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Chapter- 1

Sustainable Management of Organic Wastes to Enhance Soil Health via Vermicomposting

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Keywords: Organic waste, Earthworm, Vermicomposting, Soil health, Soil productivity

Abstract:

Vermicomposting is the process of converting large amounts of organic waste into organic fertilizer using earthworms. This straightforward biotechnological method utilizes specific species of earthworms to transform waste into a superior end product. Vermicomposting is an efficient waste management technique, as it produces high-quality manure quickly and yields a nutritionally rich and biologically active product at a reasonable cost. The resulting vermicompost is a highly nutritive, humus-like organic fertilizer rich in macronutrients and micronutrients. It plays a crucial role in enhancing the growth and yield of crops. The effective utilization of waste materials through vermicomposting not only supports sustainable nutrient management and the maintenance of soil health in agricultural soils but also helps in reducing environmental pollution caused by waste. This review aims to raise awareness about generating value from waste through vermicomposting.

Introduction:

Waste is defined as an unwanted material or substance that is deliberately discarded for disposal. Since the Industrial Revolution, the generation of waste has increased rapidly, exacerbated by the ever-growing human population, which has contributed to additional hazards and highlighted waste as a significant factor in environmental health (Siddiqua et al., 2022; Mohan and Joseph, 2021; Thakur et al., 2021; Das et al., 2022; Erfani et al., 2024; Hemalatha et al., 2024). With rising populations and improving living standards, the demand for our environment has increased, leading to the depletion of more raw materials, including non-renewable resources. As a result, more waste is being produced today, and unless it is

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managed properly, it will lead to increased pollution (Talashilkar et al., 1999; Kaza et al., 2018; Bandyopadhyay et al., 2023).

Scientists observed that the problems associated with various types of man-made waste are gradually increasing due to population growth, rapid industrialization and urbanization trends (Bharadwaj, 2010). Waste can be categorized into different types, such as solid, liquid, and gas, each requiring careful management, with solid waste management alone covering a vast field. Solid wastes are generated from various sources, including institutions, agriculture, and industry. In cities of developing countries, inadequate arrangements for solid waste collection and disposal contribute to environmental degradation. Local agencies often find themselves unable to manage the increasing volumes of waste, leading to uncollected waste accumulating on roadsides, street corners, or other open spaces in cities, thereby posing health risks to the public (Kaseva and Mbuligwe, 2005; Rathi, 2006; Imam et al., 2008; Thirunavukkarasu et al., 2023).

Improper disposal of large amounts of waste in developing urban areas poses threats to air, water, land, vegetation, wildlife, and humans (Awomeso et al., 2010). Inadequate disposal and management of sewage, garbage, and other unwanted substances often spread illnesses and epidemic diseases. The continuously growing human population and rising income levels contribute to increased demand and production of goods, leading to the discharge of more waste into the environment (Varian, 2010; Blanchard, 2009; Kaza et al., 2018; Thirunavukkarasu et al., 2023). Household organic waste contributes significantly to Municipal or Corporation garbage, which has become a pressing environmental issue today. Composting offers a solution by converting such waste into valuable resources. This environmentally friendly technique does not cause any pollution (Gajalakshmi et al., 2002; Bansal and Kapoor, 2000; Quadar et al., 2022; Tawarah et al., 2024).

The preparation of vermicompost is both an efficient and easily adaptable method for compost production. This system not only effectively decomposes large quantities of organic waste but also helps maintain a higher nutrient status in the composted material (Bajsa et al., 2004; Gopal et al., 2017; Thirunavukkarasu et al., 2023). Consequently, vermicomposting is recognized as a more sustainable technique for organic waste disposal through vermiculture, the science of breeding and raising earthworms. Introduced in the Philippines in the late 1970s, vermicomposting gained popularity throughout the 1980s (Guerrero, 1979; Guerrero, 2009).

Vermicomposts are noted for their exceptional biological properties, supporting microbial populations that are significantly larger and more diverse than those found in conventional thermophilic composts (Edwards, 1998). This composting process is non-toxic, requires low energy input, and produces a recycled bio-organic product. Due to the absence of toxic enzymes, vermicompost is eco-friendly and has a beneficial impact on the biochemical activities of the soil (Ali and Jahan, 2001; Ghoshal, 2017; Bhat et al., 2017). It also improves soil quality, fertility and mineral content, enhancing soil aeration, texture, and tilth while reducing soil compaction. Moreover, vermicomposting increases the soil's water retention capacity due to its high organic matter content and promotes better root growth and nutrient absorption (Nourbakhsh, 2007; Quadar et al., 2022; Tawarah et al., 2024).

This study aims to provide an overview of the potential of vermicomposting for eco-friendly organic waste management. In addition to a general overview, this work specifically explores the potential of (i) vermicomposting in organic waste management, (ii) the effects of vermicompost on soil health, (iii) the role of vermicompost in crop yield, and (iv) the use of vermicomposting to reduce the toxicity of raw materials. Therefore, this work seeks to present a comprehensive picture of vermicomposting and its role in soil health management.

Utility of vermitechnology in organic waste management

Vermicomposting is an efficient biotechnological method for composting in which specific species of earthworms are employed to convert organic waste into a superior end product (Alshehrei and Ameen, 2021; Thirunavukkarasu et al., 2023; Hemalatha et al., 2024). According to Gandhi et al. (1997), vermicomposting differs from traditional composting methods. It is a mesophilic process that utilizes microorganisms and earthworms, which are active at temperatures between 10°C and 32°C (not the ambient temperature, but the temperature within the pile of moist organic material). This process is faster than regular composting, and as the material passes through the earthworm's digestive system, it undergoes significant transformation. The resulting earthworm castings, or worm manure, are enriched with beneficial microbes and plant growth regulators and possess pest repellent properties.

Earthworms are known to consume and break down a wide range of organic residues, including agricultural, animal, industrial, and domestic wastes, sewage sludge, and crop residues. Solid waste, including wastewater sludge from the paper pulp and cardboard industries, breweries and distilleries, sericulture industry, vegetable oil factories, potato and corn chip manufacturing industries, sugarcane industry, aromatic oil extraction industries, and logging and carpentry industries, provides excellent feed material for vermicomposting by earthworms (Gajalakshmi et al., 2002; Bansal and Kapoor, 2000; Ndegwa et al., 2000; Singh and Suthar, 2012; Lakshmi and Vijayalakshmi, 2000).

As Dominguez (2004) describes, vermicomposting involves earthworms processing large amounts of organic residues into organic manures. It has been demonstrated to be a cost-effective technique due to its low expenses. The process involves the bio-oxidation and stabilization of organic materials through the combined action of earthworms and microorganisms. Microbes are responsible for the biochemical degradation of organic matter, while earthworms play a crucial role in conditioning the substrate and altering its biological activity. Dominguez's study highlights that earthworms can process sewage sludge, soils from wastewater, materials from breweries, paper wastes, urban residues, and animal wastes.

Palaniappan and Annadurai (2008) reported that vermiculture biotechnology involves using earthworms as versatile natural bioreactors to effectively recycle non-toxic organic wastes, leading to soil improvement and sustainable agriculture. This technology is currently being utilized to establish cost-effective units for treating various non-toxic organic solid and liquid wastes from cities, dairies, sugar and distillery units, pulp and paper mills, tanneries, fermentation industries, and food processing units (Tawarah et al., 2024; Thirunavukkarasu et al., 2023).

Aira et al. (2002) noted that vermicomposting involves the stabilization of organic material through the combined action of earthworms and microorganisms. In this process, earthworms are essential drivers, conditioning the substrate and modifying its biological activity, while microbes are responsible for the biochemical degradation of organic matter. Epigeic earthworms have been utilized for organic waste management due to their effectiveness in accelerating the composting process (Suthar, 2006; Benitez et al., 2005; Garg and Kaushik, 2004; Yadav and Garg, 2011; Bhat et al., 2017).

Ndegwa and Thompson (2001) explained that during vermicomposting, nutrients are released and converted into forms that are soluble and available to plants. Elvira et al. (1996) observed that the earthworm *Eisenia andrei* effectively converted paper-pulp mill sludge mixed with primary sludge into vermicompost. Suthar (2008) studied the recycling of post-harvest crop residues and cattle shed manure through vermicomposting using the epigeic earthworm *Eudrilus eugeniae*, which significantly accelerated the composting process and enhanced the availability of nutrients in the vermicompost.

When combined with industrial effluents, Hema and Rajkumar (2012) found that vegetable wastes could be effectively degraded by earthworms, increasing nutrient content and worm populations in the order of dairy, distillery, and water. They concluded that vermicomposting is an appropriate technique for efficiently recycling and disposing of non-toxic solid and liquid wastes. According to Prabha et al. (2005), vermi-technology is a significant aspect of biotechnology, utilizing earthworms to process various organic wastes into valuable resources. Lal et al. (2003) reported that vermicomposting helps process waste and simultaneously produces manure and protein. Thus, vermi-technology can be effectively used to clean the environment by using wastes as raw materials to transition from polluted, costly chemical farming to sustainable agriculture.

Role of vermicompost in improving soil health and productivity

Vermicompost, also known as vermicast, is a type of organic compost that is rich in essential nutrients like nitrogen, phosphorus, and potassium (NPK), as well as various micronutrients necessary for plant growth (Bhardwaj et al., 2023; Tawarah et al., 2024). This compost has become increasingly popular among organic farmers because it promotes faster and more vigorous plant growth without the need for chemical fertilizers. While thermophilic composting has long been known for its ability to improve soil fertility (Zaller and Kopke, 2004; Mane and Raskar, 2012; Santra et al., 2015) and suppress plant diseases (Hoitink and Fahy, 1986), research is showing that vermicompost can also provide these benefits (Edwards and Burrows, 1988; Edwards et al., 2004).

Vermicompost is a finely textured, peat-like material with high porosity, good aeration, excellent drainage, and strong water-holding capacities. It is produced through the breakdown of organic waste by earthworms and microorganisms, without the material passing through a thermophilic (heat-producing) stage (Domínguez, 2004; Quadar et al., 2022; Tawarah et al., 2024). This process results in composts rich in nutrients like nitrates, calcium, phosphorus, and potassium, which plants easily absorb. Vermicompost also provides numerous microsites for microbial activity and has large surface areas that help retain nutrients (Edwards and Burrows, 1988).

What makes vermicompost stand out is its outstanding biological properties. It supports a larger and more diverse microbial population than conventional thermophilic composts (Edwards, 1998). Vermicompost is produced through a non-thermophilic process where organic matter is broken down by the interactions between earthworms and microorganisms under aerobic (oxygen-rich) conditions (Bhardwaj et al., 2023). This type of compost is valuable because it releases nutrients at a balanced rate, providing essential elements like nitrogen, potassium, calcium, magnesium, and phosphorus, which plants can easily take up (Edwards, 1998; Edwards and Fletcher, 1988).

Most studies have focused on the impact of solid compost and vermicompost on soil fertility and plant disease suppression (Addabdo, 1995; Edwards, 1998; Dominguez, 2004), with less research on their use as liquid extracts. Organic manures, including vermicompost, have been shown to improve soil microbial properties, which can lead to high and sustained crop yields when used in combination with balanced NPK fertilization (Makinde et al., 2001; Bayu et al., 2006; Bhat et al., 2017). Nutrients in organic manures are released slowly and remain in the soil for longer periods, ensuring a prolonged residual effect (Sharma and Mitra, 1991).

Adding organic amendments like compost or vermicompost to soil can enhance its buffering capacity and significantly influence its physicochemical behavior, thanks to the humic acid content and its associated charge development and acid–base properties (Gondar et al., 2005; Campitelli et al., 2006; Benitz et al., 2005). Applying vermicompost improves soil health by enhancing water-holding capacity, soil structure, and fertility (Jeyabal and Kuppuswamy, 2001; Chaoui et al., 2003; Tawarah et al., 2024).

Vermicompost is a nutrient-rich plant food that contains NPK, micronutrients, and beneficial soil microbes like nitrogen-fixing bacteria and mycorrhizal fungi. It includes growth-promoting hormones like auxins and gibberellins, which boost plant development (Tomati et al., 1985). The mycorrhizal fungi encouraged by earthworms help increase the solubilization of mineral phosphate, enhancing phosphorus availability. Vermicompost also contains enzymes such as amylase, lipase, cellulase, and chitinase, which continue to break down organic matter in the soil, releasing nutrients that plants can easily absorb (Chaoui et al., 2003; Quadar et al., 2022; Bhardwaj et al., 2023).

Rich in microbial diversity, especially fungi, bacteria, and actinomycetes (Brown, 1995; Chaoui et al., 2003; Singh, 2009; Lim et al., 2016), vermicompost fosters a thriving soil ecosystem. Studies have shown that vermicompost contains a high concentration of beneficial bacteria, including Actinomycetes, Azotobacter, Rhizobium, Nitrobacter, and phosphate-solubilizing bacteria (Suhane, 2007).

Incorporating vermicompost into soil management practices can significantly improve soil health, enhance plant growth, and promote sustainable agriculture.

Application of vermicompost in improving crop yield and quality

Vermicompost significantly enhances the growth and yield of a variety of crops, including field crops, vegetables, flowers, and fruits. For instance, the application of vermicompost led to a notable increase in germination rates of mung bean (Vigna radiata) to 93%, compared to 84% with the control. Furthermore, vermicompost application resulted in superior growth and yield of mung bean. Similarly, in a pot experiment, cowpea (Vigna unguiculata) showed higher fresh and dry matter yields when soil was amended with vermicompost rather than biodigested slurry (Karmegam et al., 1999; Karmegam and Daniel, 2000).

Desai et al. (1999) assessed the efficiency of vermicompost in field studies, finding that its application, combined with fertilizer nitrogen, resulted in higher dry matter (16.2 g per plant) and grain yield (3.6 t ha^-1) of wheat (Triticum aestivum). Additionally, it improved the dry matter yield (0.66 g per plant) of coriander (Coriandrum sativum) in a sequential cropping system. Positive outcomes were also reported with vermicompost application for other field crops such as sorghum (*Sorghum bicolor*) (Patil and Sheelavantar, 2000; Tawarah et al., 2024) and sunflower (Helianthus annuus) (Devi and Agarwal, 1998). Vadiraj et al. (1998) noted that vermicompost provided herbage yields of coriander cultivars comparable to those obtained with chemical fertilizers.

In ornamental horticulture, vermicompost enhanced the growth of Chrysanthemum chinensis, with the highest fresh weight of flowers achieved using 10 t ha^-1 of vermicompost combined with 50% of the recommended dose of NPK fertilizer. The maximum number of flowers per plant (26), flower diameter (6 cm), and yield (0.5 t ha^-1) were observed with this treatment. The vase life of flowers (11 days) was extended with a combination of 15 t ha^-1 of vermicompost and 50% of the recommended NPK fertilizer (Nethra et al., 1999; Bhardwaj et al., 2023).

Vermicompost is a highly nutritious organic manure, rich in humus and essential nutrients such as nitrogen (2-3%), phosphorus (1.55-2.25%), and potassium (1.85-2.25%), along with micronutrients and beneficial soil microbes, including nitrogen-fixing bacteria and mycorrhizal fungi. It has been scientifically validated as an effective plant growth promoter (Tiwary et al., 1989; Binet et al., 1998; Chaoui et al., 2003). Its high porosity, aeration, drainage, and water-holding capacity make it an excellent medium for plant growth. Vermicompost contains plant-available nutrients and enhances their retention over extended periods. Importantly, it increases plants' biological resistance to pests and diseases through repelling or suppressing pathogens (Anonymous, 2001; Rodriguez et al., 2000; Edwards and Arancon, 2004).

Murarkar et al. (1998) investigated the effects of vermicompost on mulberry (Morus sp.) leaf yield, finding that a combination of full-dose NPK fertilizers and vermicompost, along with a half dose of farmyard manure, significantly improved the number of branches, plant height, number of leaves per plant, and leaf yield per plant. Tomar et al. (1998) reported that brinjal plants grown with vermicompost had higher yields (97.0 g per plant) compared to those grown with other treatments. Similarly, carrots grown with vermicompost yielded 94.9 g per pot, compared to 29.9 g and 36.0 g with unamended soil and farmyard manure, respectively.

Vermicompost enhances soil properties, increases crop yields, and significantly improves the growth of plants such as Pisum sativum compared to pit compost and garden soil (Khan and Ishaq, 2011; Lim et al., 2016). George and Pillai (2000) found that applying vermicompost, alone or in combination with chemical fertilizers, stimulated crop growth and reduced the amount of recommended NPK by up to 25% in Guinea grass grown as an intercrop in coconut. Increased crop yields and quality have been frequently observed in plants grown with earthworm castings, and organic produce is often noted for its superior nutritional quality, taste, and storage life (Palaniappan and Annadurai, 2008; Lim et al., 2016; Bhardwaj et al., 2023).

Vermicompost, containing antibiotics and actinomycetes, enhances plants' biological resistance to pests and diseases, leading to reduced pesticide use (Suhane et al., 2008; Quadar et al., 2022). Athani and Hulamani (2000) reported that bananas treated with vermicompost and NPK fertilizers had extended shelf life, with plants receiving 125,000 earthworms ha^-1 showing the longest shelf life. Lazcano et al. (2011) demonstrated that both vermicompost and manure significantly increased plant growth and marketable yield, highlighting the positive effects of organic fertilizers on crop yield and quality.

Using vermicomposting to decrease the toxicity of raw materials

Vermicomposting is an advanced biotechnological process where earthworms convert various organic wastes into a humus-like substance known as vermicompost. Earthworms can decompose a wide range of organic materials, including sewage sludge, animal waste, agricultural residues, household waste, and industrial by-products. Sewage sludge, in particular, is used extensively in agriculture worldwide, either in its raw form or as processed products (Buta et al., 2021). Sewage sludge contains valuable macro- and micronutrients as well as organic compounds essential for plant growth, enhancing crop production and soil quality (Tu et al., 2012; Latare et al., 2014; Bourioug et al., 2014). However, it also harbors hazardous contaminants like Potentially Toxic Elements (PTEs), including Pb, Cr, Cd, Ni, As, Zn, and Cu, which can adversely affect the environment (Villar et al., 2016; Lv et al., 2016). These contaminants pose significant environmental health risks due to their toxicity and potential for bioaccumulation in the food chain.

Vermicomposting involves a synergistic action between earthworms and microorganisms that bio-oxidize and stabilize organic materials. Microorganisms primarily handle the biochemical breakdown of organic waste, while earthworms assist in this process. Vermicomposting can also act as an environmental sink for PTEs, converting most organic matter into nutrient-rich products containing nitrogen, phosphorus, and potassium (NPK) and humic substances (Lv et al., 2016; Dume et al., 2022). Additionally, earthworms accumulate metals in their tissues, thereby reducing the concentration of PTEs in the final vermicompost product (Sizmur et al., 2009; Li et al., 2010).

The pH of vermicompost can vary depending on the raw materials used. For instance, vermicompost from sewage sludge typically has a pH of 7.2 (Masciandaro et al., 2000), while vermicompost from pig manure ranges from 5.3 (Atiyeh et al., 2002a) to 5.7 (Atiyeh et al., 2000). In contrast, vermicompost derived from sheep manure has a pH of 8.6 (Gutiérrez-Miceli et al., 2008). This variation in pH is linked to the characteristics of the raw materials used in vermicomposting. Vermi-composting of sheep manure for 60 days has been shown to eliminate pathogens such as E. coli, Shigella spp., Salmonella spp., and total coliforms compared to untreated raw sheep manure (Gutiérrez-Miceli et al., 2008). This reduction in pathogens is likely due to the antibacterial properties of vermicompost, which are attributed to the hemolytic activity of earthworms (Sinha et al., 2002).

Aira et al. (2012) studied the impact of the earthworm species *Eisenia andrei* on pathogen reduction during cow dung vermicomposting in an industrial-scale continuous feeding vermi-reactor. They found that while *Eisenia andrei* did not significantly reduce Enterobacteria, total coliforms, or Clostridium, it did lower Escherichia coli, fecal coliforms, and fecal enterococci levels. The effectiveness of pathogen reduction can vary depending on the earthworm species used (Aira et al., 2012; Fernando et al., 2021).

Research suggests that the decrease in total coliforms during vermicomposting may be related to the natural characteristics of earthworms, their digestive capabilities, and the enzymatic digestion performed by bacteria in their gut (Monroy et al., 2008; Monroy et al., 2009; Edwards et al., 2011). Earthworm species such as *Eisenia fetida*, *Eisenia andrei*, *Eudrilus eugeniae*, and *Lumbricus rubellus* have effectively reduced total coliform counts (Monroy et al., 2008). Esmaeili et al. (2020) demonstrated that combining composting with vermicomposting using pistachio waste and cow dung produced a superior end product with a low C

ratio, decreased total organic carbon and increased total nitrogen and phosphorus content.

Heavy metal contamination from agricultural and industrial activities is a significant concern, with lead (Pb) being particularly problematic. However, animal manure and crop residues have been identified as effective organic adsorbents for heavy metals (Wang et al., 2015; Wnetrzak et al., 2014). Zhang et al. (2020) found that biochar derived from cow manure-based vermicompost could effectively adsorb Pb^{2+} from solutions. Produced through pyrolysis at temperatures of 350°C and 700°C, this biochar has an acidic pH (2.0 and 3.0) and rich mineral content, which facilitates the rapid removal of Pb^{2+}. Thus, biochar from cow manure vermicompost offers an affordable solution for heavy metal removal from soil and water (Fernando et al., 2021).

Figure 1. Raw material for vermicomposting.

Figure 2. Mature vermicompost.

Figure 3(a&b). Earthworm faeces.

Figure 4(a&b). Earthworm for vermicompost production.

Conclusion and Future Direction:

Organic waste management is a critical challenge due to waste accumulation's environmental and health impacts. Vermi-composting, utilizing earthworms to convert organic waste into nutrient-rich compost, offers an effective solution. This process manages waste and improves soil health and fertility, thereby enhancing crop production. The vermicompost's physical, chemical, and biological properties vary, affecting plant growth and soil quality.

Looking ahead, integrating nanotechnology and artificial intelligence (AI) into vermicomposting presents promising advancements. Nano-technology can enhance the efficiency of composting by improving nutrient availability and contaminant breakdown. AI can optimize the process through real-time monitoring and data analysis, enabling precise control over composting conditions. Combining these technologies with traditional vermicomposting methods could lead to more effective waste management, better soil health, and improved agricultural outcomes, addressing the pressing challenges of organic waste management in a sustainable manner.

Conflict of interest:

None

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