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Vermicompost Application in Crop Production and Urban Waste Management: A Review Article

Reshid Abafita Abawari
Jimma Agricultural Research Centre,
Natural Resource management Research, Jimma, Ethiopia

Abstract

The marvelous increase in population, industrialization, urbanization, and agricultural output results in buildup amounts of solid wastes which lead to serious problematic in the environment. The waste management and crop residues are serious problems in the world. The burning of crop residues causes environmental pollution like smog. Disposal of these wastes safely can be achieved by bio-composting and vermicomposting of farm, agro-industrial waste and urban wastes. To manage all kind of waste vermicomposting is the best technique that is economically viable, environment friendly and socially acceptable approach which converts garbage in to black gold; called vermicomposts. Vermicomposts enhances soil biodiversity by promoting the beneficial microbes which in turn enhances plant growth directly by production of plant growth-regulating enzymes and hormones and indirectly by controlling plant diseases, nematodes and other pests, thereby enhancing plant health and minimizing the yield loss. Vermicompost may be used to promote sustainable agriculture due to its distinctive biochemical, biological and physiochemical properties and also used for the safe management of agricultural, domestic, industrial and hospital wastes which may otherwise pose serious threat to life and environment. In preparation of vermicompost, organic waste products are being oxidized via the mutual activity of useful microbes and earthworm. Vermicompost is rich source of all macro and micro nutrients, i.e., Nitrogen (N), Phosphorous (P), Potassium (K), Iron (Fe), Zinc (Zn), Copper (Cu), manganese (Mg), growth promoters and regulators hormones like Auxin, gibberellin, enzymes i.e., protease, lipase, chitinase, beneficial bacteria and fungi. Almost 3,000 species of earthworms are identified for vermicomposting, in which Eisenia fetida, Eisenia Andrei, Eudrilus eugeniae and Perionyn excavates are most suitable for vermicompost preparation. This review focuses on relevant research performed and success in using vermicomposts during the last decade that can help us improve sustainable crop production and municipals and household waste disposal.

Keywords: Bio-fertilizers; Earth worm; Organic inputs; soil fertility; urban waste; vermicomposts

INTRODUCTION

Vermicomposting is a simple process of waste conversion and produce a better end product in which epigeic species of earthworms are used. It is the process of converting the organic wastes into highly nutrient fertilizers for plant and soil by the help of earthworms [1-2]. Vermicompost

is a nutrient-rich organic input which can be applied to soil to enhance plant growth. Application of the earthworms is very crucial for this purpose due to their ability to convert organic matter in to nontoxic and usable nutrient forms for soil conditioner and plant growth. Vermicomposting has many environmental benefits that are proven to be an easy way of getting rid of garbage waste. This technique is also beneficial to the soil and results in a lower use of synthetic fertilizers. Vermicompost is the casts of earthworms after the intestinal digestion of organic matter. It is a finely divided peat-like material with excellent structure, porosity, aeration, drainage and moisture-holding capacity [3]. Research has revealed vermicompost contains many macro nutrients such as NPK, micro nutrients like Mn, Fe, Mo, B, Cu, Zn etc. in addition to some of the growth regulators [4-5]and beneficial soil microbes [nitrogen fixing and phosphate solubilizing bacteria and actinomycetes [6]. These nutrients are very essentials for photosynthesis, the chlorophyll content of the leaves and plant components such as roots, shoots and the fruits. Besides the high percentage of humic acids in vermicompost contributes to plant health, as it promotes the synthesis of phenolic compounds such as anthocyanins and flavonoids which may improve the plant quality and act as a preventive to pests and diseases [7]. Some nutrients are immediately absorbed by the plant from the vermicompost while others are only released at slow rates, ensuring long lasting nutrition [8]. Vermicompost increases the amount of readily available water, induction of N, P and K exchange, which results in better growth of the plants [9]. Vermicompost is also a sustainable alternative to chemical fertilizers, which is an excellent growth promoter and protector for crop plants [10].

Chemical fertilizers has been used due to its dramatic effects on the yield of high-value crops in developing countries, but it has been reported that long-term fertilization of synthetic fertilizers, especially nitrogenous fertilizers, resulted in soil acidification, depletion of lands, deterioration of soil fertility, soil erosion, soil salinization, health hazards, and poor sustainability of agricultural lands and degradation of biodiversity [11] which resulted in soil nutrient deficient to limit plant growth and yield decrease and soil biochemical ingredient formation [12]. Today agricultural research seeks new management strategies and technologies to reorient the current and future needs and constraints. For this reason, the eco-friendly and cost-effective technologies should be adopted [13]. To discourse the impact of impaired soil quality, crop nutrient deficiencies, and other forms of environmental pollution, it is important to consider emerging alternatives to conventional fertilizers, like employing organic-based fertilizer technology.

Organic inputs in agriculture can address these problems by reducing the adverse effects of chemical fertilizers on soil health and environment. Use of vermicompost could be an effective solution to the problem where it could substitute the chemical fertilizers in crop productivity and reduce the economic cost and on the other hand may also lead to organic produce which realizes higher price in the market. This approach is affordable and often readily available because it uses natural fertilizers, such as vermicompost. Vermicompost is rich in vitamins [14], phytohormones such as gibberillic acid and auxins [15], and enzymes such as protease and amylase [6]. Vermicompost is a natural fertilizer, rich in available nutrients, improving the chemical, physical and biological properties of soil [16] and thus reducing the use of chemical fertilizers [17]. This review summarizes the role played by vermicomposts and advances in the use of vermicompost and organic inputs in crop production, including the reported microbial

diversity associated with vermicomposts and the role of vermicomposts in urban waste managements.

EFFECTS OF VERMICOMPOST ON SOIL PROPERTIES

Vermicompost can physically, chemically and biologically improve the soil fertility [18]. Soils amended with vermicompost have improved porosity, aeration, greater potential for water retention and lower bulk density. Soil chemical properties have greatly improved, such as electrical conductivity, pH, nutrient and organic matter status leading to improved plant growth and yield due to vermicompost application [19]. According to Ali et al. [20], the addition of vermicompost improved the soil properties such as organic matter, total nitrogen, phosphorus, potassium, sulfur, zinc, and boron contents; grain and straw yields of rapeseed also increased significantly, when increasing the dose of vermicomposts.

Moreover, earthworms secrete several hormones, enzymes and vitamins during casting that promote the activity of other beneficial microbes in the soil, thereby improving soil health. Earthworms' casting contains a high percentage of humus. Humus helps in aggregation of soil particles resulting into better porosity, which in turn improve aeration and water holding capacity of the soils. In addition, humic acid in humus provides binding sites for a variety of plant nutrients, i.e., potassium, iron, calcium, sulphur and phosphorus. These nutrients are stored in humic acid in the form of readily available nutrients and released when needed by plants [21].

Earthworm casts ingested soil might create even more favorable environment to plant growth because of higher moisture content and nutrient availability in fresh casts [22]. Jeyabal and Kuppuswamy [23] have reported increased growth of rice stalks and improvement in soil fertility status following vermicompost application. Earthworm casts are commonly considered to be responsible for better soil structure and enhance soil physical properties, i.e., water retention, resistance to erosion and infiltration [24]. Thus, soils imbedded with vermicompost have a higher rate of plant growth hormones and humic acid, less root pathogens or soil borne diseases, higher microbial activity and population and exhibit higher cation exchange capacity [25-26] and overall improvement in plant growth and yield [27]. Lee [28] stated that microorganisms in the worm casts could fix atmospheric N in amounts that are important for the metabolism of earthworms and as a source of nitrogen for plant growth. The findings reported by Casenave & Valentin [29] support above results as they have also been reported five folds higher infiltration rate in soil following fertilization of vermicompost.

EFFECTS OF VERMICOMPOST ON CROP GROWTH AND PRODUCTIVITY

In sustainable agriculture, vermicompost is a potential input which creates beneficial effects on soil. It contains high level of humic acid and hormones that create a useful effect on plant health [30]. Vermicompost also has a beneficial impact on vegetative development and stimulating the development of shoot and root [31]. Its application increase morphology of crop plants such as leaf areas [32] and stimulated flowering, increase in the number and biomass of flowers [33] and overall increase in fruit yield [34].

The growth and yield of mung bean was significantly higher with vermicompost application. The combined application of vermicomposts and N fertilizer gave higher dry matter (16.2g per plant) and grain yield (3.6t per hectar) of wheat and higher dry matter yield (0.66g per plant) of the following coriander crop in sequential cropping system [35]. Moreover, vermicompost application to sorghum [36] and sunflower [37] showed positive results. Similarly, yield of tomato was significantly increased (5.8 t ha^{-1}) at application of vermicompost 5 t ha^{-1} compared to application of farmyard manure (3.5 t ha^{-1}) [35].

Amendment of vermicompost to vegetables during greenhouse studies had the highest amount of red marketable fruit without symptoms of early blight lesions on the fruit at harvest. The yield of pea was also higher with the application of 10t ha^{-1} vermicompost when combined with recommended N, P and K than the sole chemical fertilizers [38]. Vadiraj et al., [39] reported that application of vermicompost produced herbage yields of coriander cultivars [39] and fresh weight of flowers of Chrysanthemum chinensis [40]. The combination of 10t ha^{-1} vermicompost with 50% NPK fertilizer showed increased number of flowers per plant [41], flower diameter (6 cm) and yield (0.5t ha^{-1}). 100% inorganic fertilizers with 5-10t ha^{-1} of vermicompost is suitable for higher production of potato and economically profitable [42]. Atiyeh et al.,[30], Arancon et al., [43] and Singh et al., [34], and Verma et al., [35] reported, vermicomposts amendments produced significant improvements in the growth and yield of sweet corn. A combination of 25% of vermicomposts and 75% recommended inorganic fertilizers produced significantly increased plant height and marketable crop yield than those produced by 100% inorganic fertilization.

A range of studies revealed that vermicomposts application significantly stimulates the growth of some aromatic and medicinal plants[44,45], cereals such as sorghum and rice [46], fruit crops such as banana and papaya [47], and ornamentals such as geranium [48], marigolds [49], petunia [33], chrysanthemum [50] and poinsettia [51] and several horticultural crops such as tomato [52], pepper [53], garlic [54], aubergine [55], strawberry [43], sweet corn and green gram[56].

Similarly, the effects of vermicompost have also been observed in forestry species such as acacia, eucalyptus and pine tree [57, 52]. Likewise, some studies show that vermicompost water-extracts, used as substrate amendments or foliar sprays, also promote the growth of tomato plants [52-58] and strawberries [59]. Seed germination was also reported due to vermicomposts amendments in several plant species such as green gram [56] tomato plants [60], petunia [33], and pine trees [57]. Vermicompost also has a positive effect on vegetative growth, stimulating shoot and root development including alterations in seedling morphology such as increased leaf area and root branching [32-31], stimulates plant flowering, increasing the number and biomass of the flowers produced [33], increasing fruit yield [58,52] as well as increasing the nutritional quality of some vegetable crops such as strawberries [34], spinach [61], sweet corn [62], and lettuce [63]. However, even though the large body of scientific evidence showing the positive effects of vermicompost on plant growth and yield, there is also strong evidence that these effects are not constant, and that there is great variability in the magnitude of the effects reported in different studies.

Vermicompost incorporation methods, and its chemical, physical and biological characteristic as well as original feedstock and the earthworm species may influence the effects of vermicopost on the plant growth [64]. Germination, seedling elongation, biomass allocation, fruit morphology and chemical properties of three tomato varieties were influenced by Vermicompost application [60]. High dose of vermicomposts (40%) in potting media had shown a suppressive growth of tomato plants at this higher dose [65]. Similar variation was observed on the germination and early growth of six different progenies of maritime pine due to vermiwosh application [57]. Plant genotypes enhance root growth or modify root exudation patterns in order to increase nutrient uptake [66]. However, after the application of vermicompost to sweet corn crops, the different genotypes showed important differences in their rhizosphere microbial community [67].

Vermicompost plays a pivotal role in improving growth and yield of different field crops, vegetables, and flower and fruit crops. Higher germination rate of mung bean (93%) was obtained due to application of vermicomposts compared with biodigested slurry (84%). Similarly, the fresh and dry matter yields of cowpea (Vigna unguiculata) during pot experiment were higher when soil was amended with vermicompost than with biodigested slurry [68].

INTEGRATION OF VERMICOMPOSTS AND CHEMICAL FERTILIZER ON CROP GROWTH AND PRODUCTIVITY

The increase of chemical fertilizer causing decrease in organic matter contents, which is the primary attributes of the sustainable cultivating frameworks [69]. The application of inorganic fertilizer was found to be suitable for increased in crop production from couple of years, however longer use of inorganic fertilizer degraded the soil fertility and organic matter [70]. Vermicomposts (casting of earthworms) are natural materials which are separated by collaborations between minute microorganisms and earthworms to produce fully balanced natural soil modifications with low C: N proportions [71]. Earth worms improve crop production by raising soil fertility levels through the release of beneficial soil microbes and the secretion of polysaccharides, proteins and various nitrogen compounds into the dirt [72-73]. The excreta by earthworms were seen to improve, the soil organic matter and nutrient status, by recycling available nutrients especially N, P, K, Ca and Mg [74].

Vermicomposts, simple compost and chemical fertilizer, combined application help in keeping yield and nutrient stability and reduced lack of nutrients, improving the efficacy of associated supplements and ensuring desirable soil physical conditions [75]. Integration of vermicompost with NPK fertilizers resulted in higher content of total nitrogen compared to FYM in combination with NPK fertilizers or control. Vermicomposts also resulted in significantly higher content of phosphorus. Application of coir dust coir pith into soil contributes 20.7 kg N, 10.5 kg, P_2O_5 and 30.8 kg K_2O per hectare annually [76].

Vermicompost (VC) improves the growth and yield of crop plants because it contains humic acid and plant growth hormones [49]. Singh and Wasnik [77] determined the combined effect of vermicompost and chemical fertilizer (CF) on rosemary (Rosmarinus officinalis L) and found that the use of vermicompost ($8tha^{-1}$) together with N-P-K fertilizer at concentration of (150-25-25 kg ha^{-1} respectively) provided optimal rosemary herbage and oil yield compared to

control. Adding VC and CF to the field crop may be a very good choice provided the availability of nutrients to sustain soil fertility and productivity [78].

Integration of vermicomposts with chemical fertilizer enhances seed germination, seedling growth and increase plant production. It also increases germination percentage and yield of mungbean as compared to control [79]. Similarly, Gutierrez-Miceli, et al. [80], investigated that germination increased with the application of vermicompost than other amendments. Application of vermicompost 10t ha^{-1} together with recommended chemical nutrient doses gave maximum pea yield compared with sole use of chemical nutrients [81]. Same results have also been reported [79] while working on tomato. Other scientists also reported that vermicompost contain less heavy metals, some growth promoting hormones which are released from earthworms [82]. Addition of hormones in vermicompost shows better result in growth and development of plants and makes the soil rich in nutrients. It increases root length, biomass, plant growth and also overall plant physiology [83]. Positive results of vermicompost addition to soil in tomato crop have also been registered by Federico, et al., [84]. Vegetative growth of paddy like shoot weight, root weight, root and shoot length influenced significantly by the addition of vermicompost in comparison with sole application of chemical fertilizers [85]. Angadi and Radder [86] reported that rice grain and straw yield increase with the application of vermicompost and save chemical fertilizer NPK up to 50 percent in upland rice. Earthworm produced is better source for productivity enhancement and also indicated the possibility of substituting 50kg N ha^{-1} from the recommended dose of N [87]. Thus, vermicompost usage reduced dependence on costly fertilizer input and enhanced net returns from rice produce [88]. Several studies have witnessed increased biomass and grain yield in different crops following judicious application of vermicompost and chemical fertilizers [89-90]. Positive changes in the quality of wheat flour because of increased gluten content were reported by Gopinath, et al., [91] in vermicompost imbedded treatments. Beside above presented results, there are several examples in the literature that documented enhanced growth of a wide range of plant species following vermicompost incorporation as it is an instant source of nutrients supply [92]. In light of this evidence, it is clear that vermicompost constitutes a promising alternative to inorganic fertilizers in promoting plant growth. However, further research into the exact mechanisms and circumstances that stimulate plant growth by this organic substrate is necessary in order to maintain consumer confidence in this type of fertilizer.

EFFECT OF VERMICOMPOST ON SOIL PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES

The ability of earthworm to increase plant nutrient availability is likely to be dependent on the activity of earthworm gut micro-flora. The dynamics of soil chemical processes is indirectly influenced by earthworms due to their comminuting the litter and affecting the activity of the soil micro-flora [93].

Investigation on vermicompost reveals that it increases macro pore space ranging from 50 to 500µm, resulting in improved air-water relationship in the soil which favorably affects plant growth [52,58]. The application of vermicompost favorably affects soil pH, microbial population and soil enzyme activities [94]. It also reduces the proportion of water-soluble

chemical species, which cause possible environmental contamination [95]. A field experiment was conducted by Kannan et al., [96], with tomato to study the influence of different organic N sources viz, FYM, Vermicompost and compost with bioferilizers on the soil physical properties, nutrient availability and biological properties reported application of vermicompost (75%N) with azospirillum was found superior in influencing the soil physical, chemical and biological environment such as beneficial bacterial and fungal population over the other treatments.

MICROBIOLOGICAL DIVERSITY OF EARTHWORM CASTS AND THEIR ROLE IN SOIL FERTILITY ENHANCEMENT

There is a complex association between earthworms and microbes. When microbes such as yeast, protozoa and certain groups of fungi such as Fusarium oxysporum, Alternaria solani, and microfungi pass through the earth worm's digestive system they have been destructed by the gut of Drawida calebi, Lumbricus terrestris and Eisenia foetida which evidenced that they were found to be a part of earthworm's diet. A number of Bacillus cereus var mycoides were reported to decrease during gut passage while Serratia marcessens and Escherichia coli were completely eliminated during gut passage [97]. The number of bacteria such as Pseudomonas, Rhizobium, Bacillus, Azosprillium and Azotobacter increased due to the ideal micro-environment of the Earthworms guts [98]. This specific group of bacteria stimulates plant growth directly by solubilization of nutrients [99], production of growth hormone, 1-aminocyclopropane-1-carboxylate (ACC) deaminase [100], nitrogen fixation [101], and indirectly by suppressing fungal pathogens. Fungal cell-wall degrading enzymes such as chitinases and glucanases, ntibiotics, fluorescent pigments and siderophores produced by bacteria stimulates the fungal growth-suppression [102, 103]. Free living soil bacteria have association with Earthworms and constitute the drilosphere [104]. Microbes associated with Earthworm guts mineralize the organic matter and also facilitate the chelation of metal ions [105]. Microbes in the gut of Allolobophora terrestris, L. terrestris, and Allolobophora caliginosa were believed to be higher in number compared to soil [106]. The excreta of Earthworms contain five times as much as increased number of microorganisms [107] while the ingested organic materials increased the number of bacteria and 'actinomycetes' up to 1,000-fold while passing through their gut [97]. Due to inoculation of microorganisms the period of composting was reduced by about 4 weeks. Various studies also indicated the possibility of augmenting the quality of compost through inoculation with Azotobacter and phosphate solubilizing microorganisms in the presence of rock phosphate [108]. Edwards and Lofty, [109] studied the symbiotic interaction between earthworms and microorganisms in the breakdown and fragment organic matter progressively. The role of earthworms as vectors of beneficial soil bacteria and their capacity of influence the population dynamics and impact of microorganisms on soil and plants was studied.

Several nitrogen fixers (Clostridium butyricum, Clostridium beijerinkii and Clostridium paraputrificum) have been isolated from Eisenia foetida casts, microbial growth was limited by the amount of available carbon immobilization of phosphate in earthworm casts is probably caused by mainly abiotic processes, carbon mineralization by soil microflora fertilizer with glucose and phosphorous was limited by nitrogen, except in freshly deposited casts [110].

Matthur, et al., [108] states that the gut of earthworm behaved as an epigenic/anecic species in sugarcane fields in Australia. Karsten [110] reported that the digestive enzymes and intestinal microflora of earthworms seem to play an important role in digestive of soil organic matter, the various enzymes viz., acid phosphatase, cellulose, amylase, xylanase, endonuclease, cellbiose, and their activities in the gut of the two selected earthworms, Eudrilus eugenie and Eisenia foetida. Yasir et al. [111] showed that changes in bacterial community play a major role during vermicomposting. In addition to bacteria, fungi especially cellulolytic fungi also play an important role during vermicomposting. Cellulase produced by cellulolytic fungi plays a major role in decomposition of cellulolytic materials of organic wastes. Esakkiammal, et al.,[112] also reported that the fungal population is found to be significantly higher in the fresh vermicast obtained from Vermicompost of Eudrilus eugeniae and Eisenia fetida. Anastasi, et al.,[113] were isolated and documented a total of 142 fungal species that are associated to vermicompost. Eisenia fetida and Eudrilus eugeniae used two wastes as food as standardized recycling technique to study their effect on fungal cellulolytic population, cellulase activity and their isozyme pattern, chitin content and microbial biomass of waste mixture during vermicomposting [114]. Increasing Volume of Nitrogen proportion from 25% to 50% or even higher, counts of both fungi and cellulolytic fungi in waste mixtures were significantly increased during vermicomposting. Hence, application of vermicasts to agricultural soil are said to be inoculation of bio-inoculants which improves the biological properties of rhizosphere soil.

ROLE OF VERMICOMPOSTING IN URBAN WASTE MANAGEMENTS

Vermicomposting of cattle manure using earthworm species E. andrei [115] and E. foetida [116] favored nitrification, resulting in the rapid conversion of ammonium-nitrogen to nitrate-nitrogen. The concentration of nitrate-nitrogen was increased to 28-fold after 17 weeks due to vermicomposting, while only 3-fold was increased in conventional compost [117-118]. The harmful effects of Pythium and Fusarium dispersed by earthworms [97] outweigh during vermicomposting due to the presence and amplification of antagonistic disease-suppressing and other plant growth-promoting beneficial bacteria [119]. Vermicomposting accelerates the rate of mineralization and increases the concentration of ash [120]. Ash is an alkaline substance which hinders the formation of H_2S as well as improves the availability of O_2 and thereby renders composts odorless. The observed increase of total phosphorous (TP) in vermicomposts is probably due to mineralization and mobilization of phosphorus by microorganisms in the gut epithelium of the earthworms [121-122]. Research carried out by Gezahegn Degefe et al., [123] in Ethiopia indicated that vermicomposting could be a good option to improve solid waste management performance of Ethiopian cities and towns through the production of excellent bio fertilizer obtained by vermicomposting Coffee Husk, Enset waste (Enset ventricosum), Khat waste (Catha edulis) and Vegetable waste amended with Cow Dung using an epigeic earthworm Eisenia Andrei for agronomic purpose. All sewage sludge, biosolids and biomedical wastes contain an array of pathogenic microorganisms and have to be disinfected in safe, cheap and easy methods before being disposed into the environment [124]. Vermicomposting of biodegradable Municipal Solid Waste and household waste is in vogue in many places and instances but there is an emerging commercial trend of aerobically incubating an extract of compost with a carbohydrate and a protein source, producing a microbially enhanced liquid [125]. However, few reports reveal that vermicomposting converts the infected biomedical waste containing various pathogens viz., Proteus vulgaris, Staphylococcus

aureus, Escherichia coli, Pseudomonas pyocyaneae to harmless waste containing commensals like aerobic spore bearing microorganism and Citrobactor freundii existing in the soil and alimentary canal of earthworms [126]. Decomposition of wastes by earth worms brings about biological transformation and stabilization of organic matter and effectively reduces infectious diseases [127]. Vermicomposting leads to a noticeable reduction in the pathogen indicators such as Salmonella sp. from 39,000 MPN/g to 0MPN/g and < 3MPN to < 1MPN/g respectively and helminth ova and enteric virus in the biosolids [128,129]. Vermicomposting of municipal sewage sludge completely eliminated Escherichia sp. ranging 10–14 × 10^2 CFU/g and Salmonella sp. ranging 15–17 × 10^3 CFU/g in the gut after 70 days of vermicomposting period [130]. Indirect means of eliminating pathogen might be due to elevation of aerobic conditions which could bring down the load of coliforms while direct means of reduction in microbial numbers during gut passage might be due to the digestive enzymes and mechanical grinding [134-135]. Activities by Decomposition by earthworms on sludge reduced levels of infectious diseases and odors of putrefaction and enhanced sludge maintenance [131]. The decrease or removal of enteric pathogenic bacteria at the end of vermicomposting period correlates with the findings that earthworm's diet includes microorganisms and earthworms' ability to selectively digest them [93]. In addition, Earthworms encourage the growth of bacteria in wastewater which acts as chemical degraders, aerators, crushers, biological stimulators and grinders [132]. Earthworms also granulate the clay particles and increase the hydraulic conductivity and natural aeration and further grind the silt and sand particles and increase the total specific surface area and thereby Earthworms enhance adsorption of the organic and inorganic matter from the wastewater and their bodies also act as a 'biofilter' and remove the biological oxygen demand (BOD) from wastewater by 90%, chemical oxygen demand (COD) by 80–90%,, total dissolved solids (TDS) by 90–92% and total suspended solids (TSS) by 90–95 by 'ingestion' and remove organic wastes and heavy metals by biodegradation and by their 'absorption' through body walls [133].

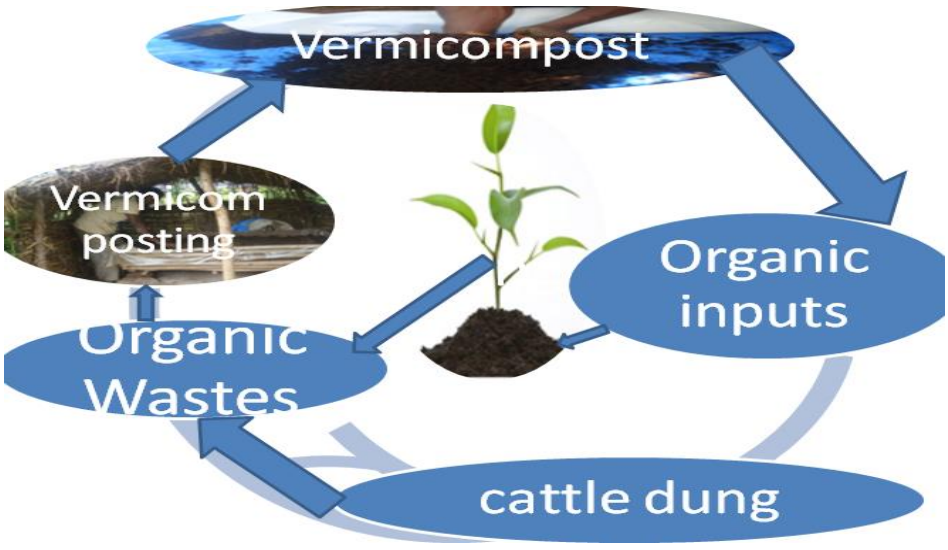


Fig. 1 A graphical representation of the concept of vermicomposting: organic waste is consumed by earth worms in the vermin-boxes. The organic wastes can be used as earth worm feeds and the collected vermicomposts can be used as organic fertilizer.

Livestock population in Ethiopia shared 65 million cattle, 40 million sheep, 51 million goats, 8 million camels, and 49 million chickens in 2020[136]. In 2017, the sector contributed up to 40% of agricultural GDP, nearly 20% of total GDP, and 20% of national foreign exchange earnings [137]. Family dairy production was found to be the main source of household income for the majority of the surveyed farmers of the Jimma Zone, Oromia Regional State, [138]. Tulu et al. [139] also reported that there are 500 livestock farms in Jimma. However, Lombebo and Wosoro [140] reported that animal waste disposal in its current form causes environmental and public health problems. This will become even more severe as urban livestock numbers increase. Inappropriate handling organic waste can contribute to the occurrence of diseases and have adverse influences on the environment. In Ethiopia, currently the government encouraging and promoting urban agriculture and the sector participating multi-stakeholder. However, their environmental concern was very low. It is known that 55.9% of the challenges of urban agriculture to the environment are waste dumping, soil loss, and loss of biodiversity due to ignorance of environmental attention while farming in the town. The study conducted in Debre Markos Town, Amhara Regional State, revealed that composting of both municipal and household waste for urban agriculture is a neglected activity which would have been used for supplementing soil fertility instead of polluting the urban environment [141]. Vermicomposting is the best solution for waste dumping problems and is connected to urban agriculture via vermicompost. Vermicomposting has the potential to act as an economic incentive to improve manure management. The un optimized system proved highly efficient in transforming cattle manure and food waste into odorless, porous, and homogenized vermicompost, demonstrating a 45.9% material reduction on a TS basis. The waste-to-biomass conversion rate was estimated to be 3.5% on a TS basis [142]. During vermicomposting nitrous oxide emissions decreased by 40% with higher moisture and by 23% with lower moisture and methane emissions also decreased by 22-26%. Similarly, vermicomposting decreased methane emissions by 32% and 16% with higher and lower moisture, respectively. The effect of vermicomposting on greenhouse gases contributes to climate change mitigation. Vermitechnology also aids in the reduction of soil salinity, soil erosion with less run-off and wasteland development. From this present review, it is concluded that the organic wastes are effectively recycled by microorganisms followed by earthworms and plays a major role in the development of growth and yield of agricultural crops. Similarly, vermicomposts contain beneficial microorganisms which are essential for nutrient mineralization and make it available for plant uptake. Therefore, promotion of vermiculture technology for bio-waste conversion in urban areas is essential for appropriate waste management, livelihood improvement, and climate change mitigation.

CONCLUSIONS

Vermicomposting is a cost-effective and eco-friendly waste management technology which takes the privilege of both earthworms and the associated microbes and has many advantages over traditional thermophilic composting. Vermicomposts are excellent sources of bio fertilizers and their addition improves the physiochemical and biological properties of agricultural soil. Vermicomposting amplifies the diversity and population of beneficial microbial communities. Vermicomposts with excellent physio-chemical properties and buffering ability, fortified with all nutrients in plant available forms, antagonistic and plant growth-promoting bacteria are fantabulous organic amendments that act as a panacea for soil

reclamation, enhancement of soil fertility, plant growth, and control of pathogens, pests and nematodes for sustainable agriculture. Vermicompost is composed of earthworm faeces, humified organic matter and microorganisms, which when added to the soil or plant growing media, increases germination, growth, flowering, fruit production and accelerates the development of a wide range of plant species. The enhanced plant growth may be attributed to various direct and indirect mechanisms, including biologically mediated mechanisms such as the supply of plant-growth regulating substances, and improvements in soil biological functions. Use of this type of organic fertilizer therefore has great potential; however, some recent studies raise serious doubts about the general applicability of these results and propose a more complex model of action for these types of effects. Stimulation of plant growth may depend mainly on the biological characteristics of vermicompost, the plant species used, and the cultivation conditions. Extensive research on inorganic fertilization and plant breeding, carried out within the framework of conventional agriculture, has permitted agricultural producers to modify nutrient inputs and plant needs in order to exploit yields. However, such detailed knowledge has not yet been attained as regards the interactions between plants and organic fertilizers in sustainable agriculture. Due to the complex and flexible configuration of vermicompost in comparison with inorganic fertilizers and the myriad of effects that it can have on soil functioning, a clear and objective concept of vermicompost is required, and the multifaceted interactions between vermicompost-soil-plant must be threadbare in order to preserve consumer confidence in this type of organic fertilizer. There are multiple benefits of vermitechnology; low-cost production of biofertilizer, environmental management of solid wastes and agricultural residues, enhanced soil productivity, tastier quality food, among others. The nutritive value of compost material is high and the composting process effectively converts the waste product into useful by-product.

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The research on vermicomposts, vermicompost production and dissemination is being carried out in jimma agricultural research center.

Conflict of Interest

We declare no conflict of interest.

References

[1] Gajalakshmi S, Abbasi SA. (2004). Neem leaves as a source of fertilizer-cum-pesticide vermicompost. Bioresource Technology, 92:291-296.

[2] Devi J, Prakash M. (2015). Microbial Population dynamics during vermicomposting of three different substrates amended with cowdung. Int J Curr Microbiol Appl Sc, 4(2):1086– 1092 https ://www. ijcma s.com

[3] Edwards CA. (2011). Human pathogen reduction during vermicomposting. In: Edwards CA, Arancon NQ, Sherman R (eds) Vermiculture technology: earthworms, organic wastes and environmental management. CRC Press, Boca Raton, pp 249–261

[4] Hidalgo, P.R., Matta, F. B. and Harkess, R.L. (2006) "Physical and Chemical Properties of Substrates Containing Earthworm Castings and Effects on Marigold Growth''. HortScience, 41, pp. 1474-1476

[5] Sundaravadivelan, C, Isaiarasu, L. Manimuthu, M., Kumar, P., Kuberan, T. and J. Anburaj. (2011). Influence of vermiwash on biological productivity of marigold. Madras Agric. J., 91 (4-6): 221-225.

[6] Zambare, V.P., Padul, M.V., Yadav, A.A., and Shete T.H. (2008). Vermiwash: Biochemical and microbiological approach as ecofriendly soil conditioner. ARPN J. Agric. & Biol. Sci., 3(4): 1-5.

[7] Theunissen, P., Ndakidemi A. and Laubscher, P. (2010). Potential of vermicompost produced from plant waste on the growth and nutrient status in vegetable production. Int. J. Phys. Sci5: 1964-1973.

[8] Wintgens, J.N. (2009). Coffee: Growing, Processing, Sustainable Production: A Guidebook for Growers, Processors, Traders and Researchers. John Wiley and Sons, Weinheim, Germany, ISBN-13: 9783527322862, Pages: 1040.

[9] Manivannan S, Balamurugan M, Parthasarathi K, Gunasekaran G, Ranganathan LS. (2009). Effect of vermicompost on soil fertility and crop productivity-beans (Phaseolus vulgaris). J Environ Biol, 30: 275-281.

[10] Chauhan HK, Singh K. (2015). Potancy of Vermiwash with Neem plant parts on the Infestation of Earias vittella (Fabricius) and Productivity of Okra (Abelmoschus esculentus) (L.) Moench. Asian J Res Pharm Sci, 5(1):36–40. https ://doi.org/10.5958/2231-5659.2015.00006 .5

[11] Qiao, C., Xu, B., Han, Y., Wang, J., Wang, X., Liu, L., Liu, W., Wang, S., Tan, H., Liu, Y., and Zhao, X. (2018). Synthetic nitrogen fertilizers alter the soil chemistry, production and quality of tea. A meta-analysis. Agron. Sustain. Dev., 38 (10). https://doi.org/10.1007/ s13593-017-0485-z.

[12] Li, J. and Xia, J. (2005). Summary on nitrogen (N), phosphorus (P), potassium (K) and tea quality. Chinese Agricul Sci Bull., 21:62–65.

[13] Caffey, R. H., Kazmierczak, R. F. and Avault, J. W. (2001). "Incorporating Multiple Stakeholder Goals into the Development and Use of a Sustainable Index: Consensus Indicators of Aquaculture Sustainability''. Department of Ag. Econ and Agribusiness of Louisiana State University, USA. Staff Paper, pp. 8-40.

[14] Chattopadhyay, A. (2015). Effect of vermiwash of Eisenia foetida produced by different methods on seed germination of green mungbean, Vigna radiate. Int. J. Recy Org Waste Agricult, 4, 233-237.

[15] Gopal M., Gupta, A., Palaniswami, C., Dhanapal, R. and Thomas G.V. (2010). Coconut leaf vermiwash: a bio-liquid from coconut leaf vermicompost for improving the crop production capacities of soil. Curr Sci, 98(9):1202–1210.

[16] Ansari A, Jaikishun S. (2011). Vermicomposting of sugarcane bagasse and rice straw and its impact on the cultivation of Phaseolus vulgaris L. in Guyana, South America. J Agric Tech, 7 2:225–234. http://www.ijat-aatse a.com.

[17] Chanda GC, Bhunia G, Chakraborty SK. (2011). The effect of vermicompost and other fertilizers on cultivation of Tomato plants. J Hortic For. 3:42-45.

[18] Lim, S. L., Wu, T. Y., Lim, P. N., & Shak, K. P. (2015). The use of vermicompost in organic farming: overview, effects on soil and economics. Journal of the Science of Food and Agriculture, 95(6), 1143-1156.

[19] Aslam, Z., Ahmad, A., Idrees, M., Iqbal, N., Akbar, G., Ali, U., Ibrahim, M. U., Bellitürk, K., Naeem, S., Nawaz, M., Nadeem, M., Waqas, M., Rehman, W. U., Sajjad, M., Samiullah., & Akram, Y. (2020). Comparative analysis of nutritional sources on the morpho-physiological characteristics of mung bean (Vigna radiata). International Journal of Agriculture and Food Science, 4(3), 314-322.

[20] Ali M, Hossain M, Rahman M, Islam M. (2012). Effect of vermicompost on growth, yield, chemical composition, and Oil content of rapeseed (var. SAU SHARISHA-1). J Experimental Biol Sci,3 (2): 91-96.

[21] Adhikary, S. Vermicompost, the story of organic gold: (2012). A review. Agricultural Sciences, 3(7), 905-917.

[22] Hendriksen. (1997). Production of earthworm Eisenia fetida has a potential economical source of protein. Biotechnology and Bioengineering, 23, 1812-1997.

[23] Jeyabal, G., & Kuppuswamy. 2001). Recycling of organic wastes for the production of vermicompost and its response in rice-legume cropping system and soil fertility. European Journal of Agronomy, 15(3), 153 170.

[24] Rose, C. J. & Wood, A. W. (1980). Some environmental factors affecting earthworm populations and sweet potato production in Tari basin, Papua New Guniea Highlands. Papua New Guinea. Journal of Agricultural Science, 31, 1-13.

[25] Arancon, N., Lee, S., Edwards, C., & Atiyeh, R. (2003). Effects of humic acids derived from cattle, food and paper-waste ver-micomposts on the growth of greenhouse plants. Pedobiologia, 47(5), 741-744.

[26] Perner, H., Schwarz, D., & George, E. (2006). Effect of mycorrhizal inoculation and compost supply on growth and nutrient uptake of young leek plants growth on peat-based substrates. Horticultural Science, 41, 628-632.

[27] Bellitürk, K., Aslam, Z., Ahmad, A., & Rehman, S. U. (2020). Alteration of physical and chemical properties of livestock ma-nures by Eisenia fetida (Savigny, 1926) and developing valuable organic fertilizer. Journal of Innovative Sciences, 6(1), 47-53.

[28] Lee, K. E. (1992). Some trends on opportunities in earthworm research or: Darwin's children—the future of our discipline. Soil Biology and Biochemistry, 24, 1765-1771.

[29] Casenave, C., & Valentin. (1988). In Surface states: one of the keys to Sahelian hydrology. Proc. Sahel Forum on the state-of-the-art of hydrology and hydrogeology in the arid and semi-arid areas of Africa. (UNESCO/IWRA, Urbana, IL, USA. 61-72).

[30] Atiyeh RM, Dominguez J, Sobler S, Edwards CA. (2000). Changes in biochemical properties of cow manure during processing by earthworms (Eisenia andrei) and the effects on seedling growth. Pedobiologia. 44:709-724.

[31] Edwards, C. A., Dominguez, J., & Arancon, N. Q. (2004). The influence of vermicomposts on plant growth and pest incidence. In: Soil Zoology for Sustainable Development in the 21st Century (Shakir, S. H., Mikhaïl, W. Z. A., Eds.), Cairo, pp. 397-420.

[32] Lazcano, C., Arnold, J., Tato, A., Zaller, J. G., & Domínguez, J. (2009). Compost and vermicompost as nursery pot compo-nents: Effects on tomato plant growth and morphology. Span. Journal of Agricultural Research, 7, 944-951.

[33] Arancon NQ, Edwards CA, Babenko A, Cannon J, Galvis P, Metzger JD. (2008). Influences of vermicomposts, produced by earthworms and microorganisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse, Applied Soil Ecology, 39:91-99.

[34] Singh R, Sharma RR, Kumar S, Gupta RK, Patil RT. (2008). Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry (Fragaria x ananassa Duch.). Bioresource Technology. 99:8507-8511.

[35] 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.

[36] Patil SL, Sheelavantar MN. (2000). Effect of moisture conservation practices, organic sources and nitrogen levels on yield, water use and root development of rabi sorghum [Sorghum bicolor (L.)] in the vertisols of semiarid tropics. Annals of Agricultural Research. 21(21):32-36.

[37] Devi D, Agarwal SK. (1998). Performance of sunflower hybrids as influenced by organic manure and fertilizer. J. of Oilseeds Research. 15:272-279.

[38] Reddy, R., Reddy, M., Reddy, Y. T. N., Reddy, N.S., Anjanappa, N., & Reddy, R. (1998). Effect of organic and inorganic sources of NPK on growth and yield of pea (Pisum sativum L.). Legume Research, 21(1), 57-60.

[39] Vadiraj BA, Krishna Kumar M, Jeyakumar and Naidu R. (1992). Studies on vermicomposts and the effect of cardomum nursery seedlings. Fourth national symposium on soil, soil biology and ecology.

[40] Nethra NN, Jayaprasad KV, Kale RD. (1999). China aster [Callistephus chinensis (L)] cultivation using vermicompost as organic amendment. Crop Research, Hisar. 17:209-215.

[41] Hashemimajd K, Kalbasi M, Golchin A, Shariatmadari H. (2004). Comparison of vermicompost and composts as potting media for growth of tomatoes. Journal of Plant Nutrition. 6:1107-1123.

[42] Alam MN, Jahan MS, Ali MK, Ashraf MA, Islam MK. (2007). Effect of vermicompost and chemical fertilizers on growth, yield and yield components of potato in barind soils of Bangladesh. J of Applied Sciences Res. 3(12):1879-1888.

[43] Arancon NQ, Edwards CA, Bierman P, Welch C, Metzger JD. (2004). Influences of vermicomposts on field strawberries: 1. effects on growth and yields. Bioresource Technology, 93:145-153.

[44] Anwar M, Patra DD, Chand S, Kumar A, Naqvi AA, Khanuja SPS. (2005). Effect of organic manures and inorganic fertilizer on growth, herb and oil yield, nutrient accumulation, and oil quality of French basil. Communications in Soil Science and Plant Analysis. 36(1-14):1737-1746.

[45] Prabha ML, Jayraay IA, Jayraay R, Rao DS. (2007). Effect of vermicompost on growth parameters of selected vegetable and medicinal plants. Asian Journal of microbiology, Biotechnology and Environmental Sciences. 9(2):321-326.

[46] Sunil K, Rawat CR, Shiva D, Suchit KR. (2005). Dry matter accumulation, nutrient uptake and changes in soil fertility status as influenced by different organic and inorganic sources of nutrients to forage sorghum (Sorghum bicolor). Indian Journal of Agricultural Science. 75(6):340-342.

[47] Cabanas-Echevarría M, Torres–García A, Díaz-Rodríguez B, Ardisana EFH, Creme-Ramos Y. (2005). Influence of three bioproducts of organic origin on the production of two banana clones (Musa spp AAB.) obtained by tissue cultures. Alimentaria, 369:111-116.

[48] Chand S, Pande P, Prasad A, Anwar M, Patra DD. (2007). Influence of integrated supply of vermicompost and zinc-enriched compost with two graded levels of iron and zinc on the productivity of geranium. Communications in Soil Science and Plant Analysis. 38:2581-2599.

[49] Atiyeh RM, Arancon N, Edwards CA, Metzger JD. (2002). The influence of earthworm-processed pig manure on the growth and productivity of marigolds. Bioresource Technology, 81:103-108.

[50] Hidalgo PR, Harkess RL. (2002a). Earthworm casting as a substrate amendment for Chrysanthemum Production. Hortscience. 37(7):1035-1039.

[51] Hidalgo PR, Harkess RL. (2002b). Earthworm casting as a substrate for Poinsettia production. Hortscience, 37(2):304-308.

[52] Verma S, Singh A, Pradhan SS, Singh JP, Verma SK. (2018). Effects of organic formulations and synthetic fertilizer on the performance of pigeonpea in eastern region of Uttar Pradesh. Bangladesh Journal of Botany, 47(3):467-471.

[53] Arancon NQ, Edwards CA, Bierman P, Metzger JD, Lucht C. (2005). Effects of vermicomposts produced from cattle manure, food waste and paper waste on the growth and yield of peppers in the field. Pedobiologia. 49:297-306.

[54] Argüello JA, Ledesma A, Núñez SB, Rodríguez CH, Díaz Goldfarb MDC. (2006). Vermicompost effects on bulbing dynamics nonstructural carbohydrate content, yield, and quality of 'Rosado Paraguayo' garlic bulbs. Hortscience. 41(3):589-592.

[55] Gajalakshmi S, Abassi SA. (2004). Earthworms and vermicomposting. Int J Biotechnol, 3:486–494 http://hdl.handl e.net/12345 6789/5894

[56] Karmegam N, Alagumalai K, Daniel T. (1999). Effect of vermicompost on the growth and yield of green gram (Phaseolus aureus Roxb.). Tropical Agriculture. 76:143-146.

[57] Lazcano C, Sampedro L, Zas R, Domínguez J. (2010). Vermicompost enhances germination of the maritime pine (Pinus pinaster Ait.). New Forest. 39:387-400.

[58] Verma S. (2016). Bio-efficacy of organic formulations along with fertilizers on growth, yield and quality of pigeonpea [Cajanus cajan (L.) Millsp] (Doctoral dissertation, Institute of Agricultural Sciences,Banaras Hindu University).

[59] Singh R, Gupta RK, Patil RT, Sharma RR, Asrey R, Kumar A, Jangra KK. (2010). Sequential foliar application of vermicompost leachates improves marketable fruit yield and quality of strawberry (Fragaria x ananassa Duch.). Scientia Horticulturae, 124:34-39.

[60] Zaller JG. (2007). Vermicompost as a substitute for peat in potting media: Effects on germination, bio mass allocation, yields and fruit quality of three tomato varieties. Scientia Horticulturae. 112:191-199.

[61] Peyvast G, Olfati JA, Madeni S, Forghani A. (2008). Effect of vermicompost on the growth and yield of spinach (Spinacia oleracea L.). Journal of Food Agriculture and Environment. 6:110-113.

[62] Wang D, Shi Q, Wang X, Wei M, Hu J, Liu J., Yang, F. (2010). Influence of cow manure vermicompost on the growth, metabolite contents, and antioxidant activities of Chinese cabbage (Brassica campestris ssp. chinensis). Biology and Fertility of Soils. 46:689-696.

[63] Coria-Cayupán YS, De Pinto MIS, Nazareno MA. (2009). Variations in bioactive substance contents and crop yields of lettuce (Lactuca sativa L.) cultivated in soils with different fertilization treatments. Journal of Agricultural and Food Chemistry, 57(21):10122-10129.

[64] Roberts P, Jones DL, Edwards-Jones G. (2007). Yield and vitamin C content of tomatoes grown in vermicomposted wastes. Journal of the Science of Food and Agriculture. 87:1957-1963.

[65] Reshid Abafita, Tesfaye Shimbir and Tesfu Kebede. (2014). Effects of different rates of vermicompost as potting media on growth and yield of tomato (Solanum lycopersicum L.) and soil fertility enhancement. Sky Journal of Soil Science and Environmental Management, Vol. 3(7), pp. 073 - 077, Available online http://www.skyjournals.org/SJSSEM

[66] Cavani N, Mimmo T. (2007). Rhizodeposition of Zea mays L. as affected by heterosis. Archives of Agronomy and Soil Science, 53:593-604.

[67] Aira M, Gómez-Brandón M, Lazcano C, Bååth E, Domínguez J. (2010). Plant genotype strongly modifies the structure and growth of maize rhizosphere microbial communities. Soil Biology and Bioche. Mistry. 42(12):2276-2281.

[68] Karmegam N and Daniel T. (2000). Effect of vermicompost on the growth and yield of green gram (Phaseolus aureus Rob.), Tropical Agriculture, 76(2), 143–146.

[69] Liu, M., Hu, F., Chen, X., Huang, Q., Jiao, J., Zhang, B., & Li, H. (2009). Organic amendments with reduced chemical fertiliz-er promotes soil microbial development and nutrient availability in a subtropical paddy field: the influence of quantity, type and application time of organic amendments. Applied Soil Ecology, 42, 166-175.

[70] Satyanarayana, V., Murthy, V. R. K., Vara Prasad P. V., & Boote, K. J. (2002). Influence of integrated use of farmyard manure and inorganic fertilizers on yield and yield components of irrigated lowland rice. Journal of Plant Nutrition, 25(10), 2081-2090.

[71] Ramasamy, P. K., & Suresh, S. N. (2011). Effect of vermicompost on root numbers and length of sunflower plant (Helianthus annuus L.). Journal of Pure and Applied Microbiology, 4(1), 297-302.

[72] Hatti, S. S., Londonkar, R. L., Patil, S. B., Gangawane, A. K., & Patil, C. S. (2010). Effect of Eisenia fetida vermiwash on the growth of plants. Crop Science, 1(1), 6-10.

[73] Rekha, G. S., Valivittan, K., & Kaleena, P. K. (2013). Studies on the influence of vermicompost and vermiwash on the growth and productivity of black gram (Vigna mungo). Advance in Biological Regulation, 7(4), 114-121.

[74] Kitturmath MS, Giraddi RS and Shakarmurthy (2005). Management of distillery waste using the eugine earthworm, Eudrillus eigeniae (kingberg) pest management, Econ. Zool., 13, 203-206.

[75 Gill, J. S., & Walia, S. S. (2014). Influence of FYM, brown manuring and nitrogen levels on direct seeded and transplanted rice (Oryza sativa L.) A review. Research Journal of Agricultural and Environmental Sciences, 3(9), 417-426.

[76] Kale RD, Mallesh BC, Bano K and Bagyaraj DJ. (1992). Influence of vermicompost applications on the available macro nutrients and selected microbial population in a paddy field, Soil Biology and Biochemistry, 24, 1317–1320.

[77] Singh, M., & Wasnik, K. (2013). Effect of vermicompost and chemical fertilizer on growth, herb, oil yield, nutrient uptake, soil fertility, and oil quality of rosemary. Communications in Soil Science Plant Analysis, 44(18), 2691-2700.

[78] Ahmad, A., Aslam, Z., Iqbal, N., Idrees, M., Bellitürk, K., Rehman, S. U., Ameer, H., Ibrahim, M. U., Samiullah, & Rehan, M. (2019). Effect of exogenous application of osmolytes on growth and yield of wheat under drought conditions. Journal of Envi-ronmental and Agricultural Sciences, 21, 6-13.

[79] Nagavallemma, K., Wani, S., Stephane, L., Padmaja, V., Vineela, C., Babu, R. M., & Sahrawat, K. (2004). Vermicomposting: recycling wastes into valuable organic fertilizer. Journal of SAT Agricultural Research, 2, 1-16.

[80] Gutierrez-Miceli, F. A., Santiago-Borraz, J., Molina, J. A. M., Nafate, C. C., Abud-Archila, M., Llaven, M. A. O., Rin-con-Rosales, R., & Dendooven, L. (2007). Vermicompost as a soil supplement to improve growth, yield and fruit quality of tomato (Lycopersicum esculentum). Bioresource Technology, 98(15), 2781-2786.

[81] Reddy VM and Ohkura K. (2004). Vermicomposting of rice straw and its effects on sorghum growth, Tropical Ecol., 45, 327-331.

[82] Suhane, R. K. (2007). Vermicompost. Rajendra Agriculture University, Pusa, pp. 88.

[83] Grapelli, A., Tomati, U., Galli, E., & Vergari, B. (1985). Earthworm casting in plant propagation. Horticultural Science, 20, 874-876.

[84] Federico, J. S., Borraz, J.A., Molina, M., Nafate, C., Archila, C., & Oliva, L. M. (2007). Vermicompost as a soil supplement to improve growth, yield and fruit quality of tomato (Lycopersicum esculentum). Bioresource Technology, 98(15), 2781-2786.

[85] Kale, R. D. & Bano, K. (1986). In: Proceedings Nat. Semi on Organic waste Utilization. pp. 151-160.

[86] Angadi, V. V., & Radder, G. D. (1996). In: Organic Farming and Sustainable Agriculture. National Seminar, G.B.P.U.A.T, Pantnagar. 34.

[87] Jadhav, A. D. J. (1997). Maharashtra agriculture University, 22, 249-250.

[88] Nagarajan, S. (1997). Kisan World, 24(8), 49-50.

[89] Sarwar, G., Hussain, N., Schmeisky, H., & Muhammad, S. (2007). Use of compost an environment friendly technology for enhancing rice-wheat production in Pakistan. Pak. Journal of Botany, 39(5), 1553-1558.

[90] Sarwar, G., Hussain, N. Schmeisky, H. Muhammad, S. Ibrahim, M. and Safdar, E. (2008). Improvement of soil physical and chemical properties with compost application in rice-wheat cropping system. Pakistan Journal of Botany, 40, 275-282.

[91] Gopinath, K. A., Saha, S., Mina, B. L., Pande, H., Kundu, S., & Gupta, H. S. (2008). Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production. Nutrient Cycling in Agroeco-systems, 82, 51-60.

[92] Grigatti, M., Giorgonni, M., & Ciavatta, C. (2007). Compost-based growing media: influence on growth and nutrient use of bedding plants. Bioresource Technology, 98, 3526-3534.

[93] Edwards CA, Bohlen PJ. (1996). Biology and Ecology of earthworms. Chapman and Hall, London, p 426.

[94] Maheswarappa HP, Nanjappa HV, Hegde MR. (1999). Influence of organic manures on yield of arrowroot, soil physico-chemical and biological properties when grown as intercrop in coconut garden. Annals of Agricultural Research. 20:318-323.

[95] Mitchell A, Edwards CA. (1997). The production of vermicompost using Eisenia fetida from cattle manure. Soil Biology and Biochemistry. 29:3-4.

[96] Kannan P, Saravanan A, Krishnakumar S, Natarajan SK. (2005). Biological Properties of Soil as Influenced by Different Organic Manures. Res. J of Agriculture and Biological Sciences. 1:181-183.

[97] Edwards CA, Fletcher KE. (1988). Interaction between earthworms and microorganisms in organic matter breakdown. Agric Ecosyst Environ, 20:235–249.

[98] Sinha RK, Agarwal S, Chauhan K, Valani D. (2010). The wonders of earthworms and its vermicompost in farm production: Charles Darwin's 'friends of farmers', with potential to replace destructive chemical fertilizers from agriculture. Agricultural sciences, 1:76–94.

[99] Ravindra NP, Raman G, Badri Narayanan K, Sakthivel N. (2008). Assessment of genetic and functional diversity of phosphate solubilizing fluorescent pseudomonads isolated from rhizospheric soil. BMC Microbiol, 8:230.

[100] Correa JD, Barrios ML, Galdona RP. (2004). Screening for plant growth promoting rhizobacteria in Chamaecytisus proliferus (tagasaste), a forage tree-shrub legume endemic to the Canary Islands. Plant Soil, 266:75–84

[101] Han J, Sun L, Dong X, Cai Z, Yang H, Wang Y, Song W. (2005). Characterization of a novel plant growth-promoting bacteria strain Delftia tsuruhatensis HR4 both as a diazotroph and a potential biocontrol agent against various pathogens. Syst Appl Microbiol. 28:66–76.

[102] Pathma J, Kamaraj Kennedy R, Sakthivel N. (2011a) Mechanisms of fluorescent pseudomonads that mediate biological control of phytopathogens and plant growth promotion of crop plants. In: Maheswari DK (ed) Bacteria in Agrobiology: Plant Growth Responses. SpringerVerlag, Berlin, pp 77–105

[103] Pathma J, Rahul GR, Kamaraj Kennedy R, Subashri R, Sakthivel N. (2011b). Secondary metabolite production by bacterial antagonists. Journal of Biological Control, 25:165–181

[104] Ismail SA. (1995). Earthworms in soil fertility management. In: Thampan PK (ed) Organic Agriculture, pp 77–100

[105] Canellas LP, Olivares FL, Okorokova FAR. (2002). Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence and plasma membrane H+– ATPase activity in maize roots. Plant Physiol, 130:1951–1957.

[106] Parle JN. (1963). A Microbiological Study of Earthworm Casts. J Gen Microbiol, 31:13–22.

[107] Edwards CA, Lofty R. (1977). The Biology of Earthworms. Chapmann and Hall, London.

[108] Matthur RS, Magu SP, Sadisavam KV and Gaur AC, (1986). Accelerated compost and improved yields, Biocycle, 42-44.

[109] Edwards CA and Lofty JR, (1982). Nitrogenous fertilizers and earthworm population in agricultural soul, Soil Biology and Biochemistry, 14, 515-521.

[110] Karsten ER, (1995). Making a high-quality compost tea, Biocycle, 40: 94.

[111] Yasir M, Aslam Z, Kim Lee SW, Joen CO and Chung YR, (2009). Bacteria community composition and chiti -nase gene diversity of vermicompost with antifungal activity. Bioresource Technology, 100, 4396–4403.

[112] Esakkiammal, B., Esaivani, C.,Vasanthi, K., LakshmiBai, L. and Shanthi Preya, N. (2015). Microbial diversity of Vermicompost and Veriwash prepared from Eudrilus euginae. Int.J.Curr.Microbiol.App.Sci. 4(9): 873-883.

[113] Anastasi, A., Varese, C.G., Marchisio, F.V. (2005). Isolation and identification of fungal communities in compost and vermicompost. Mycologia, 97(1), pp. 33–44.

[114] Prabhat P. and Young Chung, R. (2011) Changes in fungal population of fly ash and vinnase mixture during vermicomposting: Documentation of cellulase isozyme in vermicompost, Waste Management, 1-7.

[115] Atiyeh RM, Subler S, Edwards CA, Bachman G, Metzger JD, Shuster W. (2000b). Effects of vermicomposts and composts on plant growth in horticulture container media and soil. Pedobiologia, 44:579–590.

[116] Hand P, Hayes WA, Frankland JC, Satchell JE. (1988). Vermicomposting of cow slurry. Pedobiologia, 31:199–209.

[117] Subler S, Edwards CA, Metzger PJ. (1998). Comparing vermicomposts and composts. Biocycle, 39:63–66.

[118] Atiyeh RM, Dominguez J, Subler S, Edwards CA. (2000a). Changes in biochemical properties of cow manure during processing by earthworms (Eisenia andrei, Bouché) and the effects on seedling growth. Pedobiologia, 44:709–724.

[119] Brown GG. (1995). How do earthworms affect microfloral and faunal community diversity? Plant Soil, 170:209–231

[120] Albanell E, Plaixats J, Cabrero T. (1988). Chemical changes during vermicomposting (Eisenia fetida) of sheep manure mixed with cotton industrial wastes. Biol Fertil Soils, 6:266–269.

[121] Zhang BG, Li GT, Shen TS, Wang JK, Sun Z. (2000) Changes in microbial biomass C, N, and P and enzyme activities in soil incubated with the earthworms Metaphire guillelmi or Eisenia foetida. Soil Biol Biochem, 32:2055–2062.

[122] Garg P, Gupta A, Satya S. (2006). Vermicomposting of different types of waste using Eisenia foetida: a comparative study. Bioresour Technol, 97:391–395

[123] Gezahegn Degefe, Seyoum Mengistu and Dominguez, J. (2012). Vermicomposting as a sustainable practice to manage coffee husk, Enset waste (Enset ventricosum), Khat waste (Catha edulis) and vegetable waste amended with cow dung using an epigeic Earthworm Eisenia Andrei (Bouch'1972). Int. J. PharmTech Res., 4: 15-24.

[124] Hassen A, Belguith K, Jedidi N, Cherif A, Cherif M, Boudabous A. (2001). Microbial characterization during composting of municipal solid waste. Bioresour Technol, 80:217–225.

[125] Pant AP, Radovich TK, Hue NV, Talcott ST and Krenek KA. (2009). Vermicompost extracts influence growth, mineral nutrients, phytonutrients and antioxidant activity in pak choi grown under vermicompost and chemical fertilizer, J. Sci. Food Agric., 125-129.

[126] Umesh B, Mathur LK, Verma JN, Srivastava. (2006). Effects of vermicomposting on microbiological flora of infected biomedical waste. ISHWM Journal, 5:28–33.

[127] Masciandaro G, Ceccanti B, Gracia C.` (2000). In situ' vermicomposting of biological sludges and impacts on soil quality. Soil Biol Biochem, 32:1015–1024.

[128] Sidhu J, Gibbs RA, Ho GE, Unkovich I. (2001). The role of indigenous microorganisms in suppression of Salmonella regrowth in composted biosolids. Water Res, 35:913–920.

[129] Dominguez J, Edwards CA. (2004). Vermicomposting organic wastes: A review. In: Shakir Hanna SH, Mikhail WZA (eds) Soil Zoology for sustainable Development in the 21st century., Cairo, pp 369–395.

[130] Ganesh kumar A, Sekaran G. (2005). Enteric pathogen modification by anaecic earthworm, Lampito Mauritii. J Appl Sci Environ Mgt, 9:15–17.

[131] Hartenstein R. (1983). Assimilation by earthworm Eisenia fetida. In: Satchell JE (ed) Earthworm ecology. From Darwin to vermiculture. Chapman and Hall, London, pp 297–308.

[132] Sinha RK, Heart S, Agarwal S, Asadi R, Carretero E. (2002). Vermiculture technology for environmental management: study of the action of the earthworms Eisenia foetida, Eudrilus euginae and Perionyx excavatus on biodegradation of some community wastes in India and Australia. The Environmentalist, 22:261–268.

[133] Sinha RK, Bharambe G, Chaudhari U. (2008). Sewage treatment by vermifiltration with synchronous treatment of sludge by earthworms: a low-cost sustainable technology over conventional systems with potential for decentralization. The Environmentalist, 28:409–420.

[134] Aira M, Gómez-Brandón M, González-Porto P, Domínguez J . (2011). Selective reduction of the pathogenic load of cow manure in an industrial-scale continuous-feeding vermireactor. Bioresource Technol, 102:9633–9637.

[135] Edwards CA, Subler S, Arancon N. (2011). Quality criteria for vermicomposts. In: Edwards CA, Arancon NQ, Sherman RL (eds.) Vermiculture technology: earthworms, organic waste and environmental management. CRC Press, Boca Raton, pp 287–301 https://www.crcpr ess.com

[136] CSA (2020). Federal democratic republic of Ethiopia, agricultural sample survey 2019/20 [2012 E.C.]. Volume II report on livestock and live-stock characteristics (private peasant holdings). Central Statistical Agency (CSA) Statistical bulletin 587. Addis Ababa, Ethiopia.

[137] Middle east and north Africa.(2013).West Bank and Gaza Social, Urban, Rural and Resilience Recipient Executed Activities Investment Project Financing FY Seq No: 7 ARCHIVED on 29-Nov-2017 ISR30407

[138] Belay Duguma. (2022). Milk composition, traditional processing, marketing, and consumption among smallholder dairy farmers in selected towns of Jimma Zone, Oromia Regional State, Ethiopia, Food Sci Nutr. 10:2879–2895.

[139] Dereje Tulu , Melkam Aleme , Gezahegn Mengistu , Ararsa Bogale , Amsalu Bezabeh & Esayas Mendesil . (2020). Improved beekeeping technology in Southwestern Ethiopia: Focus on beekeepers' perception, adoption rate, and adoption determinants, Cogent Food & Agriculture, 6:1, 1814070.

[140] Lombebo WA, Wosoro ES . (2019). Challenges and Opportunities of Urban Dairy Cattle Keeping and its Role in Poverty Reduction of Livelihoods in Hosanna Town, Southern Ethiopia. Vetry Sci Rech , Vol: 1, Issu: 1 (11-17).

[141] Maru Abebaw Berhanu and Juliet Akola (2014). Environmental Perspective of Urban Agriculture in Debre Markos Town, Amhara Regional State, Ethiopia. Journal of Environment and Earth Science; www.iiste.org ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online) Vol.4, No.1

[142] Lalander H., Fidjeland J., Diener S., Eriksson S. , Vinnerås B. (2014). High waste-to-biomass conversion and efficient Salmonella spp. reduction using black soldier fly for waste recycling, Agron. Sustain. Dev. DOI 10.1007/s13593-014-0235-4