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Review

A review:
The Effect of Vermicompost and Vermicompost Tea on Plant Growth, Yield, Quality and Plant Health

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Abstract: The primary objective of the review is to demonstrate the impact of vermicompost on crop yield. Vermicompost, a nutrient-dense organic fertilizer, contains high concentrations of macro- and micronutrients, vitamins, growth hormones, enzymes such as proteases, amylases, lipases, cellulase, and chitinase, and immobilized microflora. Unlike expensive chemical fertilizers produced in high-tech factories, vermicompost can be cost-effectively produced on farms using simple procedures. Both vermicompost and vermicompost tea have been shown to improve plant germination, growth, biomass, and yields. They enhance plant mineral nutrition levels and significantly boost antioxidant activity and total phenolics in plants, outperforming synthetic fertilization. Additionally, these organic fertilizers are effective in treating plant diseases and pests. As a result, they are recognized as viable alternatives to chemical pesticides and fungicides, contributing to sustainable agriculture and food security.

Keywords: biomass, management of diseases and pests, mineral nutrients

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1. Introduction

Recent years have seen an increase in environmental and economic problems due to the disposal of organic waste from domestic, agricultural, and industrial sources, prompting the development of numerous technologies to address this issue (Olle, 2019). One possible way to handle the waste problem is with vermicompost (VC) technology. Agriculture's green revolution has been a technological achievement globally (Sharma et al., 2019). It asserts that green revolution methods, such as high-yielding plant and animal varieties, mechanized tillage, synthetic fertilizers and bio-pesticides, and transgenic crops, are required to produce enough food for the world's growing population (Behera et al., 2012; Patel et al., 2020).
Organic farming is based on agro-ecological principles (Dufeu et al., 2020). These principles include enhancing and maintaining the agroecosystem through soil fertility conservation and maintenance,

promoting biologically active soil life, enhancing biodiversity, preventing the exploitation and pollution of natural resources, mobilizing natural nutrients, conserving water, managing pests through biological pest control, avoiding the use of synthetic agrochemicals, prohibiting the use of genetic engineering and related products, and utilizing farm manures and crop resistance (Malik et al., 2022). Earthworms promote VC in organic farming systems, which can effectively address a variety of issues such as food safety, security, and productivity, as well as farmland and farmer protection, at the lowest possible cost (Gamage et al., 2023).

Vermiculture is the growth of earthworms on organic wastes; VC is the processing of organic wastes by earthworms. "Bio oxidation and stabilization of organic material involving the joint action of earthworms and mesophilic micro-organisms" describes VC (Lirikum et al., 2022). Under appropriate conditions, worms eat agricultural waste and reduce the volume by 40 to 60% (Olle, 2019; Olle, 2020). VC is made by earthworms and is full of macro- and micronutrients, vitamins, growth hormones, enzymes like proteases, amylases, lipases, cellulase, and chitinase, and microflora that has been immobilized (Verma et al., 2022). The enzymes continue to degrade organic matter even after ejecting from the worms (Olle, 2019).

Ancient civilizations such as Greece and Egypt valued earthworms. The ancient Egyptians were the first to recognize the earthworm's beneficial status (Olle, 2019). Earthworms were considered so important to the agricultural economy in Ancient Egypt that Cleopatra allegedly declared them sacred, and any export of them was punishable by death (Abdul-Soud et al., 2009). The removal of earthworms from Egypt was a capital offense. The fertility god forbade Egyptian farmers from even touching an earthworm (Singh et al., 2020). Ancient Greeks believed that the earthworm significantly improved soil quality (Olle, 2019). Darwin referred to earthworms as farmers' friends and nature's ploughmen in 1881 (Singh and Sinha, 2022). Furthermore, Aristotle named earthworms as the 'instine of earth' because they digest a wide variety of organic materials (Mistry, 2015).

It is also practiced using water extracts from VC, known as compost teas, in addition to VC. People have been using various compost-based plant sprays since the 1920s. A very old gardening practice involves applying compost in a liquid form, such as compost water or compost tea, to plants. The plant seeds were soaked in compost water. Plant health has improved as a result (Scheuerell, Mahaffee, 2002). VC tea, as a liquid fertilizer, can be a good source of nutrients for agricultural plants (Arosha and Sarvananda, 2022).

Foliar nutrient application can help compensate for reduced root intake of essential elements (Aghighi and Sahahverdi, 2020). Vermiwash, a VC extract, combines earthworm secretions and extracts with micronutrients and organic molecules from the soil, providing significant benefits to plant growth when applied foliarly to the plant shoot (Tadayyon et al., 2018). This liquid fertilizer contains enzymes such as protease, amylase, and phosphatase, which are beneficial to plant growth and development, yield increase, and stress resistance (Abdrabbo et al., 2019). Microbial studies on microorganisms in vermiwash have identified nitrogen-stabilizing bacteria such as azotobacter, agrobacterium, and rhizobium, as well as phosphate-soluble bacteria (Tadayyon et al., 2018).

Therefore, this review focuses on the impact of VC on crop production. The second aim of this review article is to describe the effect of VC tea on plant growth, yield, quality, and plant health.

2. Materials and Methods

2.1. Literature Search

To compile and analyze the scientific evidence on the effects of vermicompost (VC) and vermicompost tea (vermiwash) on plant growth, yield, quality, and health, a structured literature search was conducted.

Searches were performed in the Scopus, Web of Science (Clarivate™), and CAB Direct databases between January 2022 and March 2025. The search used combinations of the following keywords:

- "vermicompost" OR "vermiculture" OR "vermitechnology"*
- Combined with: "plant growth" OR "crop yield" OR "vermiwash" OR "vermicompost tea" OR "organic fertilizer" OR "soil health" OR "biopesticide"

The primary search yielded over 3,200 results. A refined search using combinations such as "vermicompost AND plant productivity" and "vermicompost tea AND pest resistance" returned 438 results. Abstracts and full texts were screened for relevance. Review and original research articles were included if they discussed vermicompost or vermiwash in relation to plant development, productivity, disease control, or soil enhancement.

Ultimately, 132 peer-reviewed journal articles, 7 book chapters, and 11 conference papers were selected for review. Publications not focused on agricultural applications or those lacking experimental data or field trials were excluded.

2.2 Data Extraction and Categorization

From the selected literature, we extracted and categorized the following data:

- Type of organic amendment used (VC, vermiwash, or both)
- Plant species involved in the study (e.g., cereals, legumes, vegetables, fruits)
- Application method (e.g., soil amendment, foliar spray, seed treatment)
- Experimental setting (greenhouse, field trial, or laboratory)
- Observed impacts on:
  - Germination rates
  - Biomass accumulation
  - Nutrient content (macro- and micronutrients)
  - Yield improvements
  - Pest or disease resistance

We also noted the source of vermicompost (raw material used and earthworm species) where specified, to better understand the variability in composition and effectiveness.

2.3 Data Synthesis and Interpretation

A qualitative comparative analysis was conducted to identify consistent trends and benefits of VC and vermiwash over conventional fertilizers. In studies with quantitative data, we recorded values for nutrient enhancement (e.g., NPK content), plant biochemical responses (e.g., total phenolics, antioxidants), and yield differentials. Where studies included control groups, relative performance percentages were noted.

Though no original experiments were performed, the results from comparative and meta-analyses in the literature were synthesized to assess:

- The agronomic efficiency of vermicompost relative to traditional compost
- The pest and disease control efficacy of vermiwash versus chemical pesticides
- The sustainability and economic viability of vermicomposting practices

3. Waste management by earthworms

Various epigeic and anecic earthworm species have been the subject of extensive research on solid waste management worldwide (Das et al., 2020; Rupani et al., 2023; Sim, Wu, 2010; Suthar, 2009; Yuvaraj et al., 2021). Ding et al. (2019) have proposed earthworms as a potential source of human protein. Earthworms participate in VCing through physical and biochemical processes. Physical processes include substrate aeration, mixing, and grinding. Earthworm guts contain various enzymes that decompose waste, and microbes in their intestine also influence these biochemical processes (Sharma et al., 2009).

Earthworms eat, grind, and digest organic wastes with the help of some aerobic and some anaerobic microflora. This makes the waste much smaller, more humus-like, and more microbially active (Dume et al., 2022).

Agro-industrial wastes are a huge source of plant nutrients (Mitri et al., 2022). Disposing of that waste means wasting a valuable resource. Table 1 (Olle, 2019) lists a few agro-industrial wastes used for VCing.

Table 1. Potential agro-industrial processing wastes (Olle, 2019).

Agricultural wastes
rice husk, cereal residues, wheat bran, millet straw etc.
Food processing waste
Canning industry waste, breweries waste, dairy industry waste, sugar industry waste press mud and
trash, wine industry waste, oil industry waste-non edible oil seed cake, coffee pulp, cotton waste etc.
Wood processing waste
Wood chips, wood shavings, saw dust
Other industrial wastes
Fermentation waste, paper and cellulosic waste, vegetal tannery waste
Local organic products
Cocofiber dust, tea wastes, rice hulls etc.
Fruits and vegetable processing waste

4. The content of VC and vermiwash.

Abiotic and biotic elements are crucial to the VCing process. Temperature, pH, moisture content, aeration, feed quality, light, and the C/N ratio are examples of abiotic variables. The biotic variables are earthworm stocking density, microorganisms, and enzymes (Sharma and Garg, 2018).

According to reports (Joshi et al., 2015; Sharma et al., 2009), VC has a higher N, P, and K content. Both VCing and composting are viable biowaste management technologies; however, VCing is preferred due to better nutrient availability and less time required for preparation (Patra et al., 2022). Table 2 (Sharma et al., 2009) compares the nutrient composition of VC and garden compost.

Table 2. The comparison between vermicompost and garden compost nutrient composition (Sharma *et al*., 2009).

Nutrient	Vermicompost (%)	Garden compost (%)
Organic carbon	9.8-13.4	12.2
N	0.51-1.61	0.8
P	0.19-1.02	0.35
K	0.15-0.73	0.48
Ca	1.18-7.61	2.27
Mg	0.093-0.568	0.57

Vermiwash is a pale-yellow liquid biofertilizer that is transparent. Earthworm excretory products, mucous secretions, and plant micronutrients comprise its composition (Gawas et al., 2019). It is a powerful biofertilizer to improve plant growth and yield. Vermiwash contains a variety of enzymes, including proteases, amylase, urease, and phosphatase. In addition, it also contains soluble plant nutrients, organic acids, and earthworm and microbe mucus (Gudeta et al., 2021).

Vermiwash had lower pH and electrical conductivity than VC. The nitrogen and potassium content of the VC were 57% and 79.6% higher, respectively, than that of the vermiwash. Though vermiwash had 84% more phosphorus than VC. When compared to the VC, the vermiwash was 89.1% and 97.6% richer in Ca and Mg, respectively. In addition, the sodium content of the vermiwash was 97.8% higher than the sodium content of the VC (Verma et al., 2018).

5. Advantages and disadvantages of VC versus conventional compost

According to Wako and Muleta (2022), VC is four times more nutritious than traditional cattle dung compost. Farmers in Argentina, who use VC, discover it to be seven times richer in nutrients and growth-promoting values than conventional compost (Teka, 2023). VC retains nutrients for a longer period than conventional compost, which lacks adequate amounts of macro and micronutrients

(Rahman et al., 2020). The VC also delivers N, P, and K to plants faster than other media (Thakur et al., 2021). Researchers have also found an increased content of Ca and Mg in the casts (Joshi et al., 2015).

According to its humus content, VC has high porosity, aeration, drainage, and water-holding capacity (Kaur, 2020). Encourage the growth of "beneficial decomposer aerobic bacteria" in waste biomass to increase the biodegradation and decomposition of organic materials from 60% to 80% (Arora et al., 2022). VC has significantly improved in quality, being rich in key minerals and beneficial soil microbes (Shaikh and Shaikh, 2025). The worms produce anti-pathogenic coelomic fluid in the waste biomass, which disinfects and eliminates pathogens (Thakur et al., 2021).

VC contains plant growth regulators and other plant growth promoters produced by microorganisms (Olle, 2019). Researchers have documented the production of cytokinin's and auxins by earthworms. They also release vitamins B and D in the soil (Joshi et al., 2015).

In India, simple techniques can produce VC "on-farm" at a low cost, while factories produce high-tech and expensive chemical fertilizers (Mistry, 2015). Similarly, studies have found that VC technology is a low-cost biofertilizer production method (Saranraj and Stella, 2012). Vermiculture could reduce food costs by 60 to 70% when compared to chemical fertilizers, producing "safe, chemical-free food" for Indian society (Mistry, 2015).

The disadvantage of VC is that it requires at least two months to noticeably transform phytomass into vermicast (Yatoo et al., 2021). A large amount of leaf litter and an equal amount of animal manure are required. Worm castings have a less developed market than regular compost. Frequent aeration and a heterogeneous product are required to produce VC (Thakur et al., 2021).

Adding VC to soil has a positive effect on the soil environment (Olle, 2019). As the soil's organic matter rises, the number of beneficial microbes increases, the soil's cation exchange capacity rises, the soil's bulk density falls, which stops erosion and compaction, the rate of soil-borne pathogens decreases, the soil's ability to hold water rises, and its pH value stays at its ideal level.

The addition of vermiculite to the soil enriches it with beneficial plant growth hormones, essential nutrients, and beneficial microbes that suppress diseases and pests and enhance the overall growth and productivity of crops (Yatoo et al., 2021).

6. The effect of VC on the plant growth, yield, and chemical composition

Adding VC or VC tea to plants tends to increase germination, growth yield, and nutrient content of plants (Table 3, Joshi et al., 2015).

Composted materials may directly or indirectly affect plant growth and yield by chemical, biological, and physical mechanisms (Gomez-Brandon et al., 2015). Possible direct and indirect physiological effects of VC on plants are in Table 4 (Grantina-Ievina et al., 2015).

According to Sarma et al. (2010), the use of organic fertilization accentuated the effect of all VC teas on plant production. VC teas are increasing the yield of plant production. According to a meta-analysis, adding the VC to soil increases commercial crop production by 26%, overall biomass by 13%, and root and shoot biomass by 57% and 78%, respectively (Yatoo et al., 2021). Figure 1 shows the yield increase that VC adds to all tested crops in agricultural farms in Northwest Russia (Gamaley et al., 2001).

Table 3. How plants are affected by vermicompost application (Joshi *et al*., 2015).

Item	Plants affected by vermicompost application
Germination	soybean, tomato
Growth	wheat, tomato, lettuce, pea, eggplant, cucumber, maize, potato, pepper
Yield	wheat, potato, tomato, lettuce, pea (root weight), eggplant, cucumber, tomato (plant weight), pepper

Nutrient content	soybean, wheat, lettuce, cucumber, maize
Mycorrhizal colonization	maize, sorghum

Table 4. Possible direct and indirect physiological effects of vermicompost on plants (Grantina-Ievina et al., 2015).

Constituent	Concentration or level	Possible benefits	Possible negative consequences
Minerals	Relatively low, variable, and unbalanced in respect to elements	Directly used for needs of mineral nutrition, increased plant growth, and development	Do not meet optimum needs at low level of application. Certain elements can be at toxic level.
Organic matter	Relatively high	Indirect benefit from improving soil properties, long term effect from acting as nutrients for microorganisms	Decrease in plant availability of certain minerals.
Biologically active substances	Highly variable, usually high	Promote plant growth, improve uptake of minerals, induce resistance against pests and diseases	Positive effect will be seen only at optimum level of mineral supply. Include growth inhibitory substances
Microorganisms	Highly variable, usually high	Promote availability of mineral nutrients through mineralization and solubilization. Release biologically active substances	Can contain potentially harmful microorganisms

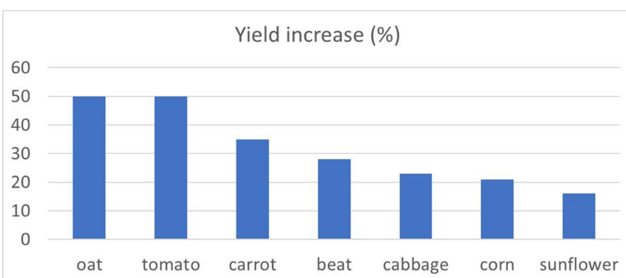

Figure 1. Yield increase (%) of various crops with vermicompost extracts. Plants: 1 – oats, 2 – tomato, 3 – carrot, 4 – beat, 5 – cabbage, 6 – corn, 7 – sunflower (Gamaley et al., 2001).

It was applied foliar sprays of vermiwash (at 50 l ha-1) and water at 15, 35, and 50 days of crop age, while it was applied water sprays to the remaining plots based on the treatment. The vermiwash foliar spray produced more vegetable pea branches (3.23) than the water spray (2.96). When compared to water spray, the mean grain yield with vermiwash was significantly higher (10.42 q ha-1) than with water spray (9.68 q ha-1). When compared to the control, the use of VC together with vermiwash (5 or 10%) resulted in a 70% increase in fresh yield for vegetable pea plants (Verma et al., 2018).

Vermiwash is an excellent liquid manure that has a significant impact on crop growth and productivity during foliar spraying. Coelomic fluid extraction contains enzymes, plant growth hormones such as cytokinins, gibberellins, and vitamins, as well as micro- and macronutrients. It improves the crop's disease resistance (Verma et al., 2017).

According to Blouin et al. (2019), VC has increased commercial yield by 26% in the Cucurbitaceae, Asteraceae, Fabaceae, and Poaceae families of plants. It has also increased total biomass by 13%, shoot biomass by 78%, and root biomass by 57%.

The use of organic fertilization most noticeably increased mineral nutrients and total carotenoids in all VC (VC) teas. Organic fertilization resulted in higher antioxidant activity and total phenolics in plants than synthetic fertilization (Sarma et al., 2010). Figure 2 illustrates how VC enhances the nutritional value of beets in agricultural farms in Northwest Russia (Gamaley et al., 2001).

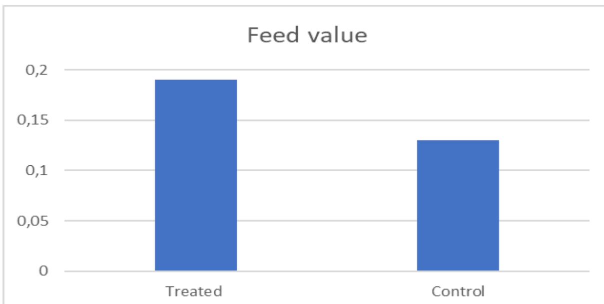

Figure 2. The effect of vermicompost extracts on the beat feed nutritional value (Gamaley et al., 2001).

In an experiment in Northwest Russia, the use of VC extract had no effect on the quality of oat seeds, but it did influence the shoot composition (Table 5). The protein content of the leaves, as well as the lignin content of the leaves and straw, was higher in treated plants than in untreated plants (Gamaley et al., 2001).

Table 5. The protein content of the leaves, as well as the lignin content of the leaves and straw of oats plants (Gamaley et al., 2001).

Sample	Lignin	Protein
Leaves, control	21.8	19.7
Leaves, treated	25.2	22.8
Straw, control	27.4	12.2
Straw, treated	33.9	12.7
$LSD_{0,5}$	1.3	1.6

Researchers have found that organic fruits and vegetables are more nutritious, rich in antioxidants, organic acids, and polyphenolic compounds, and beneficial to human health compared to chemically grown food (Serri et al., 2021). VC boosts the mineral content of organic foods (Rehman et al., 2023). Mistry (2015) discovered that tomatoes grown in a VC substrate exhibited significantly higher levels of antioxidants, total carotene, iron (Fe), zinc (Zn), crude fiber, and lycopene compared to other organically grown tomatoes. Organic apples, cabbage, carrots, beetroots, spinach, tomatoes, turnips, celery, lentils, lettuce, peppers, potatoes, and pears all had higher vitamin C levels (Mistry, 2015).

7. Plant health

In the last two decades, the liquid solution of VC, i.e., VC tea, has been widely used for the management of plant diseases and pests (Edwards and Arancon, 2022). VC tea, which is also called organic biofertilizer, has microbes, nutrients, and plant growth promoters in it. Using it helps seeds sprout, increases growth and yield, and stops plant diseases (Yatoo et al., 2021).

Vermicast is believed to transfer nutrients and microbes into a liquid solution known as VC tea, enhancing its usefulness (Emam and Mohamed, 2022). VC teas also have significant pest control potential due to the presence of phenolic substances that render plant tissues unpalatable (Yatoo et al., 2021). Vermiwash acts as a pesticide, disease curative, and crop tonic (Verma et al., 2018). For managing *Leptocorisa varicornis* and increasing rice crop productivity, vermiwash with bio-pesticide is a better option than chemical fertilizers and pesticides. Vermiwash is a mild biopesticide that works better when mixed with plant allelochemicals to reduce the population of *Leptocorisa varicornis*. This increases crop yields (Verma et al., 2018). The combination of vermiwash with bio-pesticide is more effective in promoting the growth of the brinjal crop, enhancing productivity, and managing the *Leucinodes orbonalis* infestation. The foliar spray of vermiwash provides the growing plant with the nutrients it requires for elongation, early flowering, and fruiting. Biopesticides are more effective against fruit and shoot borer larvae and caterpillars without contaminating fruits. Biopesticides are an alternative to chemical fertilizers and pesticides for *Leucinodes orbonalis* population management (Verma et al., 2018). Table 6 (Joshi et al., 2015; Yatoo et al., 2021) illustrates the impact of VC and VC tea on plant health. General disease suppression is made up of antibiosis, hyper-parasitism or predation, nutrient competition, and systemic-induced resistance (Yatoo et al., 2021). In different ways of getting rid of pests, phenolic substances are released, microbes and predatory nematodes become more common, food becomes more available, and toxic chemicals are released (Yatoo et al., 2021).

Table 6. The plant health effect of vermicompost and vermicompost tea (Joshi et al., 2015; Yatoo et al., 2021).

Crop	Disease / pest
Corn	earworm
Cabbage	earworm, aphids, mealy bugs, white caterpillars
Chickpea	fusarium wilt
Pea	powdery mildew
Mustard	aphid
Cucumber	beetles, hornworms, green peach aphid, citrus mealybug, two spotted spider mites, damping off, root rot, fusarium wilt
Tomato	green peach aphid, citrus mealybug, two spotted spider mites, hornworm, beetles, late blight disease, aphids, mealy bugs, white caterpillars, fusarium wilt
Pepper	aphids, mealy bugs, white caterpillars
Radish	dampng off, root rot
Potato	late blight disease
Rice	foot rot
Onion	sclerotium cepivorum
Zucchini	reniform nematode

Scientists tested various types of compost tea (aerated VC tea (ACTV), non-aerated VC tea (NCTV), aerated compost tea (ACTC), and non-aerated compost tea (NCTV)) to see which one could stop *Fusarium moniliforme* foot rot disease in rice plants. They then compared the results with a treatment of carbendazim. Among the compost teas, ACTV produced the healthiest seedlings. Treatment of rice seeds with compost tea revealed the highest efficiency of ACTV in reducing the number of affected seeds in comparison to the field trial experiment. The use of compost tea also increased the % of seeds that germinated, with ACTV having the greatest effect (Sarma et al., 2010).

Applying extracts from composted cow manure, composted pine bark, organic farm compost, or composted yard waste as foliar sprays to tomato transplants resulted in a moderate but statistically significant reduction in the severity of bacterial spots caused by *Xanthomonas vesicatoria*. Extracts prepared from composted cow manure significantly reduced the population of *X. vesicatoria* in

infected leaves. Spraying the leaves with the best compost extracts gave control that was about the same as using the plant stimulant acibenzolar-S-methyl (Sarma et al., 2010).
According to a study (Sarma et al., 2010) strong VC tea to kill CMM (*Clavibacter michiganensis* subsp. michiganensis) in the lab and on young tomato seedlings that had the pathogen put into them in a greenhouse. Results of a study (Sarma et al., 2010) showed that VC tea could prevent the occurrence of bacterial canker on tomato plants caused by CMM in greenhouse conditions.
VC tea can also coat leaf surfaces, reducing available sites for pathogen infection or increasing microbial diversity, which can kill harmful pathogens (Yatoo et al., 2021).
The aerated VC teas suppressed the plant diseases caused by *Fusarium*, *Verticillium*, *Plectosporium*, and *Rhizoctonia*. VC teas also significantly reduced spider mite (*Tetranychus urticae*) and aphid (*Myzus persicae*) populations. Lastly, research at The Ohio State University has shown that VC teas can significantly reduce attacks on tomatoes and other vegetable crops. The reduction of plant parasitic nematodes, like tomato cyst eelworms, and root knot nematodes, like Meloidogyne, is possible (Mistry, 2015).
VC tea, as eco-friendly organic amendments and a replacement for inorganic pesticides and fungicides, can successfully manage diseases and pests without harming human health or the environment, paving the way for the provision of chemical-free food for humanity in the future (Yatoo et al., 2021).

8. Results and Discussion

This section discusses the findings derived from the review of the available literature on the use of VC and vermiwash in sustainable agricultural practices. The analysis covers the benefits of these organic amendments in improving soil health, plant growth, and overall agricultural sustainability.

8.1. Nutrient Enhancement in Soil and Plant Growth

Research consistently highlights the superior nutrient content of VC compared to conventional compost. VC is rich in essential macro- and micronutrients, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and trace elements like copper, zinc, and manganese. These nutrients are made more bioavailable to plants due to the microbial activity during vermiculture. Numerous studies have demonstrated that the application of VC leads to improved soil fertility, enhancing both nutrient availability and the physical structure of the soil (e.g., porosity and water retention capacity) (Edwards et al., 2010).
When applied to plants, VC has been shown to improve growth rates, enhance root development, and increase overall yield. This has been confirmed in a variety of crops, including vegetables, fruits, and grains. VC teas are increasing the yield of the plant production. According to a meta-analysis, adding the vermicompost to soil increases commercial crop production by 26 percent, overall biomass by 13 percent, and root and shoot biomass by 57 and 78 percent, respectively (Yatoo et al., 2021). Similar improvements were seen in the growth of rice, wheat, and corn when treated with VC (Chowdhury, 2007).

8.2. Microbial Activity and Soil Health

VC enhances the microbial biodiversity in the soil, promoting beneficial microorganisms such as nitrogen-fixing bacteria, mycorrhizal fungi, and other plant growth-promoting rhizobacteria (PGPR). These microbes play a critical role in improving soil health by enhancing nutrient cycling, decomposing organic matter, and promoting disease suppression (Arancon et al., 2004). Studies indicate that soil treated with VC exhibits higher microbial biomass and diversity compared to soils treated with chemical fertilizers (Pascual et al., 2006).
Moreover, the microbial communities in VC contribute to the suppression of soil-borne diseases, such as those caused by Fusarium and Pythium species (Bishnoi et al., 2007). The presence of beneficial microorganisms in VC has been linked to an increase in disease resistance in plants. This provides a

natural, environmentally friendly alternative to synthetic pesticides, supporting sustainable agriculture by reducing chemical inputs (Bishnoi et al., 2007).

8.3. Vermiwash and its Effects on Plant Growth

Vermiwash, a liquid extract produced from the leachate of VC, has also garnered attention for its beneficial effects on plant growth. This liquid contains water-soluble nutrients, enzymes, growth hormones (such as auxins, cytokinins, and gibberellins), and beneficial microorganisms. Several studies have shown that vermiwash can stimulate seed germination, improve plant growth, and enhance resistance to plant diseases (Yadav and Singh, 2010).

VC encompasses a wide array of beneficial components, including hormones, enzymes, vitamins, proteins, diverse macro- and micronutrients, and abundant microbial populations, all of which contribute to establishing a favorable environment for plant growth. These constituents mitigate abiotic stress while simultaneously creating conditions that are unfavorable for pathogenic soil microorganisms and pests. Moreover, the rapid proliferation of beneficial soil microbes associated with earthworms in VC and vermiwash enhances competitive interactions and provides effective defense against disease-causing agents. Consequently, the incorporation of vermiwash or VC into soil, or their application as foliar sprays, has been shown to significantly suppress plant pathogens and pests, thereby improving overall crop health and productivity (Gudeta et al., 2021).

8.4. Soil Structure and Water Retention

The application of VC significantly improves the physical properties of the soil. VC enhances soil aeration, water-holding capacity, and aggregate stability, which are critical factors for maintaining healthy soil, particularly in areas prone to drought or erosion (Edwards et al., 2010). In addition to nutrient enrichment, VC has been shown to increase soil organic matter content, which in turn improves the soil's water retention capacity (Olle, 2019). These benefits are particularly important in arid and semi-arid regions where water conservation is essential for crop production (Bünemann et al., 2006).

8.5. Environmental Sustainability and Cost-Effectiveness

Vermiculture practices contribute to the reduction of waste, as they involve the recycling of organic matter, such as agricultural residues, food waste, and animal manure. This waste-to-resource conversion not only reduces landfill waste but also minimizes the carbon footprint associated with the production of synthetic fertilizers (Edwards et al. 2010). The carbon sequestration potential of VC also contributes to mitigating climate change (Hepperly, Setboonsarng, 2015).

From an economic perspective, the production of VC can be highly cost-effective, especially in regions where organic waste is abundant. Small-scale farmers and household gardeners can produce their own VC and vermiwash, reducing their dependence on commercial fertilizers and chemical pesticides (Ndegwa and Thompson, 2000). Use of VC not only reduces the requirement of chemical fertilizers but also supplements important all essential nutrients to increase crop yield besides improving the soil properties and processes, which increase profits (Sharma and Banik, 2014).

8.6. Challenges and Limitations

Despite its numerous benefits, there are challenges associated with the widespread adoption of vermiculture. The primary limitation is the lack of standardized protocols for the production and quality control of VC and vermiwash. Variability in the quality of VC can arise from differences in the source material used, earthworm species, and environmental conditions (Pascual et al., 2006). This necessitates further research to establish guidelines for optimizing vermiculture systems and ensuring the consistency of the products.

Additionally, while VC is a powerful tool for improving soil health, it may not provide immediate results comparable to chemical fertilizers, particularly in nutrient-depleted soils. As such, a balanced approach that incorporates both organic and conventional farming practices may be necessary in some cases to meet immediate agricultural needs while working toward long-term sustainability (Olle, 2019).

8.7. Future Directions

Future research should focus on optimizing vermiculture systems, developing efficient production methods, and enhancing the bioavailability of nutrients in VC and vermiwash. Investigating the effects of different types of organic waste on the quality of VC is essential for improving its efficiency as a fertilizer (Edwards et al., 2010). Additionally, exploring the potential of vermiwash in combination with other biocontrol agents and organic amendments could lead to more integrated pest management systems (Bishnoi et al., 2007).

The development of low-cost, automated vermiculture systems for smallholder farmers could also promote the adoption of sustainable agricultural practices in developing regions (Ndegwa and Thompson, 2000). Increased awareness and education about the benefits of VC and vermiwash will be critical in encouraging widespread use (Olle, 2019).

9. Publishing of agricultural articles dealing with vermicompost in Scopus database

Publishing of agricultural articles dealing with vermicompost in Scopus database is illustrated on the figure 3. There was observed a trend in vermicomposting articles (2000–2024):

Early Years (2000–2009): Very few articles per year, mostly in the single digits or low double digits. Lowest was 2001 with just 5 articles. Suggests vermicomposting was a niche or emerging topic in academic or environmental literature.

Growth Phase (2010–2016): A steady increase in the number of articles. From 2010 (38 articles) to 2016 (82 articles), we see a noticeable upward trend. Indicates growing interest in sustainable waste management and organic farming techniques.

Expansion Phase (2017–2021): Articles per year continued increasing significantly. Peaked around 2021 with 148 articles. Reflects heightened global awareness of composting and eco-friendly waste processing.

Peak Years (2022–2024): 2022: 147 articles. 2023: 201 articles. 2024: 232 articles (highest yet). This shows vermicomposting has become a mainstream research topic or practice area, potentially driven by environmental policies, circular economy trends, or climate change awareness.

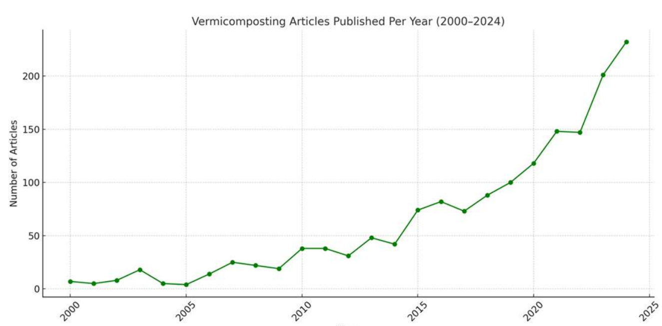

Figure 3. Publishing of agricultural articles dealing with vermicompost in Scopus database.

To conclude there is a clear and strong upward trend in the number of vermicomposting-related articles over the last two decades, especially accelerating from 2015 onward. The highest activity is in the last three years, suggesting it is a current and growing field of interest.

10. Conclusions

VC, a nutrient-dense organic fertilizer, contains high concentrations of macro- and micronutrients, vitamins, growth hormones, enzymes such as proteases, amylases, lipases, cellulase, and chitinase, and immobilized microflora. Unlike expensive chemical fertilizers produced in high-tech factories, VC can be cost-effectively produced on farms using simple procedures.

Both VC and VC tea have been shown to improve plant germination, growth, biomass, and yields. They enhance plant mineral nutrition levels and significantly boost antioxidant activity and total phenolics in plants, outperforming synthetic fertilization. Additionally, these organic fertilizers are effective in treating plant diseases and pests. As a result, they are recognized as viable alternatives to chemical pesticides and fungicides, contributing to sustainable agriculture and food security.

Future Research Directions: Enhanced Formulations: Future research could focus on optimizing the formulations of VC and VC tea to further enhance their effectiveness in different soil types and climatic conditions.

Microbial Studies: Exploring the specific microbial communities within VC that contribute to plant health and pest resistance could lead to the development of targeted bio-fertilizers.

Climate Resilience: Investigating the role of VC in improving plant resilience to climate change-related stresses, such as drought and extreme temperatures, could provide valuable insights for future agricultural practices.

Economic Analysis: Conducting comprehensive economic analyses to compare the long-term benefits and costs of VC versus chemical fertilizers would help in promoting its adoption among farmers.

Regulatory Frameworks: Developing policies and regulatory frameworks that support the production and use of VC could drive broader adoption and integration into mainstream agricultural practices.

The future of VC research holds immense potential to revolutionize sustainable agriculture, making it a cornerstone in the pursuit of ecological balance, food security, and environmental health. By continuing to explore and optimize its applications, it can pave the way for a more resilient and sustainable farming future.

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6. References

1. Abdrabbo MA, Maharik ZY, Farag AA, Abul-Soud M, Fahim MA. (2019): Potato production by using different potassium rates and vermi-wash spray applications. Acta agriculturae Slovenica. 113(2), 299-305. https://doi.org/10.14720/aas.2019.113.2.11
2. Abul-Soud M, Hassanein MK, Ablmaaty SM, Medany M, and Abu-Hadid AF, (2009): Vermiculture and vermicomposting technologies use in sustainable agriculture in Egypt. Journal of Agricultural Research 87(1), 389-401.
3. Arancon NQ, Edwards CA, Lee S, Byrne R (2004): Effects of Vermicomposts on Plant Growth and Soil Properties. In: Proceedings of the International Symposium on Earthworms and Vermiculture. 127-134.
4. Arora S, Saraswat S, Kazmi AA (2022): Vermifilter: A biofilter with earthworms for wastewater treatment. An Innovative Role of Biofiltration in Wastewater Treatment Plants (WWTPs) 87-112. https://doi.org/10.1016/B978-0-12-823946-9.00013-9
5. Arosha KPL, Sarvananda L (2022): Vermicomposting tea a potential liquid biofertilizer. Frontiers in Life Science Research 1(1), 1-5. https://doi.org/10.56397/FLSR.2022.10.01
6. Behera KK, Alam A, Vats S, Sharma HP, Sharma V (2012): Organic farming history and techniques. Agroecology and strategies for climate change 287-328. https://doi.org/10.1007/978-94-007-1905-7_12
7. Bishnoi NR, Gupta A, Kaur P (2007): Vermicompost in Sustainable Agriculture. International Journal of Environmental Science and Technology 4(1), 72-79.
8. Blouin M, Barrere J, Meyer N, Lartigue S, Barot S, Mathieu J (2019): Vermicompost significantly affects plant growth. A meta-analysis. - Agronomy for Sustainable Development 39(4), 1-15. https://doi.org/10.1007/s13593-019-0579-x
9. Bünemann EK, Schwenke GD, Smernik RJ (2006): Soil Organic Matter and Its Role in Improving Soil Quality. In: Soil Health and Fertility Management in Organic Farming. Springer, 48-63.
10. Chowdhury S (2007): Effect of integrated use of inorganic fertilizers and vermicompost on the nutrient cot'centration, uptake, yield, and oil content of soybean. Doctoral dissertation, Dept. of Soil Science, Sher-e-Bangla Nagar, Dhaka, Bangladesh.
11. Das S, Goswami L, Bhattacharya SS (2020): Vermicomposting: earthworms as potent bioresources for biomass conversion. In Current Developments in Biotechnology and Bioengineering (pp. 79-102). Elsevier. https://doi.org/10.1016/B978-0-444-64309-4.00003-9
12. Ding S, Lin X, He S (2019): Earthworms: A source of protein. The Journal of Food Science and Engineering, 9, 159-170. https://doi.org/10.17265/2159-5828/2019.05.001
13. Dufeu I, Le Velly R, Bréchet JP, Loconto A (2020): Can standards save organic farming from conventionalisation? Dynamics of collective projects and rules in a French organic producers' organisation. Sociologia ruralis 60(3), 621-638. https://doi.org/10.1111/soru.12298
14. Dume B, Hanc A, Svehla P, Michal P, Chane AD, Nigussie A (2022): Vermicomposting technology as a process able to reduce the content of potentially toxic elements in sewage sludge. Agronomy 12(9), 2049. https://doi.org/10.3390/agronomy12092049
15. Edwards CA, Arancon NQ, Sherman RL 2010. Vermiculture technology: earthworms, organic wastes, and environmental management. 1st edition. CRC Press. 623 p. https://doi.org/10.1201/b10453
16. Edwards CA, Arancon NQ (2022): The use of earthworms in organic waste management and vermiculture. In Biology and Ecology of Earthworms (pp. 467-527). New York, NY: Springer US. DOI: https://doi.org/10.1007/978-0-387-74943-3_14
17. Emam MSA, Mohamed MAS (2022): Orchard Biomass Management. In Handbook of Research on Principles and Practices for Orchards Management (pp. 15-32). IGI Global. https://doi.org/10.4018/978-1-6684-2423-0.ch002
18. Gamage A, Gangahagedara R, Gamage J, Jayasinghe N, Kodikara N, Suraweera P, Merah O (2023): Role of organic farming for achieving sustainability in agriculture. Farming System 1(1), 100005. https://doi.org/10.1016/j.farsys.2023.100005
19. Gamaley AV, Nadporozhskaya MA, Popov AI, Chertov OG, Kovsh NV, Gromova OA (2001): Non-root nutrition with vermicompost extracts as the way of ecological optimisation. - In Plant Nutrition (pp. 862-863). Springer, Dordrecht. https://doi.org/10.1007/0-306-47624-X_420
20. Gawas IG, Kolekar DT, Dongare SV, Chavan VB, Mhetre AG, Khatke SL, Malavade PS (2019): Chemical analysis of vermiwash (sp. E. foetida). International Journal of Chemical Studies 7(5), 3238-3240.

21. Gómez-Brandón M, Vela Maria, Martínez-Toledo MV, Insam H, Domínguez J (2015): Effects of compost and vermicompost teas as organic fertilizers. - Advances in Fertilizer: Technology Synthesis 1:300-318.
22. Grantina-Ievina L, Nikolajeva V, Rostoks N, Skrabule I, Zarina L, Pogulis A, Ievinsh G (2015): Impact of green manure and vermicompost on soil suppressiveness, soil microbial populations, and plant growth in conditions of organic agriculture of Northern temperate climate. - In Organic amendments and soil suppressiveness in plant disease management (pp. 381-399). Springer, Cham.
23. Gudeta K, Julka JM, Kumar A, Bhagat A, Kumari A (2021): Vermiwash: An agent of disease and pest control in soil, a review Heliyon, 7(3), 1-8. 10.1016/j.heliyon.2021.e06434
24. Hepperly PR, Setboonsarng S (2015): Carbon Sequestration in Organic Agriculture and Climate Change: A Path to a Brighter Future. Organic agriculture and post 2015 development goals. 379 pp.
25. Joshi R, Singh J, Vig AP (2015): Vermicompost as an effective organic fertilizer and biocontrol agent: effect on growth, yield and quality of plants. - Reviews in Environmental Science and Bio/Technology 14(1), 137-159. https://doi.org/10.1007/s11157-014-9347-1
26. Kaur T (2020): Vermicomposting: An effective option for recycling organic wastes. Organic agriculture, pp.1-17. https://doi.org/10.5772/intechopen.91892
27. Lirikum KLN, Thyug L, Mozhui L (2022): Vermicomposting: an eco-friendly approach for waste management and nutrient enhancement. Tropical Ecology 63(3), 325-337. https://doi.org/10.1007/s42965-021-00212-y
28. Malik N, Kumar D, Mungali M, Tripathi P (2022): Organic Farming: A Key to Sustainable Development. In Handbook of Research on Green Technologies for Sustainable Management of Agricultural Resources (pp. 370-384). IGI Global. https://doi.org/10.4018/978-1-7998-8434-7.ch024
29. Mistry J (2015): Vermicompost, a best superlative for organic farming: a review. Journal of Advanced Studies in Agricultural, Biological and Environmental Sciences 2(3), 38-46.
30. Mitri S, Koubaa M, Maroun RG, Rossignol T, Nicaud JM, Louka N (2022): Bioproduction of 2-phenylethanol through yeast fermentation on synthetic media and on agro-industrial waste and by-products: A review. Foods 11(1), 109. https://doi.org/10.3390/foods11010109
31. Ndegwa PM, Thompson SA (2000): Effects of Vermicomposting on Agricultural Waste Management and Its Economic Potential. Waste Management, 20(6), 1-9.
32. Olle M (2019): Vermicompost, its importance and benefit in agriculture. Agraarteadus 2, 93–98. https://doi.org/10.15159/jas.19.19.
33. Olle M (2020): Vermicompost is boosting greenhouse vegetable production. USA: Amazon Media EU S.à r.l. (in English), 101 pp.
34. Pascual JA, García C, Hernández MT (2006): Microbial Biomass and Activity in Soils Amended with Vermicompost. Journal of Applied Soil Ecology 31(3), 265-273.
35. Patel SK, Sharma A, Singh GS (2020): Traditional agricultural practices in India: an approach for environmental sustainability and food security. Energy, Ecology and Environment 5, 253-271. https://doi.org/10.1007/s40974-020-00158-2
36. Patra RK, Behera D, Mohapatra KK, Sethi D, Mandal M, Patra AK, Ravindran B (2022): Juxtaposing the quality of compost and vermicompost produced from organic wastes amended with cow dung. Environmental Research 214, 114119. https://doi.org/10.1016/j.envres.2022.114119
37. Rahman A, Hashem MA, Kabir AKMA, Bhuiyan MKJ, Rahman MM (2020): Influence of amount of red worm (*Eisenia foetida*) on the organic matter degradation during vermicomposting of cattle manure. Bangladesh Journal of Animal Science, 49(1), 45-54. https://doi.org/10.3329/bjas.v49i1.49377
38. Rehman SU, De Castro F, Aprile A, Benedetti M, Fanizzi FP (2023): Vermicompost: Enhancing plant growth and combating abiotic and biotic stress. Agronomy 13(4), 1134. https://doi.org/10.3390/agronomy13041134
39. Rupani, PF, Embrandiri A, Mupambwa HA, Domínguez J (2023): Potential Transformation of Organic Waste in African Countries by Using Vermicomposting Technology. In Vermicomposting for Sustainable Food Systems in Africa (pp. 335-348). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-19-8080-0_19
40. Saranraj P, Stella D (2012): Vermicomposting and its importance in improvement of soil nutrients and agricultural crops. - Novus Natural Science Research 1(1), 14-23.
41. Sarma BK, Singh P, Pandey SK, Singh HB (2010): Vermicompost as modulator of plant growth and disease suppression. Dynamic Soil, Dynamic Plant 4, 58-66.

42. Scheuerell S, Mahaffee W (2002): Compost tea: principles and prospects for plant disease control. - Compost Science & Utilization 10(4), 313-338. DOI: https://doi.org/10.1080/1065657X.2002.10702095
43. Shaikh KM, Shaikh RU (2025) Vermicompost: role in sustainable agriculture. Infinite Path Res Across Disciplines. Pp. 125-131.
44. Serri F, Souri MK, Rezapanah M (2021): Growth, biochemical quality and antioxidant capacity of coriander leaves under organic and inorganic fertilization programs. Chemical and Biological Technologies in Agriculture 8(1), 1-8. DOI: https://doi.org/10.1186/s40538-021-00232-9
45. Sharma RC, Banik P. (2014): Vermicompost and fertilizer application: Effect on productivity and profitability of baby corn (Zea Mays L.) and soil health. Compost Science & Utilization. 22(2), 83-92.
46. Sharma K, Garg VK (2018): Vermicomposting: a green technology for organic waste management. Waste to wealth 199-235. https://doi.org/10.1007/978-981-10-7431-8_10
47. Sharma R, Aravind T, Sharma R (2019): Sustainable agriculture: Trends and opportunities for 21st century. Journal of Applied and Natural Science 11(3), 666-672. https://doi.org/10.31018/jans.v11i3.2156
48. Sharma S, Kumar A, Singh AP, Vasudevan P (2009): Earthworms and vermitechnology – a review. - Dynamic soil, Dynamic plant 3(2), 1-12.
49. Sim EYS, Wu TY (2010): The potential reuse of biodegradable municipal solid wastes (MSW) as feedstocks in vermicomposting. Journal of the Science of Food and Agriculture 90(13), 2153-2162. https://doi.org/10.1002/jsfa.4127
50. Singh A, Omran ESE, Singh GS (2020): Vermicomposting Impacts on Agriculture in Egypt. Technological and Modern Irrigation Environment in Egypt: Best Management Practices & Evaluation 181-203. https://doi.org/10.1007/978-3-030-30375-4_9
51. Singh S, Sinha RK (2022): Vermicomposting of organic wastes by earthworms: Making wealth from waste by converting 'garbage into gold'for farmers. In Advanced Organic Waste Management (pp. 93-120). Elsevier. https://doi.org/10.1016/B978-0-323-85792-5.00004-6
52. Suthar S (2009): Vermicomposting of vegetable-market solid waste using *Eisenia fetida*: Impact of bulking material on earthworm growth and decomposition rate. Ecological engineering 35(5), 914-920. *https://doi.org/10.1016/j.ecoleng.2008.12.019*
53. Tadayyon A, Naeimi MM, Pessarakli M (2018): Effects of vermicompost and vermiwash biofertilizers on fenugreek (*Trigonella foenum*) plant. Communications in Soil Science and Plant Analysis, 49(19), 2396-2405. https://doi.org/10.1080/00103624.2018.1510950
54. Teka K (2023): The role of local earthworms in plant nutrient addition in the Ethiopian Drylands. Scientia Agricola, 80, p.e20220139.
55. Thakur A, Kumar A, Kumar C, Kiran B, Kumar S, Athokpam V (2021): A review on vermicomposting: By-products and its importance. Plant Cell Biotechnology and Molecular Biology 22, 156-164.
56. Verma K, Sharma P, Saini SP (2022): Impact of Integrated Nutrient Management in Enhancing the Growth and Yield of Crops. Vigyan Varta 3(9), 83-93.
57. Verma S, Babu A, Patel A, Singh SK, Pradhan SS, Verma SK, Singh JP, Singh RK (2018): Significance of vermiwash on crop production: a review. Journal of Pharmacognosy and Phytochemistry 7(2), 297-301.
58. Verma S, Singh A, Pradhan SS, Singh RK, Singh JP (2017): Bio-efficacy of organic formulations on crop production-A review. - International Journal of Current Microbiology and Applied Sciences 6(5), 648-665. https://doi.org/10.20546/ijcmas.2017.605.075
59. Wako FL, Muleta HD (2022): The role of vermicompost application for tomato production: a review. Journal of Plant Nutrition 46(1), 129-144. https://doi.org/10.1080/01904167.2022.2035751
60. Yadav SK, Singh S (2010): Vermiwash for Enhanced Growth of Legumes. Journal of Applied Horticulture 12(4), 231-236.
61. Yatoo AM, Ali M, Baba ZA, Hassan B (2021): Sustainable management of diseases and pests in crops by vermicompost and vermicompost tea. A review. - Agronomy for Sustainable Development 41(1), 1-26. https://doi.org/10.1007/s13593-020-00657-w
62. Yuvaraj A, Thangaraj R, Ravindran B, Chang SW, Karmegam N (2021): Centrality of cattle solid wastes in vermicomposting technology–a cleaner resource recovery and biowaste recycling option for agricultural and environmental sustainability. Environmental Pollution 268, 115688. https://doi.org/10.1016/j.envpol.2020.115688