Vermicomposting and its Role in Soil Health: A Comprehensive Review

Abstract

Vermicomposting, the process of using earthworms to convert organic waste into nutrient-rich compost, has gained significant attention in recent years due to its numerous environmental benefits, particularly in improving soil health. This review paper explores the concept of vermicomposting, its mechanisms, advantages, and applications in enhancing soil fertility, structure, and biodiversity. We also examine the impact of vermicompost on crop growth and the potential role of vermiculture in sustainable agriculture. By synthesizing current research, this paper provides a thorough overview of the potential of vermicomposting in promoting soil health and addressing the challenges of modern farming practices.

Key words: Vermicompost, Soil Health, Sustainable agriculture,Earthworm, Environment

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Introduction

Soil health is fundamental to agricultural productivity and ecosystem sustainability. The depletion of soil nutrients, soil erosion, and the loss of biodiversity have become major concerns for farmers worldwide. Vermicomposting is emerging as a viable solution to enhance soil quality and productivity (Chetankumar, Vaidya, & Zade, 2020). The process of vermicomposting involves the degradation of organic matter by earthworms and microorganisms, producing a nutrient-dense product called vermicompost. This paper aims to provide an extensive review of vermicomposting, focusing on its impact on soil health, the processes involved, and the benefits it offers for agricultural systems.

1. Vermicomposting: Definition and Process

Vermicomposting refers to the biological process in which earthworms break down organic materials such as kitchen waste, agricultural residues, and animal manure, transforming them into high-quality compost (Lal et al., 2024). The process involves the digestion of organic matter by earthworms, which are then excreted as worm castings. These castings are rich in nutrients, beneficial microorganisms, and humus, which is crucial for soil fertility.

The vermicomposting process involves several steps:

- **Pre-composting**: The organic material is initially broken down by microorganisms, making it easier for earthworms to process.
- **Earthworm digestion**: Earthworms consume the organic material, digest it, and excrete it as castings.
- **Vermicompost maturation**: The castings undergo further microbial activity, enhancing their nutrient content and stability.

2. Mechanisms of Soil Health Enhancement by Vermicompost

Vermicompost improves soil health in various ways. These include:

- **Nutrient Enrichment**: Vermicompost contains essential plant nutrients, including nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients. These nutrients are released slowly over time, improving soil fertility and providing a consistent source of nutrition for plants.

- **Improved Soil Structure**: The humus-rich nature of vermicompost enhances the soil's physical properties. It increases soil aggregation, which improves porosity, water retention, and drainage. This leads to better root penetration and growth.
- **Increased Microbial Activity**: Vermicompost is teeming with beneficial microorganisms, such as bacteria, fungi, and actinomycetes. These microorganisms contribute to soil health by decomposing organic matter, fixing nitrogen, and suppressing harmful pathogens. The increased microbial diversity in the soil enhances nutrient cycling and plant growth.
- **Soil pH Balance**: Vermicompost can help neutralize acidic or alkaline soils, bringing the pH to an optimal level for plant growth. This creates a more favorable environment for nutrient uptake.
- **Organic Matter Supply**: The organic matter in vermicompost adds to the soil's organic carbon content, fostering long-term soil fertility. It also enhances the cation exchange capacity (CEC), which improves the soil's ability to retain essential nutrients (Vuković et al., 2021; Keerthana, Kumar, &Mehera, 2024).

3. Benefits of Vermicomposting in Sustainable Agriculture

Vermicomposting offers several advantages that make it an essential tool in sustainable agriculture:

- **Waste Management**: Vermiculture provides an environmentally friendly way to recycle organic waste. Agricultural residues, kitchen scraps, and livestock manure can all be converted into valuable vermicompost, reducing landfill waste and greenhouse gas emissions.
- **Reduction of Chemical Fertilizer Use**: The nutrient content of vermicompost can substitute for chemical fertilizers, reducing the environmental impact of fertilizer application. This is particularly important in mitigating the problems of soil salinization, eutrophication, and the contamination of groundwater with nitrates and phosphates.
- **Improved Crop Yield**: Studies have shown that the application of vermicompost to soil can increase crop yields. This is due to the improved soil structure, enhanced nutrient availability, and the suppression of soilborne diseases.
- **Water Conservation**: The increased water retention capacity of soils treated with vermicompost can help conserve water, which is critical in areas facing water scarcity. This is particularly important for crops grown in drought-prone regions.
- **Biodiversity Support**: Vermicompost enhances soil biodiversity by promoting beneficial soil organisms. This leads to better soil health and resilience against pests and diseases.

4. Applications of Vermicompost in Agriculture

Vermicompost has a wide range of applications in agriculture, from improving soil quality to increasing crop productivity:

- **Soil Amendment**: Vermicompost can be mixed with soil to improve its physical properties. It is particularly effective in improving compacted soils, enhancing aeration, and facilitating better root growth.

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- **Seedling Growth**: Vermicompost is often used in potting mixes to promote seedling growth. It provides a balanced nutrient supply and supports the establishment of young plants.
- **Compost Tea**: Vermicompost can be dissolved in water to create a nutrient-rich compost tea. This liquid can be applied to plants as a foliar spray or soil drench to improve plant health and nutrient uptake.
- **Organic Farming**: Vermicomposting is a key component of organic farming systems. Its use helps maintain the sustainability of organic practices by reducing the need for synthetic inputs and enhancing soil fertility(Alshehrei& Ameen, 2021).

5. Impact of Vermicompost on Plant Growth

Numerous studies have demonstrated the positive impact of vermicompost on plant growth. The application of vermicompost leads to:

- **Increased Germination Rate**: Plants grown in soils amended with vermicompost tend to have a higher germination rate, possibly due to improved nutrient availability and better soil aeration.
- **Improved Root Development**: Vermicompost enhances root growth by improving soil structure and nutrient availability. It also increases the presence of beneficial soil microbes that promote root health.
- **Enhanced Disease Resistance**: The beneficial microorganisms in vermicompost can suppress harmful pathogens, reducing the incidence of soilborne diseases and improving plant health.
- **Better Crop Quality**: Vermicompost not only increases the quantity of crops but also improves their quality, with better taste, color, and nutritional content, as it enhances nutrient availability.

6. Challenges and Limitations of Vermicomposting

Despite its many benefits, vermicomposting faces several challenges and limitations:

- **Time-Consuming Process**: Vermicomposting can be a slow process, especially when large quantities of organic matter need to be processed. The time required for complete decomposition can vary depending on the type of organic material used and environmental conditions.
- **Temperature Sensitivity**: Earthworms are sensitive to extreme temperatures. High or low temperatures can adversely affect their activity and the efficiency of the composting process.
- **Initial Costs and Maintenance**: Setting up a vermiculture system may require an initial investment in infrastructure and ongoing management to ensure the health of the earthworms and the quality of the compost.
- **Limited Knowledge and Expertise**: Successful vermiculture requires a certain level of expertise, and many farmers lack the necessary knowledge to implement vermicomposting systems effectively(Nahar et al., 2023).

Different Methods and Earthworms Used in Vermicompost Preparation

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Vermicomposting is a natural and sustainable process that uses earthworms to decompose organic waste, converting it into nutrient-rich humus. The quality of vermicompost and the efficiency of the process depend on various factors, including the method used for composting and the type of earthworms chosen. In this section, we explore the different methods of vermicomposting and the various species of earthworms commonly used in this process.

1. Methods of Vermicomposting

There are several methods for preparing vermicompost, each with varying levels of complexity and efficiency. The choice of method depends on factors such as the scale of composting, available space, type of organic waste, and environmental conditions.

a) Pit Method

The pit method is one of the simplest and most traditional approaches for vermicomposting. It involves digging a pit in the soil, where organic waste is placed, and earthworms are introduced to decompose the waste.

- **Procedure**:
    1. Dig a pit about 30-50 cm deep and 1-2 meters wide.
    2. Add layers of organic waste (e.g., vegetable scraps, manure, agricultural residue) to the pit.
    3. Introduce earthworms (typically in small quantities) to the pit.
    4. Cover the pit with a layer of soil or mulch to maintain moisture and temperature.
    5. Turn the compost occasionally to ensure uniform decomposition.
- **Advantages**:
    - Simple and low-cost.
    - Suitable for large-scale operations, especially in rural areas.
    - Waste is processed naturally, without much manual intervention.

  Disadvantages:
    - Can take a long time (several months) for complete decomposition.
    - Requires regular monitoring and moisture control.
    - May attract pests or become too acidic if not managed properly.

b) Bin or Tray Method

The bin or tray method involves setting up containers or trays for composting organic waste. These bins can be made from wood, plastic, or metal, and are usually stacked in layers to optimize space and efficiency. This method is often used for small to medium-scale vermiculture operations.

- **Procedure**:
    1. Prepare a container or bin with drainage holes at the bottom.
    2. Place a layer of bedding material (e.g., shredded paper, coconut coir, or straw) at the base.
    3. Add a layer of organic waste and then introduce the earthworms.
    4. Add more layers of organic waste and bedding as the worms process the material.

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   5. Keep the bin covered and maintain moisture at appropriate levels to keep the worms active.

- **Advantages**:
  - More manageable and compact, making it ideal for urban or small-scale settings.
  - Easier to monitor and control environmental conditions (moisture, temperature).
  - Faster composting process compared to the pit method (typically 1-3 months).

  Disadvantages:
  - Requires more attention and care in terms of moisture, ventilation, and temperature.
  - Can become overcrowded if not properly managed.
  - Limited by available space for larger quantities of waste.

c) Windrow Method

The windrow method is commonly used for large-scale commercial vermiculture operations. It involves creating long, narrow piles or rows (windrows) of organic material where earthworms are added. The material is turned periodically to accelerate the decomposition process.

- **Procedure**:
  1. Create windrows (about 1-1.5 meters wide and 30-60 cm high) on a prepared surface, such as concrete or soil.
  2. Add organic waste in layers and introduce earthworms to the windrows.
  3. Turn the windrows regularly to maintain aeration and ensure uniform decomposition.
  4. Monitor moisture levels and adjust as necessary.
- **Advantages**:
  - Suitable for large-scale vermicomposting operations.
  - Facilitates better oxygen flow, which speeds up the process.
  - Can handle large volumes of organic waste.

  Disadvantages:
  - Requires more space and larger infrastructure.
  - Requires more labor for turning the material and maintaining the windrows.
  - The process can be more complex and difficult to manage.

d) Vermibed Method

The vermibed method is similar to the bin method but is typically done on a larger scale and involves placing organic material directly on the ground in beds or trenches. It is highly efficient and used by many commercial vermiculture operations.

- **Procedure**:
  1. Prepare a flat, well-drained surface, typically covered with a tarpaulin or mesh to protect the bed.
  2. Add bedding material and organic waste to the bed.
  3. Introduce earthworms to the bed, which will tunnel through the material.
  4. Maintain optimal moisture, temperature, and aeration to encourage decomposition.

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5. Harvest the finished vermicompost after a few months.

- **Advantages**:
  - Large quantities of organic waste can be processed.
  - High-quality vermicompost is produced relatively quickly.
  - Easy to scale up.

  Disadvantages:
  - Requires a large area of land.
  - Careful monitoring of temperature and moisture is needed.
  - It can be challenging to manage in extreme weather conditions.

8. Earthworms Used in Vermicomposting

The type of earthworm used in vermicomposting plays a critical role in the efficiency and speed of the composting process. Different species of earthworms are better suited for different environments and composting systems. The most commonly used earthworm species in vermiculture are **epigeic**, **endogeic**, and **anecic** earthworms.

a) *Eisenia fetida* (Red Wiggler Worm)

- **Characteristics**: *Eisenia fetida*, also known as the red wiggler, is the most commonly used earthworm in vermiculture. It is an epigeic worm, meaning it lives in the top layer of soil or organic matter. It thrives in environments with abundant decaying organic material.
- **Advantages**:
  - Highly efficient at decomposing organic waste.
  - Adaptable to confined spaces, making it ideal for bin and tray systems.
  - Active composters, producing high-quality vermicompost.
  - Tolerates a wide range of temperatures and moisture levels.
- **Disadvantages**:
  - Sensitive to extreme temperatures, especially in hot or cold conditions.
  - Requires regular care and attention to maintain optimal conditions.

b) *Lumbricusrubellus* (Red Earthworm)

- **Characteristics**: *Lumbricusrubellus* is another popular earthworm species for vermiculture. It is similar to *Eisenia fetida* but tends to be larger and can tolerate a broader range of environmental conditions.
- **Advantages**:
  - Effective in breaking down a wide variety of organic materials.
  - Well-suited for large-scale vermiculture operations.
- **Disadvantages**:
  - Less prolific than *Eisenia fetida*.
  - Can be less tolerant of fluctuating environmental conditions.

c) *Perionyx excavatus* (Indian Blue Worm)

- **Characteristics**: This species of earthworm is native to tropical and subtropical regions, particularly in India and Southeast Asia. It is an epigeic species and is often used in vermiculture systems in warmer climates.
- **Advantages**:

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- Very active and efficient in composting organic material.
- Fast-growing and able to process a large volume of waste.

- **Disadvantages**:
  - Prefers warmer temperatures and may struggle in cooler climates.
  - Requires careful moisture and temperature management.

d) *Lumbricus terrestris* (Nightcrawler)

- **Characteristics**: *Lumbricus terrestris*, or the nightcrawler, is an anecic species, meaning it burrows deep into the soil. This species is more suited for traditional composting systems where deep soil aeration is beneficial.
- **Advantages**:
  - Excellent for aerating the soil and improving soil structure.
  - Often used in soil-based vermiculture systems.
- **Disadvantages**:
  - Not as effective in confined spaces like bins or trays.
  - Slow composting process compared to epigeic species.

e) *Dendrobaenaveneta* (European Red Worm)

- **Characteristics**: *Dendrobaenaveneta* is an epigeic earthworm species that is often used in vermiculture in Europe. It is smaller than *Eisenia fetida* but still highly efficient at composting.
- **Advantages**:
  - Adaptable to various organic materials.
  - Produces high-quality vermicompost.
- **Disadvantages**:
  - May not be as robust as other species under certain conditions.

Here is a table summarizing the efficiency of different earthworm species in the production of vermicompost based on key factors such as composting speed, tolerance to environmental conditions, waste processing capacity, and overall suitability for different vermiculture systems.

Table 1: Efficiency of different earthworm species in the production of vermicompost based on different factors

Earthworm Species	Composting Speed	Waste Processing Capacity	Temperature Tolerance	Moisture Tolerance	Suitability for Systems	Additional Notes
Eisenia fetida (Red Wiggler)	High (fast decomposition)	High (efficient at processing organic waste)	Moderate (prefers 15-25°C)	Prefers moist, but not waterlogged conditions	Ideal for bins, trays, and small-scale operations	Most commonly used in vermiculture, tolerant to a variety of organic materials.
Lumbricusrubellus (Red Earthworm)	Moderate to High	Moderate to High	Moderate (best at 10-20°C)	Requires steady moisture levels	Suitable for both small-scale and	Larger than *Eisenia fetida*, slightly less

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					large-scale systems	prolific but adaptable to different conditions.
Perionyx excavatus (Indian Blue Worm)	Very High (very fast decomposition)	Very High (processes large amounts of organic material)	High (prefers warmer temperatures, 25-30°C)	High moisture requirement	Best suited for tropical and subtropical climates, works well in bins and beds	Very active and efficient but sensitive to cooler climates.
Lumbricus terrestris (Nightcrawler)	Moderate (slower compared to others)	High (effective in aerating and breaking down organic material)	High (can tolerate colder temperatures, 10-15°C)	High moisture tolerance	Best for soil-based systems, windrow method, large-scale operations	Good for soil aeration and soil amendment, less effective in confined spaces.
Dendrobaenaveneta (European Red Worm)	Moderate to High	Moderate to High	Moderate (prefers 15-25°C)	Moderate moisture preference	Ideal for both small and medium-scale systems	Small, efficient, and adaptable for composting different materials, not as robust in extreme temperatures.

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Key Points:

- **Composting Speed**: *Eisenia fetida* and *Perionyx excavatus* are the fastest decomposers, making them ideal for systems where rapid processing is desired.
- **Waste Processing Capacity**: *Eisenia fetida*, *Perionyx excavatus*, and *Lumbricusrubellus* excel at processing organic waste, with *Perionyx excavatus* having the highest capacity.
- **Temperature Tolerance**: *Lumbricus terrestris* is more tolerant of cooler conditions, whereas *Perionyx excavatus* thrives in warmer climates.
- **Moisture Tolerance**: All species require moisture, but *Perionyx excavatus* prefers high moisture levels, while *Eisenia fetida* and *Lumbricusrubellus* can tolerate moderate moisture conditions.

- **Suitability for Systems**: *Eisenia fetida* and *Dendrobaenaveneta* are highly suitable for confined systems like bins or trays, while *Lumbricus terrestris* works best in larger, open systems like windrows.

9. Future Directions and Research Needs

The potential of vermicomposting to improve soil health is vast, and further research is needed in several areas:

- **Optimization of Vermiculture Systems**: More studies are needed to develop efficient, cost-effective vermiculture systems that can be scaled up for commercial use.
- **Integration with Other Agricultural Practices**: Future research should explore the integration of vermicomposting with other sustainable agricultural practices, such as agroforestry and crop rotation.
- **Long-Term Impact on Soil Health**: Long-term studies are required to assess the cumulative effects of vermicomposting on soil health and ecosystem services over multiple cropping seasons.

Factors Affecting Vermicompost Production

Vermicomposting is a complex biological process influenced by several environmental, biological, and physical factors. These factors affect the efficiency of the process, the quality of the produced vermicompost, and the overall health of the earthworms involved. Understanding these factors is crucial for optimizing vermiculture systems and ensuring the production of high-quality compost. Below are the key factors that affect vermicomposting:

1. Temperature

- **Effect on Vermiculture**: Earthworms are sensitive to temperature, and their activity decreases outside of their preferred temperature range. Temperature influences worm metabolism, reproduction, and overall health.
- **Optimal Range**: The ideal temperature for most earthworm species, such as *Eisenia fetida*, is between 15°C and 25°C. In tropical climates, species like *Perionyx excavatus* can tolerate higher temperatures.
- **Extreme Temperatures**: Temperatures above 30°C or below 10°C can stress earthworms, slowing down composting or even leading to worm mortality.

2. Moisture Content

- **Effect on Vermiculture**: Earthworms require moist environments to facilitate their feeding and digestion process. Insufficient moisture can lead to dehydration, while excessive moisture can result in anaerobic conditions, which are harmful to earthworms and microorganisms.
- **Optimal Range**: The moisture content of the vermicomposting system should be kept at about 60-80%. The bedding material and organic waste should feel like a wrung-out sponge—moist but not soggy.

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- **Impact on Decomposition**: Proper moisture supports microbial activity, which is essential for the decomposition of organic matter.

3. Organic Waste Composition

- **Effect on Vermiculture**: The type of organic material used in vermicomposting significantly affects the decomposition process. Earthworms prefer decomposed or partially decomposed organic matter, as it is easier to digest.
- **Carbon to Nitrogen Ratio**: A balanced C:N ratio (typically 25:1 to 30:1) is ideal for effective decomposition. Too much carbon (e.g., dry leaves, straw) can slow down the process, while excessive nitrogen (e.g., fresh manure, vegetable scraps) can lead to excess ammonia production, which can harm the worms.
- **Types of Waste**: Easily degradable materials like vegetable scraps, fruit peels, and coffee grounds are ideal, while high-carbon materials like sawdust or shredded paper may need to be mixed with nitrogen-rich waste to balance the ratio.

4. pH Levels

- **Effect on Vermiculture**: Earthworms prefer neutral to slightly alkaline conditions. Highly acidic or alkaline environments can stress the worms, slow down the composting process, and hinder microbial activity.
- **Optimal pH Range**: The ideal pH for vermicomposting is between 6.5 and 8.0. Extremely acidic (below pH 5) or alkaline (above pH 9) conditions can lead to poor decomposition and earthworm health.
- **Impact on Nutrient Availability**: The pH of the environment affects the availability of essential nutrients, influencing the overall health of the earthworms and the quality of the vermicompost produced.

5. Earthworm Species

- **Effect on Vermiculture**: Different species of earthworms have varying abilities to process organic waste, reproduce, and tolerate environmental conditions. The choice of earthworm species plays a significant role in the speed and efficiency of vermicomposting.
- **Common Species**: *Eisenia fetida* (Red Wiggler), *Lumbricusrubellus*, *Perionyx excavatus* (Indian Blue Worm), and *Dendrobaenaveneta* are commonly used species, each with unique characteristics. For instance, *Eisenia fetida* is highly efficient in confined spaces and can process a wide range of organic matter quickly.
- **Reproduction and Growth**: Earthworms reproduce faster under optimal conditions, which leads to higher composting efficiency. Overcrowding or poor conditions can inhibit reproduction and reduce composting productivity.

6. Aeration and Oxygen Supply

- **Effect on Vermiculture**: Aeration is crucial for the vermicomposting process. Earthworms need oxygen to survive, and microbial decomposition also requires oxygen. Poor aeration can lead to anaerobic conditions, which are harmful to both earthworms and microbes.

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- **Optimal Conditions**: The compost should be turned periodically, and bins or beds should be designed with proper ventilation (e.g., holes for airflow) to ensure sufficient oxygen supply.
- **Impact on Decomposition**: Well-aerated compost promotes the activity of aerobic microorganisms, which decompose organic matter more efficiently and prevent the production of foul odors associated with anaerobic decomposition.

7. Feeding Rate and Frequency

- **Effect on Vermiculture**: The amount and frequency of organic waste added to the vermiculture system can affect worm health and composting speed. Overfeeding or underfeeding can disrupt the balance in the system.
- **Optimal Feeding**: It is important to feed earthworms in moderate amounts, ensuring that the waste is fully consumed before adding more. Regular monitoring is required to ensure that waste is decomposing at an appropriate rate.
- **Impact on Decomposition**: Overfeeding can create excess organic material, leading to an imbalance in the C:N ratio and potentially causing odors. Underfeeding may slow down the composting process as there may not be enough organic material for the worms to process.

8. Moisture Retention of Bedding Material

- **Effect on Vermiculture**: The bedding material serves as both a habitat for the earthworms and a medium for moisture retention. The type of bedding used (e.g., coconut coir, shredded paper, straw) influences the moisture-holding capacity of the system.
- **Optimal Bedding**: Bedding materials should be absorbent enough to maintain moisture levels while providing a comfortable environment for the earthworms. Coir and shredded cardboard are commonly used for their moisture-retaining properties.

9. Harvesting and Maintenance

- **Effect on Vermiculture**: The timing of harvest and the management of the worm population can significantly influence the efficiency of vermicomposting. Harvesting too early or too late can result in a lower-quality product or harm the earthworm population.
- **Harvesting Method**: After the composting cycle is complete (usually after 2-3 months), the vermicompost should be separated from the worms. This can be done by hand-picking or using a screen.
- **Worm Care**: Proper maintenance includes monitoring the worm population, ensuring adequate moisture levels, and preventing overcrowding. The health of the worms directly affects the quality of the compost.

10. Microbial Activity

- **Effect on Vermiculture**: Microorganisms play an essential role in the decomposition of organic materials in the vermicomposting process. The presence of beneficial bacteria, fungi, and actinomycetes helps break down complex organic compounds into simpler forms that worms can digest.

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- **Optimal Microbial Activity**: A diverse and active microbial population supports healthy worm digestion and contributes to the overall nutrient content of the vermicompost. The correct balance of bacteria and fungi is necessary for optimal decomposition rates and the production of high-quality compost.

Conclusion

Vermicomposting is a sustainable and effective solution for improving soil health. By enhancing soil fertility, structure, and microbial activity, vermicompost promotes better plant growth and supports sustainable agricultural practices. Its role in waste management, reduction of chemical fertilizers, and improved crop productivity makes it an essential tool in addressing the challenges of modern farming. As research continues to explore new applications and optimize vermiculture systems, vermicomposting will likely play an even more critical role in promoting global food security and environmental sustainability.

Disclaimer (Artificial intelligence)

Author(s) hereby declared that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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