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Review Article

An Overview on Vermicompost Environmental Impacts (From Past to Future)

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ABSTRACT

Vermicompost, as less energy demanding organic fertilizer, has been of utmost choice for agronomists for decades. Studies revealed numerous beneficial impacts of vermicompost from eco-friendly waste degradation to minimized greenhouse gases emission. Worms, the catalysts of the vermicompost biomass, are also of economic interests for the producers. The product of such process, is stabilized, nutrient-rich, pollutant-free, and compatible and bank of energy for crops. In this study, a comprehensive view is applied to better illustrate the advantageous and drawbacks of vermicompost so that agriculturalists could make a more informed decision when using such manure. Environmental and economic facets are of great significance as the objective of conducting smart agriculture should be highlighted. Thus, this study aims to provide a throughout references for the farmers to utilize when apply vermicomposting.

Keywords: Sustainability; Climate change; Vermiculture; Soil-crop nexus

INTRODUCTION

As a sustainable, eco-friendly, and non-thermophilic approach in the agriculture industry, vermicompost is a bio-oxidation decomposition process that involves organic matter stabilization and nutrients development in physical, nutritional, and biochemical terms using epigeic earthworms and microorganisms [1-7]. Benefits it provides to soil are nutrient cycling improvement, enhancement of water retention capacity, and developed microbial activity [8-10]. Epigeic earthworms cause substrates breakdown and are the most appropriate and efficient for vermicompost production as they live in organic horizons and utilize decayed organic matter [11,12]. *Eisenia fetida* is the widely used epigeic earthworm in vermicomposting process, having a wide temperature resiliency high fecundity, and the ability to live in the wide spectrum of organic wastes [8,13].

Vermicompost-applied soils are better in micro and macro-spaces, particles, Electrical Conductivity (EC), pH, nutrients, profile structure, hydraulic conductivity, and erosion resistance [14-17]. Vermicast, the product of the earthworms when they mix inorganic soil materials and organic matters in their guts, contains beneficial enzymes and hormones for crops and soil [18,19]. Casts are normally present in the 0-20 cm of the surface layer containing more water-stable aggregates than surroundings ones [20]. Presence of nitrogen fixing and phosphorus-solubilizing bacteria, in vermicast stimulates the productivity, development, growth of crops [21-26]. Several studies found the salutary effects of the vermicompost on crop productivity such as: wheat, peppermint, tomatoes, capsicum, and garlic. In addition, indirect benefits found include, pests and diseases control, parasitic nematodes suppression [27-33].

LITERATURE REVIEW

Vermicompost impacts on plants growth

Organic matter is a valuable source of nutrients that plants can easily access, and adding it to the soil can promote thriving microbial populations and activities. This leads to higher values of biomass carbon, basal respiration, the ratio of biomass carbon to total organic carbon, and the metabolic quotient (qCO_2). The inclusion of organic matter has also resulted in enhanced soil quality, leading to increased crop yields. Studies have documented significant yield improvements by using mulches made from coffee husks, as well as increased productivity through the application of animal manures and hay residues. According to Edwards and Burrows, vermicomposts were found to enhance the emergence of ornamental seedlings compared to control commercial plant growth media. Various test plants, including pea, lettuce, wheat, cabbage, tomato, and radish,

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exhibited improved growth when grown in vermicompost-supplemented mixtures. Additionally, ornamental shrubs such as *Eleagnus pungens, Cotoneaster conspicua, Pyracantha, Viburnum bodnantense, Chaemaecyparis lawsonia, Cupressocyparis leylandii* and *Juniperus communis* thrived better in vermicompost-supplemented mixtures when transplanted into larger pots or grown outdoors. Chrysanthemums, salvias, and petunias also flowered earlier in vermicomposts compared to commercial planting media. Even when substituting just 5% of a 50:50 mixture of pig and cattle manure vermicomposts into various levels of commercial plant growth medium, plants exhibited better growth. Similar positive growth trends were observed in greenhouse pot trials by using vermicompost and sand mixtures ranging from 0% to 100%. Although higher concentrations of vermicompost led to reduced radish germination, radish harvest weights increased proportionally with vermicompost application rates, with yields in 100% vermicompost being up to ten times greater than those in 10% vermicompost. The Soil Ecology Laboratory at The Ohio State University consistently found that a wide range of crops exhibited accelerated germination when treated with vermicomposts. Initially, vermicompost applications inhibited germination, but subsequent weekly applications of diluted extracts improved plant growth and increased radish yields by up to 20%. Wilson and Carlile reported that tomatoes, lettuces, and peppers exhibited optimal growth rates at substitution rates of 8-10%, 8%, and 6%, respectively, using a mixture of duck waste vermicompost and peat. However, higher substitution rates led to growth inhibition attributed to increased electrical conductivity (salt content) and excessive nutrient levels. Subler, et al., observed increased plant growth in commercial media (Metro-Mix MM360) when vermicomposts were substituted instead of traditional composts derived from biosolids and yard waste. In Scott's U.K. study involving hardy nursery stocks of Juniperus, Chamaecyparis, and Pyracantha, substituting 20-50% vermicomposts from cattle manure, pig manure, and duck waste into Metro-Mix MM360, along with regular nutrient application, resulted in better growth compared to plants grown in a peat-sand mixture. In the second year of the experiment, responses varied among the test crops, but the addition of 25%of all three types of animal waste, along with a controlled-release fertilizer (Osmocote 18:11:10), promoted increased growth of *Juniperus sabina tamariscifolia*.

Handreck conducted research to examine the effects of various vermicomposts derived from cow manure, sheep manure, poultry manure, goat manure (mixed with carpet underfelt, lawn clippings, cardboard, and domestic waste), kitchen scraps, cardboard (mixed with wheat, maize, meat, lucerne and linseed meals, rice pollard, and oat hulls), and pig wastes on plant growth. The vermicomposts were mixed with *Pinus radiata* bark and quartz sand in the growth media, with each vermicompost accounting for 30% of the mixture. Handreck found that all of these mixtures increased the dry weights of stocks (*Mathiola incana*) compared to the control group that received no vermicompost. Similar results were reported in the germination of tomatoes and peppers grown in vermicomposts mixed with a commercial peat/sand planting medium. Chan and Griffiths reported stimulating effects of pig manure vermicomposts on the growth of soybeans (Glycine max), particularly in terms of increased root lengths, lateral root numbers, and internode lengths of seedlings. In a rooting experiment, vermicomposts were found to enhance the establishment of vanilla (*Vanilla planifolia*) cuttings better than other growth media such as coir pith and sand mixtures. Similar growth responses were observed in cloves (*Syzygium aromaticum*) and black peppers (*Piper nigrum*) sown in 1:1 mixtures of vermicompost and soil. Black pepper cuttings raised in vermicomposts exhibited significantly greater height and leaf count compared to those grown in commercial potting mixtures, while cloves grown in vermicompost mixtures displayed taller plant heights, more branches, and longer taproots. The study reported enhanced growth and dry matter yield of cardamom (*Electtaria cardamomum*) seedlings in vermicomposted forest litter compared to other growth media tested. Vermicomposts produced from coir dust were found to increase onion yields (*Allium cepa*).

Economic aspects of composting and vermicomposting processes

From economic point of view, total cost of vermicompost application from the workforce to fertilizer is cheaper compared to chemical fertilizers [34]. Compost and vermicompost are well-known in terms of economical sustainability, as they, especially composting process involves low technical and capital complexity and input [9,35]. Researchers reported that a savings of € 19.56 can happen per ton of organic waste if composting used to manage wine industries waste compared to external management [35]. Galgani P, et al., also mentioned that composting was economically viable without receiving any subsidies in Bangladesh and Indonesia [9]. Carbon markets is also another factor in economic viability of the composting process [12]. Composting normally involves lower Greenhouse Gases (GHGs) emissivity but balances are not taken into account for nutrients recycling for compost production from organic waste [12]. Studies show that no robust analysis were attempted so far addressing the economic feasibility of combined compost-vermicompost system but the total cost-effectivity and annual revenue of the integrated system can hypothetically be higher than the composting technology alone [12].

Global vermicast/compost production trend and their utility

As a growing waste-free industry which contains environmentally safe by-products and final products, vermiculture; huge production of earthworms in waste materials, firstly started in Holland in 1970, then started growing in Israel, Brazil, Canada, France, England, Korea, USA, Italy, Philippines, Thailand, China, Japan, and Australia [3,8]. American Earthworms Technology company produced approximately 500 tons of vermicompost per month in 1978-79 [8]. Collier, Hartenstein and Bisesi reported sewage sludge treatment through vermiculture in USA. in 1985–87 USA exported 3000 tons of earthworms to Japan for cellulose waste degradation [36,37]. Edwards also mentioned municipal sludge sawdust, rice straw and paper waste utilization for vermicomposting producing 2–3 thousand tons of vermicompost per month [38]. Sinha reported

Bangalore and Pune vermicompsting sites with 100ton per day capacity. Bhawalkar Earthworm Research Institute (BERI), Pune is the biggest earthworm-based vermiculturing institute in India [3,39]. Senapati, Gunathilagraj and Ramesh reported treatment of coir waste, sericultural wastes and cellulosic wastes by earthworms [40,41].

Does feedstock affect vermicomposting

Numerous feedstocks can be used for feeding vermicompost from pig manure, oat straw to kitchen waste, cow dung, and industrial sludge with pH range from 5-8, and 40-55% of moisture content [7,12,22,42]. Earthworms' growth monitored in several studies, like animal manure, plant residues, and municipal wastewater but little is known about the quality of the feedstock on the earthworms [43-46]. Butt found no adverse effect on earthworms in mill sludge treated vermicompost. Elvira, et al., cited that solid paper-mill sludge mixed with sewage sludge in the 3:2 ratio resulted in the highest growth rate and the lowest mortality of *E. Andrei* [47,48]. In contrast, Papermill sludge mixed with pig slurry showed a high mortality rate which can be due to changes in the environmental factors [48]. Elvira, et al., mentioned that earthworm's reproduction and total biomass ascended between 22 and 36-fold, 2.2 and 3.9-fold, in mixed paper mill sludge and cattle manure, respectively. The vermicomposts were nitrogen and phosphorous-rich with low toxicity and high stability [48]. In addition, Karmegam, et al., found that green manure+cowdung substantially improved the reproduction and growth of earthworms [4].

According to Aslam, et al., for paper wastes, cow dung, and rice straw during the vermicomposting process, Nitrogen (N), available Phosphorus (P), available Potassium (K), Zinc (Zn), and Iron (Fe) concentrations ranged from (0.02–0.30 percent), (9.10–23.21 ppm), (127.00–1425.00 ppm), (0.41–1.06 ppm), and (1.83–4.21 ppm), respectively. In agreement with that, Chauhan and PC conducted a study on toxic weeds vermicomposting and observed a high increase in nitrogen, potassium, phosphorus and a significant decrease in organic carbon, C/N, C/P ratio in the *Eisenia fetida* inoculated experiment. In the study conducted by Chen, et al., decrease in C/N and C/P was also reported in vermiconversion of medicinal herbal residues [49,50,51]. In contrast, Bansal and Kapoor mentioned that earthworms had no effect on the total P, K and Copper (Cu) content of compost [44]. However, they found more Zn in cattle dung compost with earthworms compared to earthworms-free compost. Esmaeili, et al., reported a significant reduction in C/N and total organic carbon by 69% and 37% in pistachio waste treatment which is coincided with other studies [52-55]. Such reduction is attributed to the coupled activity of microorganisms and earthworms that led to the conversion of organic materials to carbon dioxide [56,57]. This mutual activity is defined as release of mucus and enzymes by earthworms that accelerates the microorganisms' activity, and release of extracellular enzymes into the earthworm's intestine by microorganisms [58]. Nutrient contents of the feedstock mainly affect the nutrient release of the vermicompost [59]. Earthworms have an influential role in increasing and improving the nitrogen contents of the waste by adding nitrogen-rich mucus, decaying tissues of dead worms and by enhancing microbial mediated nitrogen mineralization [60]. Earthworms' phosphatases and P-solubilizing microorganisms result in phosphorous mineralization and phosphor availability [11,61]. Jemal and Abede mentioned that total nitrogen content happened in Ambo combined with stevia leaf (2%) and high available phosphorous in Meskan+fresh foods (31.565 ppm) [62]. Van Groenigen, et al., mentioned 83% and 240%increase in P and N availability as 40 to 48% total P, N, and organic C found in casts compared to bulk soils [63].

The C/N ratio is an accepted measure of compost maturity [64]. Biruntha, et al., reported that vermi-amended compost had a lower C/N and C/P ratio compared to that of unamended ones ranging from (11 to 28%), and (30 to 43%), respectively indicating the significance of total organic carbon in the initial C/N. In line with that, Zhi-wei, et al., observed 59 to 72% decrease in C/N in rice straw and kitchen waste vermicompost [65,66]. Boruah, et al., reported 91% reduction in C/N ratio in citronella bagasse and paper mill sludge vermicomposting [67]. Soobhany, et al., also found 41.5–48% reduction in C/N ratio in solid wastes vermicomposting. This variation range in C/N ration can be attributed to earthworms' activity and reproduction rate due to food priority and appropriate C/N ratio in the initial feedstock. C/N is an indicator for the organic matter mineralization rate and compost maturity [65,68]. CO_2 emission, adding nitrogenous worms' excretion, and earthworm's bioactivity can improve the C/N reduction in vermicompost [69,70]. Ndegwa and Thompson recommended the C/N ratio of 25 for optimization of the interaction between earthworms and microbes as it provides sufficient available energy for during the bio-conversion process [71]. Gunadi and Edwards wrote that paper could better adsorb moisture and was a better bedding or bulking material as E. fetida could not survive in fresh cattle solids, fresh young pig solids, fruit wastes and vegetable wastes [72]. Warman and AngLopez observed that Kitchen Waste +Paper (KPW) was a better material for earthworms' fecundity than Kitchen Wastes+Yard (KYW) may be due to the higher nutritional content of the kitchen waste+paper casts [73]. They also found KPW cast darker and finer rather than KYW which could be attributed to castings redigestion and oxidation in the earthworm gut. The leaves and paper's fibers were also noticed in KPW and KYW as they need long time to decompose due to cellulose which can explain greater earthworms' growth in KPW [73].

Microbial communities involved in vermicomposting

Vermicompost is an organic biofertilizer which is studied not only for its chemical and nutritional qualities but also for its biological features in terms of microbial inoculums. Few studies have focused on the microbial succession during vermicomposting. Thus, the need for a throughout research is sensed for interpretation and characterization of the microbial community composition [74]. The active phase of composting is the thermophilic stage in which bacterial succession happens [75,76]. Disease suppression activity of thermophilic compost reported in several researches on different phytopathogens *viz.*, Rhizoctonia, Phytopthora, *Plasmidiophora brassicae* and *Gaeumannomyces* *graminis* and Fusarium [77-83]. Organic amendments improve the microbial population and diversity which could be the reason for disease suppression [84]. Pertinent to bacterial diversity enhancement Kolbe, et al., provided a detailed characterization of bacterial succession during vermicomposting of white grape marc and found a significant increment in bacterial diversity and community composition [85]. Such traits are also accompanied by increase in metabolic capacity and specific metabolic processes comprising cellulose metabolism, plant hormone synthesis, and antibiotic synthesis. In agreement with that Domínguez, et al., mentioned the beneficial impacts of vermicomposting of Scotch broom on bacterial community composition. Interestingly, Gómez-Brandón, et al., found a reduction in microbial biomass and diversity but an increase in microbial total activity. Several studies highlighted the significance of passage of the material through the earthworm gut as it favors the existence of smaller but metabolically more active microbial population [86-88]. In addition, Mainoo, et al., found a significant reduction both in *E.coli* plus Salmonella (31 to 70%) and *Aspergillus* (78 to 88%) loads during vermicompost while in the earthworm-free plot, there was a decline of 75%, and 16% in *E. coli* plus Salmonella, and Aspergillus, respectively during the same period in the pineapple waste-bedded [89].

Vermicomposts effect on heavy metals

Presence of the heavy metals and metalloids in soils pose serious threats to the food chain and human health [90]. Studies report that composting and maturity time of organic residuals does have positive effects on heavy metals behavior like water solubility and chemical extractabilities, consequently estimating to have low heavy metal leaching [91-96]. García, et al., these characteristics are attributed to formation of metal-humus complex [91]. Khan conducted a study on how biochar inclusion to vermiconversion can hinder the heavy metal movement during preincubation [97]. This is in agreement with the findings of the Li, et al., and Awasthi, et al., for the mobility of Zn, Cu and Ni, Lead (Pb) [98,99]. Park, et al., indicated a sharp reduction in the heavy metal build-up in Indian mustard +biochar bed [100]. Also, reduction of Zn, Pb, Fe, Cu was observed in sewage sludge and sugar cane mixture [101]. This is in line with Gogoi, et al., reported vermicompost efficacy in Zn removal rather than Cu in a 1:1 ratio (cowdung+sludge) [102]. According to Jain, et al., this happens due to microflora detoxification capability which are in earthworm's intestine. Khan, MB., reports biochar coupled with *Eisenia fetida* can be considered a significant treatment in preincubation-vermicomposting of biosolids [97,103]. Also, Wang, et al., found that the accumulation of heavy metals happened in earthworms' tissues (145 mg/kg, 64.8 mg/kg for Zn and Pb total in a treatment of (90% sewage sludge, 7% fly ash, 3% phosphoric rock and 90% sewage sludge, 3% fly ash, 7% phosphoric rock) respectively [104]. However, the results are conflicting in this regard. For example, Abbaspour and Golchin reported low transformation effect of vermicompost on Pb, Cd, Zn and Cu in an alkaline soil [105]. Chand, et al. mentioned a positive relationship between vermicompost and potential heavy metal accumulation by crops [106-109]. Hoehne, et al., showed that quantity of bioavailable Chromium (Cr) and Pb varied based on vermicompost application ratio [110]. These discrepancies indicate that despite having a significant adsorption capacity for potential heavy metals Jordão, et al., further investigation required for fully understanding of the effects [111].

Vermicompost effect on GHG emission

Emission of GHGs has always been one of the major concerns in vermitechnology since it reduces the agricultural values of the products along with polluting atmosphere [17,112,113]. Amongst gases, N_2O and CH_4 are the significant contributors to the global warming Awasthi, et al., as their potentiality are 298 and 25 times higher than CO_2 over a 100-year period [114]. Hence, deciphering the behavior of vermicomposting in generating GHGs emission is significant. Contributing factors to GHG emission in vermicomposting are temperature, moisture quantity, aeration condition, additives, bulking agents, pile scales, and C/N ratio [17,112,115-119]. Studies report contradictory results on the earthworm addition to compost. Wang, et al., and Nigussie, et al., found positive effects of the earthworms on GHG emissivity in animal manure-bed while others mentioned that earthworm-induced GHG emission increased compared to traditional composting [120-122]. Since they influence physico-chemical properties of the soil [17,123]. According to Friedrich and Trois biodegradation process that produces CO_2 and agricultural machinery used during vermicomposting are the reasons behind GHG emissivity [124]. CO_2 emission is indicative of the mineralization and degradation of the organic matter [125]. In line with that Hao, et al., Tsutsui, et al., and Luo, et al., cited that organic matter decomposition consumes O_2 and release CO_2. Some studies mentioned the impact of aeration and turning in mitigating GHG emission [126-128]. For instance, Chowdhury, et al., reported low aeration reduced GHG emission while Wang, et al., reported that intermittent aeration could better decrease GHG emission rather than a continuous one. Some studies reported the increased nitrate and CO_2 emission and decreased CH_4 emission which is linked to aerobic condition maintained by burrowing activities of earthworms while more moisture content generate more CH_4 anaerobic condition led to more GHGs emissivity [104,129-131]. Nigussie, et al., reported a reduction in CH_4 and N_2O emission during vermicomposting compared to composting by 32% and 40% respectively, while the moisture content was high but the reduction of GHGs was 16% and 23% in low moisture condition [132]. Jiang, et al., indicated the effectivity of enhanced air exchange on reduction of GHG emission. Luo, et al., studies that turning and covering pig manure with mature compost could have positive effect on GHG emission [128,133]. Between aeration and turning, a study conducted by Friedrich and Trois represented that aeration might be better than turning as turned windrow composting released 8.14% higher GHGs than aerated dome composting [124]. Researchers conducted mentioned that biochar mature compost, and C-bulking agent, such as woodchips, sawdust or crop residues could tune the condition of waste mixture and decline the GHGs emission such as CO_2 if mixed well with manure [128,129,134]. Thus, a robust analysis and a deep investigation are required experimenting the factors and conditions in understating the definitive influences of the vermicomposting on GHGs emission.

Soil organic matter and carbon characteristics affected by vermicompost

Stable compost is a state in which Organic Matter (OM) decomposition is low without any heat produced [132]. Instability of the compost leads to a reduction in plant growth as it comprises toxic compounds, causes oxygen depletion in the root zone, and compels osmotic stress [135]. Several indices have been proposed as compost stability indicators such as CO2 evaluation, lack of heat development, C/N ratio <12 and NH_4^+-N: NO_3^--N ratio <0.16 [136,137]. The quality and quantity of the Dissolved Organic Carbon (DOC) at threshold value of 4 g/kg is considered as an additional compost stability indicator [118,121,136]. Through ingestion of the substrates and governing the microbial communities, earthworms can affect the DOC. Still, little is known about the effects of the earthworms on the composition of DOC during the vermicomposting process [121]. Nigussie, et al., found that a longer pre-composting period causes a lower DOC content since it has easily degradable compounds. Consequently, C mineralization ascends. DOC in compost can affect microbial activities and C mineralization when soil is applied [121,138]. Composts with DOC content lower than 4 g kg-1 dry matter are considered more stable than non-earthworms treated ones presumably because they improve the decomposition process by interacting with microorganisms [112,132]. Soil carbon sequestration through earthworms' activity is defined as the balance of the OM mineralization and stabilization [139,140]. Wu, et al., stated that earthworms can increase soil organic carbon rates through the replacement of the old SOM with newly added straw carbon [140]. Lubbers, et al., mentioned that earthworms spurred organic matter mineralization through microbial respiration enhancement [141]. They can also accelerate carbon stabilization [140]. Through ingestion of the organic matter, they are mixing it with inorganic soil materials, passing through their guts and sending it out as casts. Subsequently, nuclei are created for the formation of the organo-minerals micro-aggregates and then macro-aggregates to protect the soil organic matter [142,143]. Furthermore, earthworms can tunnel into the soil, deposit the C in deep soil profile and protect the C there [144]. Earthworms are able to mobilize labile carbon [145]. They can also develop microbial activities toward using more diverse carbon pools [146]. Ngo, et al., mentioned that increase of organic carbon storage relies on the organic manure characteristics [147]. Earthworms lessen carbon storage organic material-amended soils. In addition, earthworms' presence results in organic matter protection in soil particles.

Zaitsev, et al., found out that earthworms can alter the microbial activity and carbon release from reapplied rice straw by stimulating aerobic microorganisms [148]. The optimal density of earthworms can be set at 500-600 per m^2 for sequestering carbon. At higher density, there could be a competition amongst earthworms for the resources and stress them. Lower than the optimal density, the straw remains unprocessed. In agreement with that, reported by Ramos, et al., microorganism activity and substrate mass (ρ =0.95) and total organic carbon (ρ =0.77) are highly correlated indicating high carbon quantity and microbial activity [149]. Cao, et al., the more earthworms population increase, the more nutrient quantity in the final product would be [150]. It can also be noted that the earthworms and carbon stabilization relation is positively correlated. Total organic carbon indicates organic carbon absorption and CO_2 emission during the vermiconversion process [151].

DISCUSSION

Literature reviews largely revealed the potentiality of the vermicompost in ensuring food quality, remediating ground water pollution, and enhancing agricultural productivity. Pacing towards a sustainable agriculture, vermicompost can benefit the consumers, producer, and the environment [151]. Vermicompost, known as "Black Gold" fulfills the concept of "zero waste" by recycling a large deal of wastes from sewage sludge to food waste [151-153]. Green Revolution had many side effects including increase in chemical fertilization and pesticide utilization for fostering crop yields which adversely affected soil health and productivity [154]. Following the approach of three Rs (reduce, reuse, recycle), vermicompost is significantly linked to the circular economy through generation of energy from wastes [70]. Circular economy is the long-term promising solution to meet the sustainable development pillars: economic, environment, social [151]. It addresses the economic aspects as it shrinks the costs of the pollution control. The environmental dimension is meet through minimization of waste and greenhouse gases emission [155]. New businesses provide new job opportunities for the society as well [151]. It can also tackle the soil fertility and food shortage problems [156]. Hence, the goal of sustainability in agriculture can be achieved once vermicompost potentials are deeply realized in terms of waste disposal management, contaminant remediation, and job offers provision.

Vermicompost, as a slow-release fertilizer, ensures agricultural sustainability and has a synergistic influence on crops [151]. It provides vital nutrients such as nitrates, solubilized potassium, magnesium, phosphorous, calcium to crops [16,84,157]. It also offers more microsites to microbes for nutrient retention through increased surface area [158,159]. It increases the production of plant growth hormones if applied with humic substances [160]. Several studies mentioned that the application of vermicomposting after composting process caused a decrease in GHGs emissivity, less heavy-metal contaminated agricultural products, more nutrient accessibility, and a greater deal of microbes [120,161-163].

CONCLUSION

While a great deal of research has shown the beneficial impacts of the vermicompost on soil nutrient efficiency, particle cohesion, and development of the soil profile, results for the greenhouse gases emissivity and environmental facets are contradictory and demand more subsequent and site-specific research. This review aimed to gather numerous studies and put them together to provide a detailed references for agriculturalists and farmers to make a more informed decision when apply vermicomposting on the farm.

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