Academia and Society: International Journal of Education and Society
Print ISSN : 2393-9419
Online ISSN : 2393-8919
HOLY CROSS
AAS 2025: 12 (1)

A Review of the Role of Vermicompost in Enhancing Crop Productivity and Soil Health

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DOI: https://doi.org/10.6025/aas/2025/12/1/21-34

ABSTRACT

Vermicompost is a nutrient-rich, sustainable biofertilizer produced through the combined action of earthworms and microorganisms on organic waste. It enhances soil fertility and plant growth by supplying essential macro- and micronutrients (N, P, K, Ca, Mg, Zn, etc.) in bioavailable forms, improving soil structure, water retention, and aeration. Crucially, vermicompost contains plant growth regulators—such as auxins, gibberellins, and cytokinins—and humic substances that stimulate seed germination, root development, and nutrient uptake. Research shows it boosts plant biomass (up to 78% in shoots), crop *yield (averaging 26% increase), and quality (e.g., higher vitamin C and sugar content in tomatoes). It also strengthens plant health by inducing systemic resistance against pests and diseases, suppressing pathogens such as Fusarium and Rhizoctonia, and enhancing tolerance to abiotic stresses, such as drought and salinity. Economically, vermicompost reduces dependence on synthetic fertilizers and pesticides, lowers input costs, and improves profitability—evidenced by a growing global market projected to reach USD 270.25 million by 2030. Its role in sustainable and organic farming is pivotal, promoting circular nutrient management, soil restoration, and ecological balance. The document concludes that vermicomposting is a cost-effective, eco-friendly solution essential for regenerative agriculture, with future research needed to optimize large-scale systems and integrate it with other sustainable practices like precision farming and biofertilizers.*

Keywords: Soil Fertility, Plant Growth, Biofertilizer, Nutrient Cycling, Sustainable Agriculture, Microbial Activity, Humic Substances, Root Development, Crop Yield

Received: 9 June 2025, Revised 3 August 2025, Accepted 11 August 2025

1. Introduction

Vermicompost is an organic material that resembles humus and is stabilized through the biological activities of earthworms and microorganisms that break down organic waste. It is produced when earthworms ingest and process organic matter, converting it into a nutrient-rich substance known as vermicast or worm castings (Lim, Wu, Nie, & Shak, 2015; Adhikary, 2012). This transformation increases microbial activity and enhances the physical and chemical properties of the resulting compost, resulting in a material rich in essential nutrients and beneficial microbes (Oyege & Bhaskar, 2023; ScienceDirect, n.d.). The significance of vermicompost in sustainable agriculture has grown due to its ability to enhance soil fertility and plant health while decreasing reliance on chemical fertilisers.

The growth and productivity are essential components of contemporary agriculture, particularly as global food demand increases and arable land declines. The sustainable improvement of plant growth necessitates the optimization of soil quality, nutrient accessibility, and environmental equilibrium.

Traditional agriculture predominantly depends on chemical fertilizers to attain high productivity; however, their persistent application has resulted in challenges such as soil degradation, nutrient imbalance, and environmental contamination (Oyege & Bhaskar, 2023). Consequently, there is increasing interest in organic amendments such as vermicompost, which not only provide nutrients but also enhance soil health, biodiversity, and ecosystem stability (Adhikary, 2012). Therefore, incorporating vermicompost into crop management practices can offer an environmentally friendly and economically feasible alternative to synthetic fertilizers.

Vermicompost promotes plant growth by enhancing soil aeration, water retention, and nutrient availability, while also introducing beneficial microorganisms and growth-enhancing substances such as humic acids, auxins, cytokinins, and gibberellins (Lamichhane, 2017; Lim et al., 2015). Research indicates that plants cultivated in soils enriched with vermicompost exhibit notable increases in biomass, yield, chlorophyll levels, and nutrient uptake (Blouin et al., 2019; Hassan et al., 2022). For example, Blouin et al. (2019) found that applying vermicompost increased yields by an average of 26% and improved shoot biomass by up to 78%. Additionally, vermicompost helps plants cope with abiotic stresses and inhibits soil-borne pathogens, thereby further boosting overall plant health (Oyege & Bhaskar, 2023). Consequently, vermicompost serves as a sustainable soil amendment, crucial for promoting plant growth and enhancing agricultural productivity through various synergistic processes.

2. Nutrient Content of Vermicompost

Vermicompost is frequently abundant in both macro- and micronutrients, typically comprising significant quantities of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and boron (B) (Suthar et al., as referenced in Vermicomposting—Facts, Benefits and Knowledge Gaps, 2021; A comprehensive review of earthworm-derived vermiproducts and applications, 2025). For inst- ance, well-decomposed vermicompost generally contains nitrogen levels ranging from 1.2 % to 2.5 %, phosphorus levels around 0.9 % to 1.7 %, and potassium levels between 1.5 % to 2.5 % (ScienceDirect Topics, n.d.). Research comparing vermicompost to farmyard manure has revealed significantly elevated concentrations of N, P, K, Ca, Cu, Mg, Fe, and Zn in vermicompost (MDPI, 2021). In one experimental study, vermicompost met national compost standards, with measurable levels of Fe, Zn, Mn, Cu, and B, as well as macronutrients (Geremu et al., as cited in "Evaluation of Nutrient Content of Vermicompost," 2020).

In addition to its nutrient content, vermicompost is distinguished by its substantial organic matter and humus content. The process of vermicomposting produces a more stable humified organic matrix—humus—that enhances soil aggregation, cation exchange capacity, and water retention (Composting and vermicomposting of sewage sludge, 2023). Compared with traditional compost, vermicompost typically contains a higher proportion of humic and fulvic acids and more stable organic compounds (Dume et al., 2023). This abundance of humified organic matter ensures that nutrients are retained in forms that release more gradually, providing a buffer against rapid leaching while promoting microbial activity over extended periods (A comprehensive review of earth worm-derived vermiproducts, 2025).

In addition to supplying nutrients and organic matter, vermicompost is rich in growth-promoting substances, such as enzymes (e.g., amylase, lipase, cellulase, chitinase) and plant hormones (e.g., auxins, cytokinins, gibberellins) that facilitate plant growth (Vermicompost, the Story of Organic Gold: A Review, 2012). These bioactive compounds function by speeding up the mineralization of organic materials and affecting root development, cell division, and responses to stress.

When compared to traditional fertilizers or composts, vermicompost frequently exhibits enhanced biological properties: it releases nutrients at a slower rate, promotes greater enzymatic activity in the soil, and encourages microbial diversity in ways that synthetic fertilizers cannot achieve (aerobic composts may be devoid of these biological stimulants) (A comprehensive review of earthworm-derived vermiproducts, 2025; Vermicomposting—Facts, Benefits, and Knowledge Gaps, 2021). For instance, studies comparing inorganic fertiliser, food waste compost, and vermicompost on radish growth indicated that vermicompost treatments led to greater biomass accumulation, likely due to synergistic biological interactions (Almaramah et al., 2024).

3. Mechanisms of Vermicompost on Plant Growth

Vermicompost plays a crucial role in enhancing soil structure and aeration by promoting soil aggregation and increasing porosity. The organic matter present in vermicompost binds soil particles into stable aggregates, which lowers bulk density and facilitates easier air penetration into the soil profile, thereby supporting improved root penetration and gas exchange (Vermicompost: Enhancing Plant Growth and Combating Abiotic and Biotic Stress, 2023; Vermicompost as Organic Amendment: Effects on Some Soil Physical, Biological Properties and Crops Performance on Acidic Soil, 2024). The activity of earthworms further contributes to the formation of macropores through their burrowing, which enhances drainage and prevents waterlogging, thus establishing a more favorable physical environment for plant roots (Vermicompost: Enhancing Plant Growth and Combating Abiotic and Biotic Stress, 2023; The Impact of Vermicomposting on Soil Health, 2024).

The effects of vermicompost on plant-soil interactions remain unclear. (Lazcanoa) Numerous studies have investigated the effects of vermicompost on plant development, yet a quantitative overview of these studies remains lacking. This is the inaugural meta-analysis offering a quantitative assessment of the effect size of vermicompost on plant development. Our findings indicate that vermicompost resulted in average enhancements of 26% in commercial yield, 13% in overall biomass, 78% in shoot biomass, and 57% in root biomass. (Blouin 2019) Chemical fertilizers account for meeting the food needs of 50% of the population in crop production [Erisman]. However, this reliance has resulted in environmental contamination and health problems due to agrochemical residues in food products [Kumar, De castro]. The detrimental impacts of chemical fertilizers have shifted scientists' attention towards "green alternatives" that have a lower environmental footprint [Beneditti]. Among these alternatives, vermicompost stands out as an attractive substitute for traditional chemical fertilizers. Vermicomposting is a non-thermophilic process that converts organic waste into valuable fertilizer through the collaboration of worms and mesophilic microorganisms [Ravindran, Rehman]. Products derived from vermicompost supply essential nutrients, various hormones, enzymes, and humic substances, as well as organic matter, to the soil. (Certitoglu)

By improving water-holding capacity, vermicompost enables soils to retain moisture more efficiently, particularly during dry spells or in soils with low organic matter content. The humic substances, fulvic acids, and organic colloids found in vermicompost function like sponges, absorbing and gradually releasing water back to plant roots (Effects of Vermicompost on Soil and Plant Health..., 2024; Vermicompost Rate Effects on Soil Fertility and Morpho-Physio-Biochemical Traits of Lettuce, 2024). This gradual water retention decreases the frequency of irrigation needed, alleviates drought stress, and sustains more stable soil moisture, thereby fostering consistent cellular turgor and metabolic activity in plants (Vermicompost: Enhancing Plant Growth..., 2023).

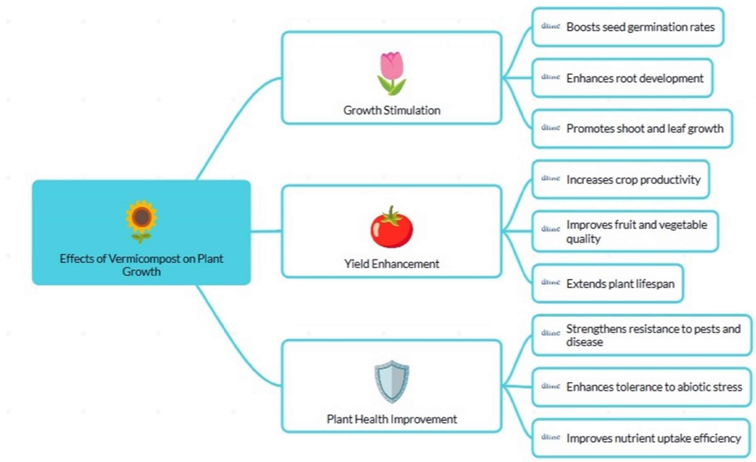

Figure 1. Vermicompost on Plant Growth

Vermicompost supports plant growth in three ways: stimulation of growth, yield enhancement, and improved plant health. (Figure 1)

3.1 Growth Stimulation

Vermicompost contains a wide array of plant growth regulators, such as auxins, gibberellins, and cytokinins, which are naturally produced during earthworm digestion. These phytohormones:

- Promote cell division and elongation, leading to faster seed germination and stronger root development.
- Enhance shoot and root growth, resulting in more vigorous seedlings and mature plants.
- Improve nutrient uptake efficiency by stimulating root hair formation and increasing the surface area for absorption.

Additionally, vermicompost releases nutrients in slow-release, bioavailable forms, providing a steady supply of essential elements like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), which are crucial during early plant development.

3.2 Yield Enhancement

The consistent nutrient supply and improved soil structure facilitated by vermicompost directly translate into higher crop yields. Key contributions include:

- Increased fruiting and flowering: The balanced nutrient profile supports reproductive growth, leading to more flowers, fruits, or grains per plant.

- Improved biomass production: Healthier, more robust plants produce greater above- and below-ground biomass.

- Enhanced photosynthetic efficiency: Better leaf development and chlorophyll content—partly due to adequate micronutrient availability—boost the plant's ability to convert sunlight into energy.

Studies across various crops (e.g., tomatoes, wheat, rice, and legumes) have shown yield increases of 20–40% when vermicompost is used compared to conventional fertilizers or untreated soil.

3.3 Plant Health Improvement

Vermicompost acts as a natural bio-enhancer that strengthens a plant's defense mechanisms and resilience:

Disease Suppression: It fosters a diverse, beneficial rhizosphere microbial community that outcompetes or inhibits soilborne pathogens, including *Fusarium*, *Rhizoctonia*, and *Pythium*.

Pest Resistance: Secondary metabolites and induced systemic resistance (ISR) triggered by vermicompost application help plants deter insect herbivores and reduce pest damage.

Stress Tolerance: Plants grown with vermicompost often exhibit greater tolerance to abiotic stresses, including drought, salinity, and temperature extremes, owing to improved root systems and osmotic regulation.

Reduced need for Chemical Inputs: Healthier plants require fewer synthetic pesticides and fungicides, thereby promoting more sustainable and environmentally friendly agriculture.

Furthermore, vermicompost improves nutrient availability and uptake by plants while promoting beneficial microbial activity in the rhizosphere. It provides vital macro- and micronutrients (including nitrogen, phosphorus, potassium, calcium, magnesium) in forms that are accessible to plants, with these nutrients being released gradually, thereby minimizing losses from leaching or volatilization (Effects of Vermicompost on Soil and Plant Health,2024; Vermicompost Rate Effects on Soil Fertility, 2024). The abundant microbial population, which includes bacteria, fungi, actinomycetes, nitrogen-fixers, and phosphate-solubilizers, plays a significant role in nutrient cycling and converts less accessible soil-bound nutrients into forms that plants can utilize; microbial enzymes (such as phosphatases and ureases) exhibit increased activity in soils amended with vermicompost, enhancing these processes (Effects of Vermicompost on Soil and Plant Health , 2024; Effect of Vermicompost Application on the Soil Microbial

Community Structure2023). Additionally, hormones or hormone-like substances present in vermicompost (auxins, cytokinins, gibberellins) support root development and nutrient uptake, thereby promoting plant growth (Vermicompost: Enhancing Plant Growth, 2023).

4. Effects on Seed Germination

Vermicompost has consistently been shown to improve seed germination rates and enhance early seedling vigor when compared to unfertilized controls or traditional composts. Various studies indicate that seeds treated with vermicompost as a soil amendment, seedling substrate, or seed coating exhibit faster germination, higher germination rates, and more uniform emergence (Atiyeh, Lee, Edwards, Arancon, & Metzger, 2000; Lim, Wu, Nie, & Shak, 2015). The enhancement in germination is typically most significant at low to moderate application rates of vermicompost or when using vermicompost extracts (water-soluble leachates); however, excessively high rates may sometimes hinder germination due to increased soluble salts or phytotoxic levels of certain compounds (Atiyeh et al., 2000; Lim et al., 2015).

The positive effects of vermicompost on germination have been documented across a wide range of crop species, including vegetables (e.g., tomato, lettuce, and cucumber), field crops (e.g., maize and wheat), and horticultural plants (ornamentals and fruit seedlings). Nevertheless, the extent of the response varies with species, seed size, and the form and quantity of vermicompost applied (Blouin et al., 2019; Oyege & Bhaskar, 2023). Comparative research often reveals that small-seed species are more susceptible to substrate salinity, resulting in a narrower optimal range of vermicompost concentration. In contrast, larger-seed species can tolerate higher levels of vermicompost in potting mixes (Blouin et al., 2019). Additionally, meta-analyses and synthesis reviews generally report favorable average effects on germination and early biomass, while also emphasizing the variability stemming from differences in vermicompost feedstock, the species of earthworms utilized, and the conditions under which processing occurs (Blouin et al., 2019).

Several studies have addressed phytotoxicity in vermicomposites in recent years. W³óka's study (2020) aimed to assess alterations in the phytotoxicity of sewage sludge contaminated with polycyclic aromatic hydrocarbons (PAHs) during composting and vermicomposting. The seed germination assay is frequently used to evaluate the maturity and phytotoxicity of composts meant for agricultural applications [Karmegam, 2019]. According to Zucconi et al. [30], compost is deemed mature and non-phytotoxic when it achieves a satisfactory Germination Index. Research by Yatoo et al. (2022) on the GI (%) of Fenugreek seeds (Methi) in fully processed vermicompost from all treatments indicated that vermicomposting renders the biomass of aquatic weeds suitable for agricultural use. A recent investigation revealed that earthworms mitigate the phytotoxicity of organic waste during vermicomposting by breaking down phenolic compounds [Sáez, 2021].

Multiple interacting mechanisms elucidate how vermicompost enhances seed germination. Firstly, vermicompost increases the availability of readily soluble nutrients (N, P, K, and micronutrients) and humic substances, which can expedite metabolic activation in seeds (Lim et al., 2015). Secondly, vermicompost is rich in biologically active compounds—such as plant growth regulators (auxins, cytokinins), vitamins, and enzymes—generated during the processing by earthworms and microbes, which can promote germination and radicle elongation (Atiyeh et al., 2000; Lamichhane, 2017). Thirdly, the microbial community associated with vermicompost can suppress seedborne pathogens and mitigate damping-off, thereby indirectly enhancing emergence rates (Oyege & Bhaskar, 2023). These mechanisms function collectively, yet their relative significance is influenced by application rate, the quality of vermicompost, and the specific physiological traits of the seeds involved, which is why practical guidelines advocate for moderate, tested application levels instead of indiscriminate heavy usage (Lim et al., 2015; Blouin et al., 2019).

5. Impact on Root Development

Numerous studies have demonstrated that vermicompost significantly enhances root length, density, and biomass compared to untreated controls. For instance, in research involving radish (Raphanus sativus), the application of 15 t/ha of vermicompost resulted in the maximum root length (approximately 29.60 cm), root diameter, root weight (H" 191.8 g), biomass weight, and root yield at 60 days post-sowing, while the control exhibited considerably lower values. In Sunflower (Helianthus annuus L.), the incorporation of vermicompost (25-100%) with red soil resulted in increases in both root number and root length over periods of 30, 60, and 90 days, with the most significant growth parameters observed at around 75% vermicompost concentration. Likewise, the application of vermicompost in combination with phosphorus has been shown to increase root length in grasses such as Setaria, suggesting that integrated nutrient management enhances root development.

In addition to size and mass, vermicompost alters root architecture and function, facilitating improved soil exploration and nutrient foraging. In a recent study involving Buxus herlandii, varying amounts of liquid vermicompost (0, 10, 20, 40, 80 mL per pot) indicated that low to moderate doses (10 mL) increased the number of root tips and overall root length, while moderate doses (40 mL) optimized root volume.Conversely, higher doses decreased root surface area, the number of forks, and root crossings—structures crucial for resource acquisition. Furthermore, the presence of humic substances and plant growth regulators in vermicompost, such as auxins and cytokinins, has been shown to promote lateral root extension and branching, thereby improving the root system's ability to explore soil volume and absorb essential water and nutrients.

Vermicompost is essential for enhancing nutrient uptake through root-mediated mechanisms and by improving the physical and biological properties of soil that facilitate root function. In the case of wetland rice, the application of mineral fertilizer in conjunction with vermicompost at a rate of 10 t/ha led to increased nitrogen (N) and phosphorus (P) uptake, which can be attributed to the enhanced availability of nutrients in the soil due to improved microbial activity and soil structure. In ginseng (Panax ginseng), various types of vermicompost, including food waste, cow manure, and paper sludge, significantly increased root yield compared to the control, although changes in ginsenoside content were not uniform, suggesting a potential trade-off; however, improved nutrient status in the roots was confirmed across many treatments. Overall, vermicompost enhances nutrient foraging by roots through both promoting root growth and improving soil conditions, such as aeration, porosity, and microbial activity, which support efficient nutrient uptake.

6. Influence on Plant Growth and Yield

Vermicompost has been shown to significantly improve vegetative growth parameters, including plant height, leaf area, and biomass accumulation. A meta-analysis conducted by Blouin et al. (2019) indicated average increases of 26% in commercial yield, 13% in total biomass, 78% in shoot biomass, and 57% in root biomass when utilizing vermicompost treatments. Likewise, Amaya-Gómez et al. (2025) found that applying vermicompost increased plant biomass by 25%, shoot weight by 61%, and root weight by 64%, along with a 23% increase in plant height. These results highlight the beneficial effects of vermicompost on vegetative growth, resulting in healthier, more vigorous plants. Furthermore, vermicompost has been shown to affect reproductive stages, particularly flowering and fruiting. Rehman et al. (2023) reported that applying vermicompost at 40% and 50% rates led to earlier flowering and fruit development in tomatoes, as well as increased fruit mass and production. This acceleration in reproductive processes may result in more extended harvesting periods and potentially higher overall yields.

Moreover, the use of vermicompost positively influences overall crop yield and quality. Wang et al. (2017) demonstrated that applying vermicompost in tomato cultivation increased fruit yield by 74%, along with improvements in fruit quality indicators, including vitamin C content (47% increase) and soluble sugar concentration (71% increase). These improvements contribute to enhanced nutritional value, flavor, and shelf life of the produce, establishing vermicompost as a valuable organic amendment for sustainable agriculture.

7. Plant Disease and Pest Resistance

Vermicompost has been demonstrated to improve plant immunity by activating systemic defense mechanisms. This enhancement occurs through the induction of systemic resistance (ISR), which is a plant's natural defense response triggered by beneficial microorganisms found in vermicompost. These microorganisms, which include bacteria, fungi, and actinomycetes, generate bioactive compounds such as enzymes, antibiotics, and hormones that strengthen plant defenses and directly combat pathogens (Sarma, 2023). Moreover, vermicompost can modulate a plant's innate resistance response to microbial threats, thereby enhancing its capacity to resist diseases (Sarma, 2023).

Multiple mechanisms mediate vermicompost's ability to suppress plant diseases. The beneficial microorganisms present in vermicompost inhibit plant pathogens through competitive exclusion, antibiosis, and the induction of systemic resistance.

Additionally, these microorganisms produce bioactive compounds, including enzymes, antibiotics, and hormones, which enhance plant defenses and directly counteract pathogens (Sarma, 2023). Furthermore, vermicompost increases the diversity and activity of antagonistic microbes and nematodes, thereby suppressing pests and diseases caused by soil-borne phytopathogens (Yatoo et al., 2021).

8. Economic Benefits of Using Vermicompost

The economic benefits of utilizing vermicompost in agriculture are becoming more widely acknowledged, especially in comparison to traditional chemical fertilizers. Although chemical fertilizers may provide immediate access to nutrients, their long-term expenses—including soil degradation, diminished microbial activity, and the necessity for additional soil amendments—can surpass their initial low cost. Conversely, vermicompost improves soil structure, boosts microbial diversity, and offers a slow-release nutrient profile, resulting in enhanced soil health over time. This comprehensive enhancement can reduce the frequency and volume of chemical inputs required, potentially loweringoverall production costs (Oyege & Bhaskar, 2023).

From an economic perspective, the use of vermicompost has been associated with higher crop yields and improved quality. For example, a meta-analysis indicated that vermicompost applications resulted in average increases of 26% in commercial yield, 13% in total biomass, 78% in shoot biomass, and 57% in root biomass (Blouin et al., 2019). These improvements can increase farmers' revenue through higher-quality produce and enhanced market value. Furthermore, crops treated with vermicompost often exhibit greater resistance to pests and diseases, reducing the need for expensive chemical pesticides and boosting profitability (Oyege & Bhaskar, 2023).

The global market for vermicompost is experiencing significant growth, indicating an increasing demand for sustainable agricultural inputs. In 2022, the global vermicompost market was valued at approximately USD 85.39 million and is anticipated to reach USD 270.25 million by 2030, reflecting a compound annual growth rate (CAGR) of 15.56% (Zion Market Research, 2023). This expansion is fueled by rising consumer demand for organic products and the adoption of sustainable farming practices. In countries such as India, initiatives like the production of vermicompost at cow shelters (gaushalas) have not only aided in waste management but have also generated considerable revenue, with one gaushala producing vermicompost valued at INR 1.75 lakh annually (Times of India, 2025). These instances highlight the economic potential of vermicomposting as both a sustainable agricultural practice and a promising business opportunity.

9. Cautions on Benefits

Even in the preceding section, we claim that vermicompost "consistently" improves outcomes; however, caution is warranted given the issues. While we acknowledge species-dependent responses (e.g., small vs. large seeds), we do not emphasise context dependence—results can vary with soil type, climate, crop rotation, and existing soil fertility. At the same time, we acknowledge the gaps in the discussion, such as carbon footprint comparisons between vermicompost and synthetic fertilisers. This work refrains from debating the contextual constraints, quality variability, and implementation challenges.

10. Conclusion

Vermicomposting is a practical, environmentally friendly approach to transforming organic waste into nutrient-rich compost that enhances soil fertility and encourages vigorous plant growth. The readily available nutrients, along with beneficial microorganisms and plant growth regulators in vermicompost, facilitate improved root development, nutrient absorption, and overall crop productivity. Additionally, the enhanced soil structure and increased water retention contribute to the long-term health and resilience of the soil.

In the realm of sustainable agriculture, vermicomposting is crucial as it reduces reliance on chemical fertilizers, decreases waste accumulation, and promotes a circular nutrient economy. Its implementation supports environmentally susta inable farming practices, ensuring ecological balance and food security for an expanding population. Looking to the future, research should prioritise optimising large-scale vermicomposting systems, investigating microbial interactions within vermicompost, and integrating this method with other sustainable technologies, such as biofertilizers and precision agriculture. With ongoing innovation and increased awareness, vermicomposting has significant potential to serve as a fundamental element of regenerative and sustainable agricultural systems globally.

Acknowledgement

We acknowledge that the critical treatment of analyses in this work is limited.

Funding: The authors have not received any funding for this work.

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