cultures also composted. Native American traditions, such as the use of locally accessible materials such as fish waste, improved the settlers' composting procedures.[10]

Composting was acknowledged as valuable by historical individuals such as George Washington and Thomas Jefferson. They wrote about its significance in soil fertility and composted on their farms. Following the publication of Justus von Liebig's thesis in the nineteenth century, there was a trend toward chemical fertilizers. However, during the next century, authors such as Sir Albert Howard and Rudolph Steiner reemphasized the value of organic matter in soil, influencing current composting procedures. As the twentieth century proceeded, synthetic fertilizers became more prevalent, raising worries about soil damage. The usage of synthetic fertilizers was spurred by World War I and the increased demand for food production. Despite this, pioneers such as Sir Albert Howard and Rudolph Steiner continued to advocate composting and organic farming, having an impact on present composting practices [10]. Composting has evolved and grown in relevance in environmentally friendly farming and management of the environment since the 1930s. Composting processes, soil research, and their uses advanced significantly during this period. The Dust Bowl, a devastating occurrence caused by bad farming techniques, a severe drought, and huge topsoil erosion, defined the 1930s in the United States. Because of the situation, there has been a lot of study into better farming techniques and soil management. Simultaneously, Sir Albert Howard was completing his research on farming techniques in India, which culminated in the invention of the Indore method of composting. This procedure, which is based on historical practices of replenishing decaying matter to the soil, has sparked a worldwide interest in composting. [10]. At the Tuskegee Institute, George Washington Carver advocated composting as a way for farmers to make their fertilizer, highlighting the cost-saving and labor-saving benefits. Lady Eve Balfour investigated and introduced organic gardening and agricultural practices in England, including composting. J. I. Rodale promoted organic agricultural methods in the United States throughout the 1940s [10]. World War II boosted food production demand, resulting in the widespread use of chemical-based fertilizers to feed combatants and war laborers. This transition, combined with agricultural mechanization, lessened the need for conventional composting because fewer animals generated less manure for composting [10].

4.2. Present day: In recently, landfills have emerged as one of the most widely adopted methods for waste disposal. Open dumps or landfills are commonly employed for trash disposal in almost three-quarters of the world's nations [21] due to their low cost and minimal technological demands. As the shift from a linear to a circular economy takes place. It is expected that advancements in research and innovation will be pivotal in enhancing composting and vermicomposting processes, ultimately contributing to the creation of premium natural fertilizers for sustainable agricultural practices. Patents associated with compost technology frequently highlight inventive composting systems, with China being the predominant holder of global patents in this domain. Vermin technology is important in agriculture because it provides an efficient waste management solution, improves soil health, and produces stable, pasteurized organic fertilizers. Through the recycling of organic waste, circular economy techniques can give potential to minimize emissions of greenhouse gases from the agriculture sector. The ability of contemporary agriculture to fulfill future food demands imposed by the world's population's rapid rise is a big concern, and fertilizers play a critical role in this respect. [29]. Agricultural research is still ongoing today, despite the increased public's interest in organic gardening and organic farming. Composting is important because soil health is connected to plant and human health. Concerns about the release of greenhouse gases from landfills, as well as disposal prices, have fueled interest in composting as an option [10]. Vermicomposting, which uses worms to break down organic debris, has gained popularity due to its natural soil-enriching capabilities

4.3 A future perspective on composting: Numerous forward-looking composting practices show great potential for the future. These include human composting, designed for sustainable burial methods, composting adapted for space travel to manage organic waste in confined environments, composting robots designed to streamline and automate the composting process, self-destructing plastic that can be composted, and citywide composting hubs aiming to efficiently manage organic waste on a larger scale. These low-cost solutions have the potential to revolutionize waste management and improve environmental sustainability. While some of these ideas are still in development, they provide a framework for future environmental advances. New technology and services are making it easier to compost, whether you live in the city or the country. The Big Compost Experiment is a citizen science project that explores opinions and behaviors towards home compostable plastics and their performance. Composting toilets are another innovative solution that transforms human waste into fertilizer, aligning with permaculture principles and promoting a harmonious relationship with the planet.

4.3.1 Human Composting: Human composting, also known by the term organic matter reduction, is a greener alternative to traditional burial and cremation practices. Bodies dissolve into soil, similar to organic matter in nature, throughout this process. It uses one-eighth the energy of cremation and nourishes soil with nutrients, benefitting the environment. Traditional burial and cremation, on the other hand, have negative environmental consequences. With about 2.7 million deaths in the United States each year, human composting appears as a long-term option to lessen the environmental impact related to post-mortem procedures.

4.3.2 Associated problem: Cremation, a prevalent post-mortem practice, involves the combustion of fossil fuels, leading to the release of detrimental pollutants. Each cremation emits 880 pounds of carbon dioxide, contributing to global warming, and releases toxins such as mercury and dioxins. On the other hand, conventional burial utilizes valuable land, contaminates soil, and relies on resource-intensive materials like caskets and headstones, further contributing to environmental harm. Typical American funerals waste significant resources, including over 20 million feet of wood, 4.3 million gallons of embalming chemicals, and numerous materials, proving to be both environmentally harmful and financially expensive.

4.3.3 Where is it lawful to compost human waste? Human composting, sometimes known as "natural organic reduction," is specifically prohibited in all except Washington, Oregon, Colorado, and, eventually, California. Each state's rules may differ, with Oregon proposing specialized facilities regulated by the Department of Environmental Quality. Similar legislation is being considered in other states, including Massachusetts, Delaware, and New York. Proponents emphasize its eco-friendliness, lower carbon footprint, resource conservation, and potential for plant development. Because of the environmental benefits, more states are anticipated to investigate human composting.

4.3.4 Composting on Mars: On Earth, microorganisms play a crucial role in breaking down organic materials within compost piles. However, these microorganisms rely on oxygen, which may not always be readily available in space or on Mars. While composting might seem unconventional in space, recent advancements have made the process feasible.

The acronym MEliSSA stands for Micro-Ecological Life Support System Alternative. The MELiSSA ecosystem is designed to recycle waste into oxygen, water, and food for prolonged human space missions. This initiative by the European Space Agency has the potential to significantly impact both space travel and life on Earth. The primary objective of the project is to develop a system capable of efficiently recycling all waste products generated by a crew of astronauts.

4.3.5. Composting Robots on Farms: recently, composting has gained popularity as a waste reduction strategy and a means of producing nutrient-rich soil for gardens and farms. However, the composting process itself can be time-consuming and labor-intensive, posing challenges for busy farmers trying to meet demand. Fortunately, there is a growing trend in utilizing robots for composting. These robots, equipped with sensors and machine learning capabilities, can identify suitable composting materials and accurately mix them in the appropriate ratios. The outcome is high-quality compost enriched with nutrients, allowing farmers to enhance crop yields while saving both time and resources. Additionally, robots designed for collecting manure can efficiently scoop it off barn floors and deposit it in designated containers.

4.3.6. What Could This Mean for the Future of Farming? Composting robots like these could have a profound impact on the future of farming. Beyond aiding farmers in resource conservation and cost savings through automation, they open up the possibility of diversifying revenue streams beyond traditional avenues such as milk and meat production. Compost, often referred to as "black gold" in the gardening community, could potentially become a lucrative product for farmers. In certain situations, selling compost might generate more income than traditional agricultural products like meat or milk. The integration of both functions suggests that farmers could, in theory, achieve the same level of profit with significantly less land, water, and resources in the future. This points towards a more sustainable and efficient approach to agricultural practices.

5.0 Compost system operation

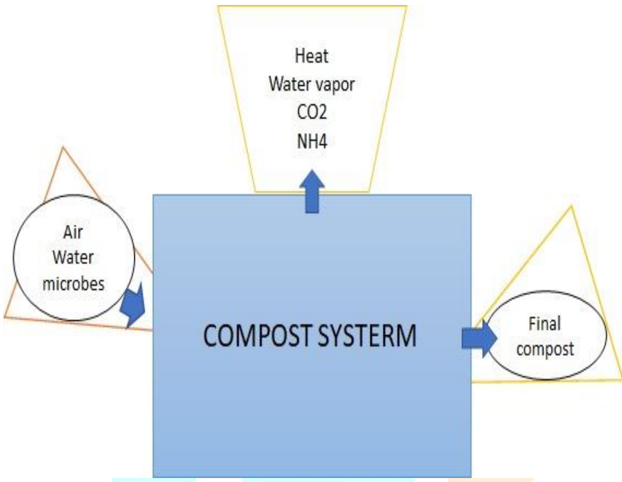

Figure 2. Technologies of composting

Just like in various other branches of engineering, several mathematical models for composting have been created in recent times. These models are designed to deepen our comprehensive understanding of the composting process and enhance composting methods at various operational levels [26]. Food waste is an organic substance with a low carbon-to-nitrogen ratio and a high nitrogen concentration, according to [12]. Food waste's easily degradable organic materials have made it a practical substrate for composting. Food processors frequently struggle with solid waste, which can account for up to 30% of raw materials. Landfilling was once prevalent, but environmental rules and increasing expenses have prompted the investigation of alternatives such as composting. Composting decreases the volume of organic waste by 40%, avoids landfill expenditures, and produces revenue-generating compost [13]. To design composting systems, a kinetic analysis of waste biodegradation is required. Few investigations have been conducted to demonstrate that organic decomposition approaches a first-order equation. To investigate the variability between parameters or variables, some studies used multidimensional statistical techniques such as PCA (principal component analysis) and hierarchical clustering analysis (HCA). PCA generates parameter groups based on factor loadings, which may be accomplished by establishing relationships between the parameters and the primary components. The HCA approach is commonly utilized in statistical analysis for pattern recognition [26], [27]. "For composting to be accepted as a viable alternative to landfilling and to other methods of MSW treatment such as incineration, effective separation of the organic fraction needs to be achieved. It is possible to practice the separation of the degradable materials at the source of generation" [3]. Composting processes differ principally in how they achieve active composting via aerobic, thermophile breakdown before curing. These approaches are classified into three broad categories, with each becoming increasingly sophisticated: Windrows or passive heaps, Windrows or piles that have been turned or aerated, and, Systems installed within vessels. [15]

5.1. Phases of composting

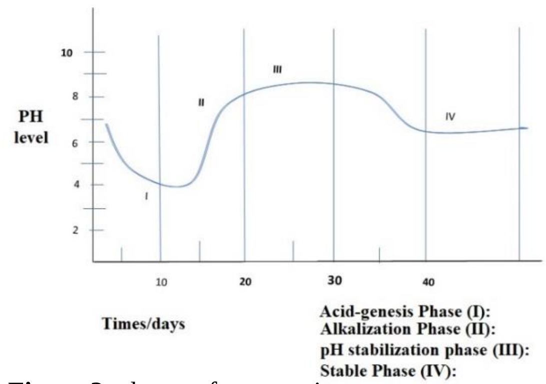

Figure 3. phases of composting

Composting success relies on meeting specific microorganism requirements, primarily addressed during the initial stages of sorting, shredding, and mixing. Crucial factors that influence microbial activity include temperature, oxygen levels, pH, moisture, carbon-to-nitrogen (C: N) ratio, and particle size. Compost materials should have a C: N ratio of 25:1 to 35:1, which typically necessitates a combination of 'wet, green' (nitrogen-rich) and 'dry, brown' (carbon-rich) materials. Inadequate C: N ratios may lead to ammonia release and odor issues. Excessive carbon content depletes available nitrogen before complete decomposition [16]. Composting is the sanitary process that transforms organic wastes into a homogenous and plant-available substance that occurs under aerobic circumstances with proper moisture and temperature. [5]. The composting process is typically categorized into four phases: the hot phase (mesophilic phase), the curing phase (thermophilic and hyalinization phase), the cooling or mesophilic phase II, and the maturation phase. Each phase is characterized by different communities of microorganisms that play specific roles in the decomposition process. The primary, secondary, finishing, and curing phases are considered essential stages of composting, while the others are considered auxiliary phases.

5.1.1 Hot phase (mesophilic phase): During the hot stage of composting, the temperature of the compost pile increases to approximately 45°C. This temperature elevation is a result of the metabolic activity of diverse microorganisms that utilize the nitrogen (N) and carbon (C) present in the organic matter for their own assimilation and growth.

5.1.2 Curing phase (thermophiles and hyalinization phase): When the temperature of the initial organic material surpasses

45°C, the composting process transitions to the curing phase. During this phase, mesophilic microbes are replaced by thermophilic microorganisms. These thermophilic microorganisms play a crucial role in breaking down complex organic matter as the compost pile continues to undergo decomposition.

5.1.3 Cooling or mesospheric phase II: Following the depletion of carbon and nitrogen supplies from the composting material, the temperature of the pile decreases to approximately 40-45°C. This marks the cooling or mesophilic phase II of the composting process.

5.1.4 Maturation phase: In the maturation period of composting, the internal temperature of the compost pile gradually decreases to the ambient temperature. This decline leads to the condensation of carbonaceous chemicals and polymerization, facilitating the formation of fulvic and hemic acids. These organic compounds contribute to the maturity and stability of the compost, indicating the completion of the composting process. Because composting decreases methane emissions owing to anaerobic conditions that occur and provides economic and environmental co-benefits, it is an essential aspect of waste management. [22]

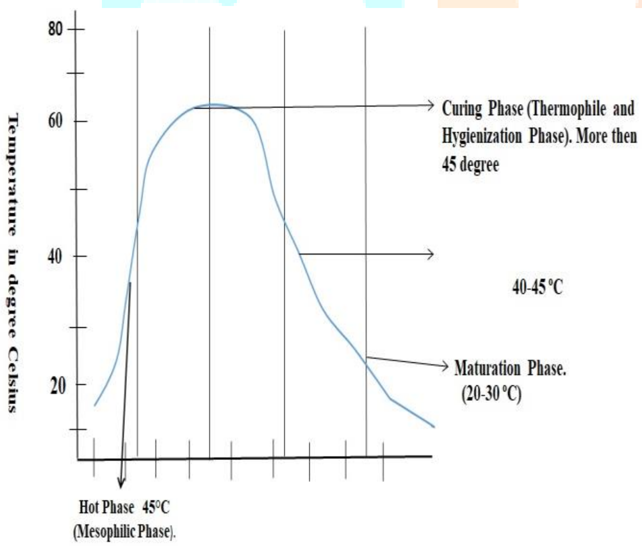

Figure 4. PH Phases of composting

During the degradation of organic waste, the initial pH level decreases due to the break breakdown of complex ammonic acid into simple organic acid such as acetate acid increasing the acidic content of the waste, at a later stage, the pH increase creating a normal environment that promote plant growth

5.2 The Compost process and parameter

International technical requirements call for a carbon-to-nitrogen ratio of 20-30 for producing high-quality compost. A high C: N ratio slows composting because microbes must break down the extra carbon, while a low C: N ratio indicates a surplus of nitrogen that may be wasted in the process. [24]. The process of composting is an action that is carried out by microbes, thus variables influencing how they flourish and multiply should be considered. Temperature, pH, carbon-to-nitrogen (C/N) ratio, oxygen or aeration, and substrate moisture are examples of internal factors that influence the composting process. External factors affecting composting include ambient conditions, the chosen method, initial ingredients, and other relevant aspects. Therefore, certain parameters may vary based on these external factors, impacting the overall composting process [18]. Composting is a biological procedure that involves the degradation of organic materials by microorganisms under controlled conditions. The growth and reproduction of microorganisms involved in composting are influenced by various factors, including aeration or oxygen levels, temperature, pH, substrate moisture, and the carbon-to-nitrogen (C: N) ratio. These factors collectively contribute to the optimal conditions for microbial activity during the composting process. [5]

5.2.1 Aeration: Composting is an aerobic process that depends on sufficient aeration for microorganisms to release carbon dioxide (CO2). Aeration plays a crucial role in preventing compaction and excessive moisture in the compost pile. The demand for oxygen is particularly high during the thermophilic phase of composting. The ideal oxygen saturation level in a compost pile is 10%, with a minimum of 5% to maintain healthy decomposition. Too much aeration can lead to temperature drops and moisture loss, hindering decomposition. Conversely, insufficient aeration (below 5%) causes excess moisture, creating an anaerobic environment that produces unpleasant odors and acidity due to compounds like acetic acid, hydrogen sulfide (H2S), and methane (CH4). Balancing aeration is crucial for successful composting [5]

5.2.2 Temperature: The aerobic composting process uses heat, evaporation, and other factors to break down organic waste into minerals, NH3, CO2, and other gases. Typically, the mesophilic, thermophilic, and mature phases are part of the composting process [19]. Temperature is a critical element in composting, both as a result and as a predictor of activity [8]. The ambient temperature undergoes significant variations depending on the stage of the composting procedure. The composting process typically begins at room temperature, and it can naturally elevate to 65°C without human intervention. In the maturation period, the compost pile gradually returns to the ambient temperature. It is important to note that maintaining higher temperatures over extended periods is beneficial for efficient degradation and hybridization. Therefore, the temperature of the compost pile should not decrease too rapidly during the composting process. [5]

5.2.3 Moisture content: [23] It has been reported that a crucial physical factor requiring consideration in material mixing and maintaining optimal conditions during the composting process is moisture content. Ensuring the right level of moisture is essential for the success of composting, influencing microbial activity and the overall decomposition process. Moisture content is determined by the waste materials fed into the rotating drum composting mix [13]. Moisture is a critical factor for microbes as, similar to all living organisms, they require water to transport nutrients and energy components across the cell membrane. Adequate moisture content is essential for the metabolic processes and activities of microorganisms involved in composting, facilitating the efficient decomposition of organic materials. It is challenging to maintain optimal moisture levels during composting, especially in an open setting. This challenge is often addressed by monitoring temperature, which indicates the ideal timing for turning, moistening, and/or ventilating the compost pile. Insufficient initial moisture levels (less than 30%) can lead to rapid dehydration of the compost, disrupting the biological process and resulting in compost that is physically stable but biologically unstable. Conversely, high humidity levels (greater than 80%) can create anaerobic conditions, affecting the composting process negatively. Regular temperature monitoring helps guide appropriate interventions to maintain the optimal moisture balance during composting environments in the compost. As a result, determining the appropriate moisture values for the composting process is critical. [18]

5.2.4 pH: pH is a significant factor in affecting microbial development throughout the composting process. [21]. The pH of composting varies depending on the source materials and undergoes fluctuations throughout the process, ranging from 4.5 to 8.5. In the initial stages of composting, the pH of the compost pile tends to become more acidic. This acidification is a result of microbes releasing various organic acids during the early phases of the composting process. The pH of the medium rises during the thermophilic phase due to ammonium conversion to ammonia, and the medium finally stabilizes at near neutral values. The pH is an important factor in microbe survival, and each type of bacteria has an optimal pH range for growth and multiplication. Between pH 6.0 and 7.5, the bulk of bacterial activity occurs, while the majority of fungal action occurs between pH 5.5 and 8.0. The ideal range lies between 5.8 and 6.8. [5].

5.2.5 Particle size distribution: Microbial activity in composting is influenced by particle size, and smaller particles enable easier access to the substrate. Composting finer particles results in an increased specific surface area, facilitating enhanced microbial access to the substrate. This increased surface area can contribute to more efficient decomposition processes during composting. 5cm to 20 cm is the ideal size for composting parent materials. "Decomposition by the microorganisms during the composting process occurs superficially on the surface of the compost heaps' particles. Smaller compost particles increase the surface area for the decomposition and may speed up the decomposition process" [23]. The density of composting material is directly linked to particle size, thereby influencing the aeration and moisture retention in the compost pile [5]. The overall density of compost is a measure of the quantity of components within a specific volume. The density of compost contributes to mechanical characteristics such as strength, porosity, and ease of compaction. Dry bulk densities usually fall within the range of 100 to 400 kg/m³, whereas wet bulk densities can vary from 500 to 900 kg/m³. Higher bulk density indicates an increase in mass, leading to reduced permeability and air volume. Exceptionally low wet bulk density, on the other hand, may indicate excessive substrate oxygenation and, as a result, a decline in the accessible water part [18].

5.2.6 Bulking agent: For ages, bulking agents in composting have been employed to boost compost output. Bulking agents or bulking particles have garnered a lot of attention in recent years due to their effectiveness and utility in composting, pollution management, and economic viability [22]. Carbon –nitrogen ratio: Numerous researchers have investigated the Carbon-to-Nitrogen (C/N) ratio, also referred to as the mixing ratio, and have generally found that the optimum C/N ratio falls within the range of 25 to 30. Some studies, such as those by Zhu (2007) and Kumar et al. (2010), reported a lower optimal ratio of 15. When employing a low C/N ratio in food waste (FW) composting, there may be no need to adjust the ratio using a bulking agent. However, this can result in significant N mineralization, leading to the production of odors, primarily from ammonia. [1]. In terms of managing the variety of substrate features, the consistency of synthetic food waste offers a major advantage over restaurant or cafeteria trash [23]. In the aerobic fermentation phase, when the initial Carbon-to-Nitrogen (C/N) ratio is high, biological substrates tend to lose more carbon through metabolism, which is then exhaled as the gas carbon dioxide, compared to the loss of nitrogen. The nitrogen is metabolized and released in a smaller quantity in the form of volatile nitrogen compounds. This dynamic contributes to the changing composition of the materials undergoing aerobic fermentation. As an outcome, the C/N ratio for extremely resistant material steadily decreases during composting. [18]. A material's carbon-to-nitrogen ratio is a significant consideration in composting. Composting works best if the carbon to nitrogen (C: N) proportion among all materials in the pile is around 30:1. Food waste and clippings of grass are two examples of materials with a low C: N ratio (15:1 or less) that must be combined with materials with a high C: N ratio for proper composting [24]. Materials with high CN ratio: Straw, shelled corn cobs, maize stalks, shrub trimmings, bark wood chips Clean and dry leaves Nutshells, Coarse Sawdust, Pine needles, brown non-legume hay, dry Horse dung with a lot of bedding, The Solid Waste Handling Program allows paper or paper products. [24].

5.2.7 Hygienization in composting: Hygienization in composting refers to the process of reducing or eliminating harmful pathogens and microorganisms in the compost. This is important for ensuring that the compost is safe to handle and use, particularly in agriculture and horticulture. Several factors impact the hyalinization process, including temperature, moisture level, chemical compounds generated during composting, and microbial activity. [18]. The high temperatures produced during the thermophilic phase of decomposition can destroy numerous pathogens and weed seeds, leaving the compost healthier to use. Furthermore, the action of bacteria and fungi throughout composting might serve to inhibit pathogens and minimize contamination risk. Composting hygienization is critical, especially for composts that may be utilized in agriculture or other delicate applications. Proper composting techniques, such as maintaining proper moisture levels, turning the compost regularly, and monitoring temperature, can help to ensure that the compost is properly hygienic. Composting is an essential aspect of waste management because it minimizes methane emissions caused by anaerobic conditions while also providing economic and environmental advantages. Depending on the type of compost and the desired amount of pathogen elimination, the sanitary temperature range for composting might vary. Here are a couple of temperature ranges identified in the literature. [18]. When the temperature rises over 60°C, the optimal temperature for most thermophiles is attained, and high temperatures begin to restrict the composting system. 70°C-80°C: The higher temperatures (70°C-80°C) can hygiene the compost, but also kill other beneficiaries' microbes. GI is a maturation and stability parameter that is frequently used to evaluate compost phytotoxicity. [21]

5.2.8 Composting agents: Compost pile interactions are highly intricate. Organic materials like leaves or plant debris are consumed by specific invertebrates such as millipedes, sow bugs, mollusks, and slugs. These invertebrates shred plant parts, increasing the surface area available for fungi, microbes, and actinomycetes to act upon. Subsequently, these microorganisms become a food source for creatures like mites and springtails. Earthworms, nematodes, red worms, and pot worms play a role in consuming decaying plants and microorganisms, enhancing compost through the excretion of organic substances. Their burrowing activity oxygenates the compost, and their feeding expands the overall area of organic waste available to microorganisms. As each decaying organism dies or excretes, the system continually receives more food for new decomposers in the composting process. [25]

5.2.9 Compost set up, monitored, and quality parameter

Composting normally begins with the addition of four key components: organic waste, moisture, oxygen, and microorganisms. The use of a starter (decomposer), which includes bacteria and enzymes to enhance the decomposition process, is required to hasten the composting of plant biomass waste. For instance, using local decomposers increased the pace of composting, and the percentage of compost mass decreased [25]. The physical, chemical, and microbiological qualities of the starting material have a significant impact on how the composting process. However, by raising temperature and pH levels, as well as changing the carbon and nitrogen content and ratio, as well as cellulose and dehydrogenase activity, a wide range of additives may be used to improve composting.

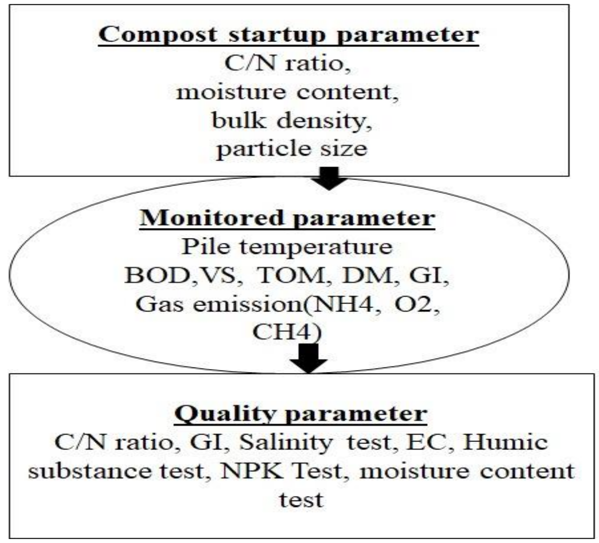

Figure 5. Composting physic-chemical parameter

6.0 How does compost affect the physical properties of soil?
Clay-rich soil possesses a greater capacity to retain water but has a lower ability to drain water effectively. In contrast, soil with a higher proportion of sand exhibits better drainage capabilities but has a lower capacity for water retention. Ideal farmable soil is characterized by a balanced ability to both retain and drain water, as well as retain nutrients and facilitate proper aeration for optimal plant growth. To have this capacity, the soil must have an aggregate structure composed of an acceptable blend of clay, sand, and "humus" as its principal constituents. [27]. Soil organic matter is critical for maintaining soil fertility and reducing nutrient losses. Because it contains both nutrients and organic components, compost is a great organic fertilizer. Organic matter enhances soil quality by strengthening its physical structure and serving as a conduit for biological activity. It improves soil production by supplying nutrients, increasing water retention, and assuring proper tilt for seed germination and plant root growth. Soil formation is a slow process influenced by climate, geography, and biology. It comprises organic and inorganic materials like rocks, clay, sand, and plant residues. Soil has solid, liquid, and gas phases, crucial for supporting plant growth. A balanced composition, around 40% solid phase, is ideal for cultivation; higher or lower percentages result in unsuitable soil consistency [27]. Soil fertility is intimately related to the mineralization of nutrients inside organic matter, which allows them to be released in plant-available forms. Compost addition and suitable cultivation methods might help to speed up this process. Organic matter, as opposed to synthetic fertilizers, maintains water and nutrients, making it necessary for profitable agriculture, particularly in damaged soils. Composting improves soil organic matter, and mature composts are more effective because of their stable carbon concentration. Compost application reliably enhances soil organic carbon levels, improving soil health and fertility, reduces bulking density, increases aggregate stability, improves water holding capacity of the soil, enhancement of nutrient

level, increases the cation exchange capacity (CEC), and increases the PH value, liming effect and improved buffering capacity of the soil. According to studies, significant amounts of compost may be required to provide long-term benefits

6.1 Challenges with the Leachability of compost nutrients to the plant: Because this technique is the most efficient, ecologically safe, and ergonomically sound, the compost may be utilized a a soil conditioner and organic fertilizer because it includes high levels of nutrients for the soil [7]. Organic manures, like compost, provide nutrients to plants gradually, and these nutrients are not immediately taken up by the plants. Consequently, plants may not absorb sufficient nutrients during the critical yield-forming period. Combining compost treatment with the application of inorganic fertilizers becomes a viable strategy to enhance crop yield. This approach allows for a reduction in the cost of inorganic fertilizers while simultaneously improving soil fertility. The gradual release of nutrients from organic sources and the targeted supplementation with inorganic fertilizers contribute to a more balanced and sustainable nutrient management strategy for agriculture.

6.2 Application of compost in the agriculture field: Composting has been shown to be useful in treating a variety of plant diseases and pests. [25]. Utilizing high-quality substrates is one of the cornerstones of seedling production at seedbeds because seedlings are susceptible to several environmental conditions during germination and the early phases of growth, such as the availability of water, air, and nutrients [27]. Bokashi, which originated in Japan and Korea, uses fermentation to break down food waste, therefore improving soil fertility. Compost's applications have expanded beyond soil nourishment. It is used to remediate soil, filter toxins from stormwater runoff, absorb volatile organic compounds from the air, and even filter smells from composting processes. Compost is also useful for controlling erosion during road building and mending soil affected by construction activity [10]. Although careful selection and mixing of compost constituent materials creates a proper habitat for microorganisms, the material must still be put and managed optimally throughout and after processing. The exact evaluation of compost characteristics is critical for evaluating composting transportation, storage, treatment, disposal, and reuse costs. [8].

7.0 Conclusion

Composting is a method of hastening the degradation of organic items such as food and paper in order to produce compost or soil for planting. It is a sustainable practice that offers environmental and economic benefits. Composting has been the subject of research, and studies have highlighted its value regarding sustainability. "The application of mature composted products to soil can lead to several benefits, including increased organic matter content, enhanced drainage in clay soils, and controlled soil erosion. It improves soil characteristics, fostering robust root structures, alleviating plant stress from drought and frost, and elevating the nutritional quality of crops grown in compost-enriched soils. Additionally, there is a reduction in environmental impact through the mitigation of soil erosion, waterlogging, nutrient loss, surface crusting, eutrophication in water bodies, and siltation of waterways. Other advantages include the promotion of soil microbial populations, improved water retention in sandy soils, a decrease in plant water requirements, attraction, and nourishment of earthworms, as well as the balancing of soil pH (acidity-alkalinity). Furthermore, this practice contributes to waste reduction and serves as an alternative to chemical fertilizers, herbicides, and pesticides. These outcomes are crucial for the production of high-quality agricultural products for the food industries. Composting is a technique that uses microorganisms to break down organic materials into a nutrient-rich soil supplement. The expansion of composting programs, such as the U-M composting program into residence halls, has been studied to determine its impact on knowledge and action around composting. Composting is a vital component of waste management because it minimizes methane emissions caused by anaerobic conditions, making it a more ecologically friendly option to putting organic

9.0 References

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