JOURNAL PUNJAB ACADEMY OF SCIENCES (Peer Reviewed Open Access Journal)
JPAS, 21: 01-14 (January-December, 2021)
Available online at www.jpas.in
ISSN 2229-7014 (P)

VERMICOMPOSTING OF DIFFERENT ORGANIC WASTES INTO ORGANIC MANURE: A REVIEW

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ABSTRACT

The massive amount of solid waste generated across the world is a severe environmental concern as a result of rapid industrialisation, population expansion, and urbanisation. Investment costs for solid waste treatment processes such as incineration, pyrolysis, and gasification are significant and at the same time none of these technologies is environmentally safe. Vermicomposting is economic and eco-friendly method of solid waste management. The purpose of this review is to offer a broad overview of the efficacy of vermicomposting technologies as an ecologically sound method for management of solid waste and its beneficial role as organic fertilizer.Vermicompost is a organic fertiliser rich in humus, NPK, micronutrients, and beneficial soil microorganisms, including bacteria that fixes nitrogen and phosphate, actinomycetes, and hormones that stimulate plant development, including auxins, gibberellins, and cytokinins.Therefore, the purpose of this review's discussion is to demonstrate how vermicomposting, a revolutionary method of handling solid organic waste in an eco-friendly manner.

Keywords: Earthworm, Nutrients, Organic waste, Vermicompost

INTRODUCTION

Globally, enormous amounts of solid waste are being produced as a result of numerous human activities, accelerating urbanisation, industrialisation, and economic expansion (Rajput et al. 2009). Worldwide production of vast amounts of organic waste creates significant environmental (unpleasant odours, pollution of ground water and soil) and disposal issues (Pillai et al. 2014). Globally, the issue with the production of solid waste is worse. The world generates 2.01 billion tonnes of municipal solid waste every year (Kaza et al. 2018). According to research conducted in 2018, worldwide waste is predicted to increase to 3.4 billion tonnes by 2050 (Figure 1). In contrast to low- and middle-income nations, where it is anticipated to rise by around 40% or more, daily per capita waste production in high-income countries is forecast to rise by 19% by 2050. By 2050, it is anticipated that the overall amount of waste produced in low-income nations would have increased by more than three times (Alshehrei and Ameen 2021; Kaza et al. 2018) (Figure 2-5).

Despite the fact that numerous strategies, such as source reduction, material recovery, curb side recycling, landfill dumping, waste to energy, incineration, and composting, have been put forth and put into practise for proper solid waste management, some of these methods of treatment and disposal could have detrimental effects on the environment (Turan et al. 2009).The dumping of waste in unscientific landfills is associated with many problems like groundwater contamination, biodiversity loss, greenhouse emissions etc (Siddiqua et al. 2022; Mohan and Joseph, 2021). Another major problem is open burning of waste. In developing countries open burning of waste is more common as it is considered efficient, fast and inexpensive way of reducing the waste. But it is also associated with significant environmental and health problems (Cogut 2016). Because of high nitrogen (N) and phosphorus (P) concentrations, sewage sludge is immediately disposed in agricultural fields; nonetheless, it may be hazardous to soil and plants and have a depressing impact on the metabolism of soil microorganisms (Khwairakpam and Bhargava 2009).

Keeping in view the above stated problems, vermicomposting can be a viable, economic, green and efficient method for organic waste management. The end product is nutrient rich organic manure called as vermicompost. Vermitechnology involves the joint action of microbes and earthworm's to bio-oxidize and stabilise the organic waste (Bhat et al. 2018). Although bacteria are responsible for the biochemical breakdown of organic materials, earthworms are the primary drivers of the process because they alter the substrate and modulate its biological activity (Arora et al. 2020). Studies conducted by various researchers established the potential of vermicomposting in management of various types of wastes; beverage industry (Singh et al. 2010), paper mill sludge (Sonowal et al. 2014), distillery sludge (Singh et al. 2013), sewage sludge (Molina et al. 2013), rice straw (Zhi-Wei et al. 2019), sugarcane bagasse (Ansari and Jaikishun, 2011).

The purpose of this study is to offer an overview of the possibilities of vermicomposting in treating solid waste in an environmentally responsible manner. Beside a general overview, this work specifically aims to cover the potential of (i) vermicomposting in management of agricultural and industrial waste, (ii) effect of vermicompost on plant growth and iii) effect of vermicompost on soil properties. The types of earthworms and their characteristics are also discussed in this review.

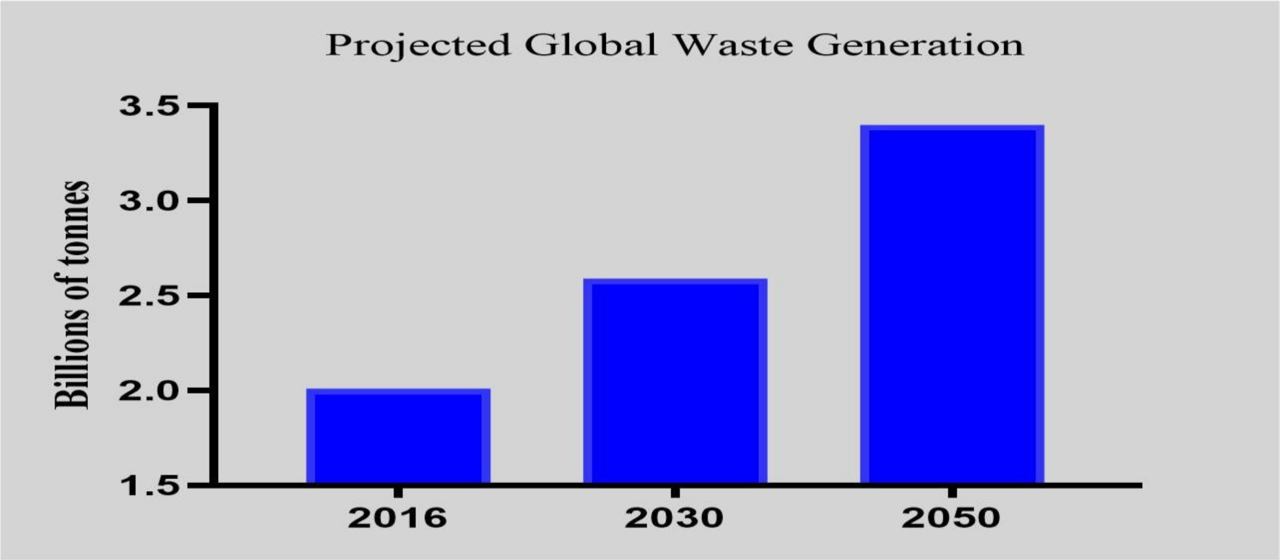

Figure 1. Projected global waste generation

Figure 2. Waste generation by income level

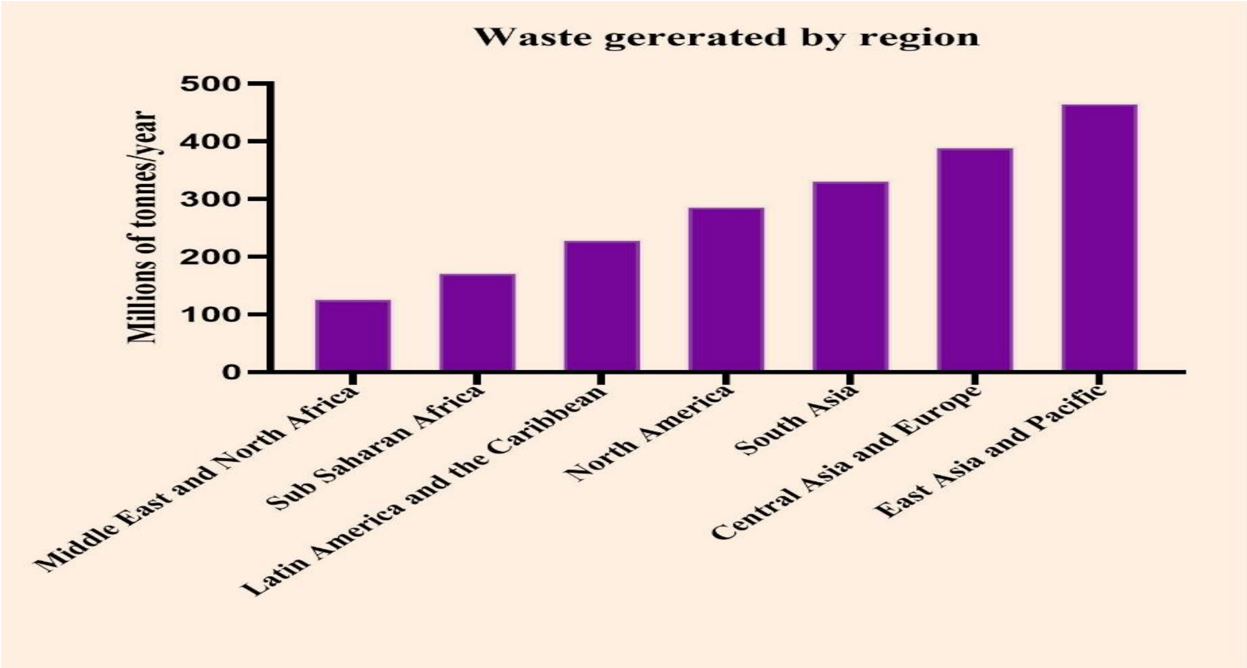

Figure 3. Waste generation by region

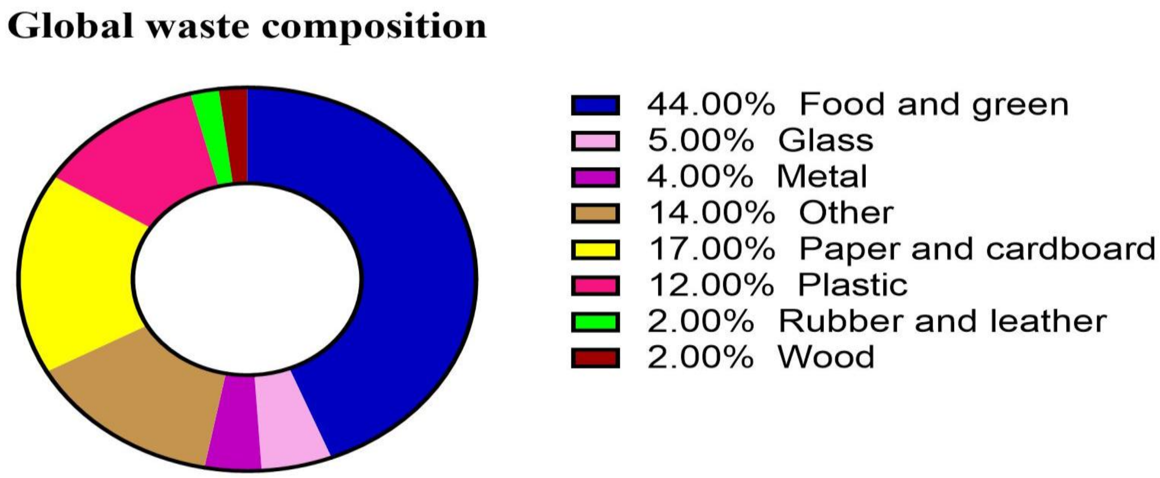

Figure 4. Global waste composition

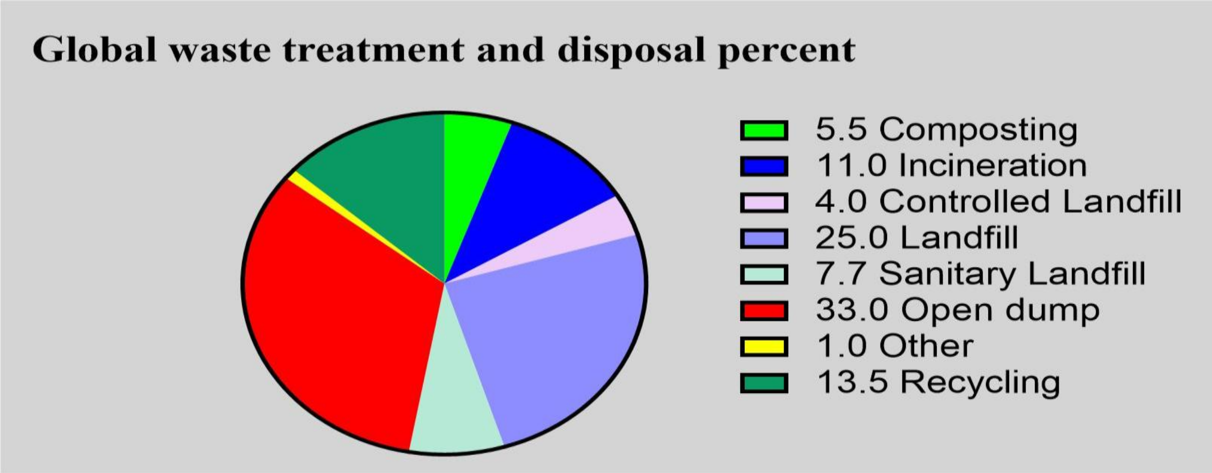

Figure 5. Global waste treatment and disposal percent

Types of earthworms and their characteristics: Earthworms are simple, cylindrical, segmented coelomates. They have a long, rounded body, a sharp head, and a somewhat flattened rear. They are characterised by the absence of cartilage or bones. They don't have any appendages, however they have several hooks that resemble chaetae for grasping the substrate. The earthworm can turn and twist because of rings that encircle its delicate, moist body. Since the earthworm lacks true legs, it crawls by moving the bristles (setae) on its body back and forth. Being hermaphrodites, earthworms have both male and female sex organs but need another worm to mate. The clitellum, a unique epidermal ring-shaped region with sexually developed worms, has glands that release substances that help to produce cocoons (Sharma et al. 2009).

Based on feeding behaviour, morphological features, physiological traits, and burrowing activities, earthworms are classified as anecic, endogeic and epigeic (Briones et al. 2005). The characteristics with examples of different types of earthworms are given in Table 1.

Table 1. Classification and characteristics of earthworms

Category	Characteristics	Examples
Anecic (Greek for "out of the earth")	• The anecic earthworms dwell in permanent, vertical burrows in deep soil. • They consume organic waste that is on the soil's surface. • They are good soil aerators	*Lampito mauritii* *Lumbricus terrestris*
Endogeic (Greek for "within the earth")	• The endogeic forms live in the mineral soil layers • They dig horizontal branched burrows. • They feeding on mineral soil particles and decaying organic matter.	*Metaphire posthuman* *Pontoscolex corethrurus* *Megascolex konkanensis*
Epigeic (Greek for "upon the earth")	• Epigeic worms live in decayed organic matter, not in soil. • They do not build permanent burrows • They are very active or quick moving	*Eisenia fetida* *Eudrilus eugeniae* *Eisenia andrei*

Source: Briones et al. 2005; Ali et al. 2015

Vermicomposting as management tool in agricultural and industrial waste: Numerous anthropogenic activities, such as increasing urbanization, industrialization and economic expansion are causing massive amounts of solid waste to be produced all over the world. The management of this solid waste has now become an ecological and technical issue for everyone (Yadav and Garg, 2011). To keep the environment safe and healthy, sustainable solid waste management approaches are essential (Singh et al., 2011). Unused trash produces a variety of environmental challenges, including the spread of unpleasant odours, the taking up of substantial quantities of land and the pollution of surface and ground water. Agro-industrial wastes have few industrial applications. These wastes, if treated sustainably and scientifically, could be converted into a sustainable renewable energy source. Vermicomposting technology, which employs suitable earthworms, has emerged in recent decades as a viable method for converting agro-industrial processing wastes into value able products (Quadar et al. 2022). Extensive study has been conducted on the vermicomposting of a wide range of organic wastes, including animal manure, industrial wastes, agricultural wastes, industrial and sewage sludge (Table 2) (Lim et al., 2016). Previous research indicated that vermicomposting could be an effective waste management solution, notably industrial sludge. A proteolytic enzyme present in the earthworm digestive system can soften, convert and digest industrial sludge (Joo et al. 2015). Mohan (2017) investigated the biotransformation of paper mill sludge into nutrient-rich manure using *Eisenia fetida* and evaluated the changes in physicochemical parameters of paper mill sludge before and after vermicomposting process. Their findings revealed that a 25% mixture of paper mill sludge and 75% cow dung could be easily transformed into valuable manure. Vermicomposting of sugar beet mud and pulp with cattle dung was studied by Bhat et al. (2015) who found that earthworm development was greatly affected with the increase in amount of the waste. According to the reports of Singh et al. (2010), the breakdown of 50:50 mixtures completed in 75 days when worms were inoculated in the feed mixture of 25g/kg during the vermicomposting of beverage industry bio-sludge combinedwith cattle dung.It has also been observed that sludge from the beverage industry can be stabilized with vermicomposting, however it must be blended with animal dung because 100% sludge is hazardous to worms. Jaybhaye and Satish (2016) investigated vermicomposting as an emerging trend in agricultural waste management. Gopal et al. (2017) discovered structural and functional changes in bacterial population during vermicomposting of coconut leaf. Nagar et.al. (2017) also examined vermicomposting of leaf litters as a method of converting waste into best manure. Sharma and Garg (2018) compared the quality of vermicompost obtained from rice straw and paper waste using the earthworm species *Eisenia fetida*. Vermicomposting of paper industry sludge with cowdung and green manure plants employing *Eisenia fetida* as a promising solution for cleaner and enhanced vermicompost production as stated by Karmegam et al. (2019). Ramnarian et al. (2019) reported vermicomposting of various organic materials utilising the epigeic earthworm *Eisenia fetida*. Boruah et al. (2019) used *Eisenia fetida* for vermicomposting of a mixture of citronella bagasse and paper mill waste. Mousavi et al. (2019) studied the vermicomposting of grass and newspaper waste mixed with cow manure using *Eisenia fetida* and physico-chemical changes during vermicomposting process. Garg et al. (2012) explored the utility of *Eisenia fetida* for vermicomposting of food industry sludges combined with different organic wastes by preparing the sludges in varied proportions with cattle dung. Thus, it has also been concluded that if waste is mixed in sufficient quantities with other organic waste, it can be vermicomposted into high-quality manure. According to Singh et al. (2016) who also studied the vermicomposting of fly ash from a thermal power plant mixed with cow dung in various proportions (%), such as 0:100, 25:75, 50:50, 75:25, and 100:0. The heavy metal content was also found to be lowest in vermicompost, indicating that earthworms' gut contains microorganisms capable of neutralising the toxic effect of waste. Amouei et al., (2017) also concluded that papermill sludge waste can be degraded by earthworm much easily.

Table 2. Vermicomposting of different agricultural and industrial wastes employing different earthworm species

S.No.	Type of waste	Earthworm species used	References
1.	Distillery sludge	*Eisenia fetida*	Suthar (2008)
2.	Agro-industrial sludge (press mud + distillery waste)	*Eisenia fetida*	Suthar (2010)
3.	Tannery sludge	*Eisenia fetida*	Vig et al. (2011)
4.	sugarcane trash and wheat straw	*Eisenia fetida.*	Suthar et al. (2012)
5.	Rice husk	*Eudrilus eugeniae*	Lim et al. 2012
6.	Pressmud	*Eudrilus eugeniae*	Balachandar et al.(2020)
7.	Corn cob and straw	*Eisenia fetida*	Silva et al. (2021)
8.	Thermal fly ash	*Eisenia fetida*	Sohal et al. (2021)
9.	Biomedical waste ash	*Eisenia fetida*	Sohal et al. (2021)
10.	Pharmaceutical industry sludge	*Eisenia fetida*	Singh et al. (2022)
11.	Coconut husk	*Eisenia fetida*	Quadar et al. (2022)

Vermicompost's influence on the physicochemical properties of soil: Vermicompost has the potential to enhance the soil's physical properties, including its porosity, aeration, drainage, resistance to corrosion, and infiltration (Arancon et al. 2008; Angmo et al. 2021) resulting in a better environment for root development. For instance, (Manivannan et al. 2009) discovered that adding vermicomposts to the soil enhanced its physical characteristics, which in turn boosted bean growth, yield, and quality. The majority of the nutrients in vermicompost are in plant-available forms, including nitrates, phosphates, exchangeable calcium, and soluble potassium. According to earlier investigations, polysaccharides seemed to be richer in vermicompost. In order to develop and sustain the soil structure for improved aeration, water retention, drainage, and aerobic conditions, polysaccharide worked as a cementing component in the soil, which provided aggregate stability (Edwards et al. 1996). The application of vermicompost in soil increased soil organic matter and decreased quantities of lime and pH value (Bellitürk et al. 2021). This is because vermicompost has a soil-regulating function. For root growth and nutrient availability to the plants, soil structure management is particularly beneficial. (Manivann et al. 2021) The soil's aggregate stability is increased by the mucus production from the earthworm's stomach and the microorganisms that live there (Bhat et al. 2017; Singh et al.2016; Singh et al.2017; Trivedi et al. 2017). The organic material in vermicomposts, which is absorbent and only stores the quantity of water the plant roots need, increases the soil's ability to retain water. (Manivannan et al. 2021; Abadi et al. 2012) also found a decrease in the bulk density of the vermicompost-treated soil. The increased microbial population and activity, which led to the development of aggregates and improved porosity of the soil, was primarily responsible for the decreases in particle and bulk densities. The base exchange capacity and oxidation potential of vermicompost have also been observed to be greater (Sharma et al. 2005; Tharmaraj et al. 2011; Marinari et al. 2000). While working with clay soil, Masciandaro et al. (1997) discovered that the addition of vermicompost into soil increased the total number of cracks but reduced the size of the cracks, an indication of enhanced soil structure. Since water may permeate and be held in soil, improvement of structure can be of significant value from an agronomic perspective. Soil with excellent physical qualities also promotes the retention of water, oxygen, and nutrients, all of which are necessary for crop output. Therefore, organic manure such as vermicompost may be used as an alternative to chemical fertilizers to mitigate their negative impacts. Vermicompost is peat-like materials that are generated by a non-thermophylic process involving interactions between earthworms and microorganisms (Edwards and Burrows, 1988), resulting in the bio-oxidation and stabilization of organic matter (Aira et al., 2000; Joshi et al. 2013). The rapid loss of soil nutrients due to runoff is a widespread issue. However, Bhattacharjee et al. (2001) found that adding vermicompost to the soil altered its physiochemical characteristics in a way that decreased nutrient loss due to leaching.

Vermicompost's influence on the biological properties of soil: Vermicomposting enhances soil quality and promotes the growth of beneficial bacteria that are essential to healthy soil. The soil plots that were treated with vermicompost and manure had considerably greater glucosidase, protease, and alkaline phosphor-mono-esterase enzyme activity rates than the soil plots that were treated with inorganic fertilizer. In addition to encouraging plant development, fertilization with vermicompost and manure also stimulated soil microbial activity. When applied in large quantities, vermicompost and manure promoted rapid bacterial growth but had little effect on the fungus population. Soil microbial biomass was increased due to organic additions, but only in areas where manure had been applied. Soil microbial biomass rose only as a result of an increase in Gram-negative bacteria, as seen by a rise in the concentration of PLFAs indicators exclusive to this group (Chaudhary et al.2004; Lazcano, C. and Domínguez, J. (2011). The use of vermicompost as a bioinoculant aids in the introduction of beneficial microorganisms into the plant's rhizosphere, which subsequently activates the nitrogenase enzyme, which is responsible for nitrogen fixation from atmospheric nitrogen in legumes. As a result, the nitrogen status of the soil will be improved, increasing the availability of nitrogen in the soil (Tharmaraj et al. 2011).

Effects of vermicompost on plant: Vermicompost provides different types of nutrients to plant for their growth and development. Vermicompost is peat-like substance employed as plant growing media and it cause direct and indirect effects on plant. Vermicompost have positive effects on plants vegetative growth, seed germination (green gram, tomato plants, petunia, root and shoot development (Edwards et al. 2004; Atiyeh et al. 2000b; Arancon et al. 2008).

Direct effects of vermicompost on plants: Vermicompost have direct impact on plant growth directly through the supply of plant growth regulating materials (PGR) (Lazcano and Domínguez, 2011). Vermicompost is a sole source of macro and micronutrients for plant that cause direct impact on shoot length, branches and leaves. Certain inorganic form of macronutrient and micronutrients are available for plants and organic matter are rapidly released by mineralization process and resulting in moderate release fertilizer that provides a consistent and steady source of nutrients for plant (Chaoui et al. 2003). Although chemical fertilizers also contain nutrients but the amount of nutrients given vary on the initial feedstock process duration vermicompost maturity (Campitelli and Ceppi, 2008). Vermicompost cause direct toxic effects on potting plant such as root development, water and air level in the substrates all of them are due to peat like substances that are present in vermicomposting (Lazcano and Domínguez, 2011). Vermicompost directly increase the production and nutritional level of particular vegetables such as tomato,cabbage, spinach, strawberries and corn Gutiérrez-Miceli et al. 2007; Wang et al. 2008, Singh et al. 2008; Locanzo et al. 2011b).

Indirect effects of vermicomposting on plants: Vermicomposting have several indirect and negligible effects on plant microbial and fungal flora such as suppression of plant disease and mitigation (Noble and Coventry, 2005; Termorshuizen et al. 2006). Suppressiveness in plant occurs due to presence of suppressive material in compost. Previous research shows the vermicompost indirectly decrease the pathogens spore (Trillas et al. 2006). Vermicompost cause indirect effect on the microbiological properties of soil because vermicompost have lower biomass microflora. This lower biomass microflora upgraded the metabolic diversity during the process vermicomposting. The usage of such microbiologically active organic medium have a significant impact on the microbial properties of plants (Dominguez et al. 2010; Aira et al. 2007; Lores et al. 2006).

CONCLUSION

Vermicomposting may be a practical and inexpensive choice for handling solid waste in an environmentally sustainable manner. Based on the foregoing discussion, it can be said that vermicomposting is a waste management technique that entails the environmentally friendly decomposition of the organic fraction of solid waste to the stage where it can be conveniently handled, stored, and applied to agricultural fields without causing any damage to the environment. Also, VC generally helps to increase the plant's growth and productivity.

Additionally, it raises soil's physical and chemical qualities in terms of agricultural output. Thus, vermicomposting technology may be employed in impoverished nations to economically recycle solid organic waste. The use of this technique to manage waste disposed of in landfills or open dumps, sewage sludge, incinerator waste, and dumps in agricultural areas is highly advised in order to prevent or minimise groundwater pollution and the toxicity of soils and plants due to various pollutants.

REFERENCES

Abadi, Z. A., Sepanlou, M. G., and Alashti, S. R. 2012. Effect of vermicompost on physical and chemical properties of soil. Journal of Science and Technology of Agriculture and Natural Resources, 15(58 (B)): 125-137.

Aira, M., Monroy, F., and Domínguez, J. 2007. Earthworms strongly modify microbial biomass and activity triggering enzymatic activities during vermicomposting independently of the application rates of pig slurry. Science of the total Environment, 385(1-3): 252-261.

Ali, U., Sajid, N., Khalid, A., Riaz, L., Rabbani, M. M., Syed, J. H., and Malik, R. N. 2015. A review on vermicomposting of organic wastes. Environmental Progress and Sustainable Energy, 34(4): 1050-1062.

Alshehrei, F., and Ameen, F. 2021. Vermicomposting: A management tool to mitigate solid waste. Saudi Journal of Biological Sciences, 28(6): 3284-3293.

Amouei, A. I., Yousefi, Z., and Khosravi, T. 2017. Comparison of vermicompost characteristics produced from sewage sludge of wood and paper industry and household solid wastes. Journal of Environmental Health Science and Engineering, 15(1): 1-6.

Angmo, D., Dutta, R., Kumar, S. I., and Sharma, A. 2020. Natural biological treatment of effluent and sludges to combat the burden of waste. In Earthworm assisted remediation of effluents and wastes (pp. 107-122). Springer, Singapore.

Ansari, A. A., and Jaikishun, S. 2011. Vermicomposting of sugarcane bagasse and rice straw and its impact on the cultivation of Phaseolus vulgaris L. in Guyana, South America. Journal of Agricultural Technology, 7(2): 225-234.

Arancon, N. Q., Edwards, C. A., Babenko, A., Cannon, J., Galvis, P., and Metzger, J. D. 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(1): 91-99.

Arora, S., Saraswat, S., Mishra, R., Rajvanshi, J., Sethi, J., Verma, A., ... and Saxena, S. 2020. Design, performance evaluation and investigation of the dynamic mechanisms of earthworm-microorganisms interactions for wastewater treatment through vermifiltration technology. Bioresource Technology Reports, 12, 100603.

Atiyeh, R. M., Arancon, N., Edwards, C. A., and Metzger, J. D. 2000. Influence of earthworm-processed pig manure on the growth and yield of greenhouse tomatoes. Bioresource Technology, 75(3): 175-180.

Balachandar, R., Baskaran, L., Yuvaraj, A., Thangaraj, R., Subbaiya, R., Ravindran, B., and Karmegam, N. 2020. Enriched pressmud vermicompost production with green manureplants using Eudriluseugeniae. Bioresource technology, 299, 122578.

Bellitürk, K., Çelik, A., and Baran, M. F. 2022. The effect of vermicompost application on soil properties in olive (Olea europaea L. cv. Memecik) plant. Erwerbs-Obstbau, 64(1): 107-113.

Bhat, S. A., Singh, J., andVig, A. P. 2015. Vermistabilization of sugar beet (Beta vulgaris L) waste produced from sugar factory using earthworm Eisenia fetida: Genotoxic assessment by Allium cepa test. Environmental Science and Pollution Research, 22(15): 11236-11254.

Bhat, S. A., Singh, J., and Vig, A. P. 2017. Instrumental characterization of organic wastes for evaluation of vermicompost maturity. Journal of Analytical Science and Technology, 8(1): 1-12.

Bhat, S. A., Singh, S., Singh, J., Kumar, S., and Vig, A. P. 2018. Bioremediation and detoxification of industrial wastes by earthworms: vermicompost as powerful crop nutrient in sustainable agriculture. Bioresource technology, 252: 172-179.

Boruah, T., Barman, A., Kalita, P., Lahkar, J., and Deka, H. 2019. Vermicomposting ofcitronella bagasse and paper mill sludge mixture employing Eisenia fetida. Bioresourcetechnology, 294, 122147.

Briones, M. J. I., Garnett, M. H., and Piearce, T. G. 2005. Earthworm ecological groupings based on 14C analysis. Soil Biology and Biochemistry, 37(11), 2145-2149.

Campitelli, P., and Ceppi, S. 2008. Chemical, physical and biological compost and vermicompost characterization: A chemometric study. Chemometrics and Intelligent Laboratory Systems, 90(1): 64-71.

Chaoui, H. I., Zibilske, L. M., and Ohno, T. 2003. Effects of earthworm casts and compost on soil microbial activity and plant nutrient availability. Soil Biology and Biochemistry, 35(2): 295-302.

Chaudhary, D. R., Bhandari, S. C., and Shukla, L. M. 2004. Role of vermicompost in sustainable agriculture-a review. Agricultural reviews-agricultural research communications centre india, 25(1): 29-39.

Cogut, A. 2016. Open burning of waste: a global health disaster. R20 Regions of climate action, 20.

Domínguez, J., Aira, M., and Gómez-Brandón, M. 2010. Vermicomposting: earthworms enhance the work of microbes. In Microbes at work (pp. 93-114). Springer, Berlin, Heidelberg.

Edwards, C. A., and Bohlen, P. J. 1996. Biology and ecology of earthworms (Vol. 3). Springer Science and Business Media.

Edwards, C. A., Dominguez, J., and Arancонl, N. Q. 2004. 18. The influence of vermicomposts on plant growth and pest incidence.

Garg, V. K., Suthar, S., and Yadav, A. 2012. Management of food industry waste employingvermicomposting technology. Bioresource technology, 126: 437-443.

Gutiérrez-Miceli, F. A., García-Gómez, R. C., Rosales, R. R., Abud-Archila, M., Angela, O. L. M., Cruz, M. J. G., and Dendooven, L. 2008. Formulation of a liquid fertilizer for sorghum (Sorghum bicolor (L.) Moench) using vermicompost leachate. Bioresource technology, 99(14): 6174-6180.

Jaybhaye, M. M., and Bhalerao, S. A. 2016. International Journal of Current Research andAcademic Review. Int. J. Curr. Res. Aca. Rev, 4(4): 61-67.

Joo, S. H., Monaco, F. D., Antmann, E., andChorath, P. 2015. Sustainable approaches forminimizing biosolids production and maximizing reuse options in sludge management: Areview. Journal of environmental management, 158: 133-145.

Gopal, M., Bhute, S. S., Gupta, A., Prabhu, S. R., Thomas, G. V., Whitman, W. B., and Jangid, K. 2017. Changes in structure and function of bacterial communities during coconut leaf vermicomposting. Antonie Van Leeuwenhoek, 110(10): 1339-1355.

Karmegam, N., Vijayan, P., Prakash, M., and Paul, J. A. J. 2019. Vermicomposting of paper industry sludge with cowdung and green manure plants using Eisenia fetida: A viable optionfor cleaner and enriched vermicompost production. Journal of Cleaner Production, 228: 718-728.

Kaza, S., Yao, L., Bhada-Tata, P., and Van Woerden, F. 2018. What a waste 2.0: A global snapshot of solid waste management to 2050. World Bank Publications.

Khwairakpam, M., and Bhargava, R. 2009. Vermitechnology for sewage sludge recycling. Journal of hazardous materials, 161(2-3): 948-954.

Lazcano, C., and Domínguez, J. 2011. The use of vermicompost in sustainable agriculture: impact on plant growth and soil fertility. Soil nutrients, 10(1-23), 187.

Lim, S. L., Lee, L. H., and Wu, T. Y. 2016. Sustainability of using composting andvermicomposting technologies for organic solid waste biotransformation: recent overview,greenhouse gases emissions and economic analysis. Journal of Cleaner Production, 111:262-278.

Lim, S. L., Wu, T. Y., Sim, E. Y. S., Lim, P. N., and Clarke, C. 2012. Biotransformation of rice husk into organic fertilizer through vermicomposting. EcologicalEngineering,41:60-64.

Lores, M., Gómez-Brandón, M., Pérez-Díaz, D., and Domínguez, J. 2006. Using FAME profiles for the characterization of animal wastes and vermicomposts. Soil Biology and Biochemistry, 38(9): 2993-2996.

Marinari, S., Masciandaro, G., Ceccanti, B., and Grego, S. 2000. Influence of organic and mineral fertilisers on soil biological and physical properties. Bioresource technology, 72(1): 9-17.

Masciandaro, G., Ceccanti, B., and Garcia, C. 1997. Changes in soil biochemical and cracking properties induced by" living mulch" systems. Canadian journal of soil science, 77(4): 579-58

Mohan, S. M. 2017. Vermicomposting of paper mill sludge with Eisenia fetida for its conversion to nutrient using different seed materials. Journal of The Institution of Engineers (India): Series A, 98(4): 545-553.

Mohan, S., and Joseph, C. P. 2021. Potential Hazards due to Municipal Solid Waste Open Dumping in India. Journal of the Indian Institute of Science, 101(4): 523-536.

Molina, M. J., Soriano, M. D., Ingelmo, F., and Llinares, J. 2013. Stabilisation of sewage sludge and vinasse bio-wastes by vermicomposting with rabbit manure using Eisenia fetida. Bioresource technology, 137: 88-97.

Mousavi, S. A., Sader, S. R., Farhadi, F., Faraji, M., and Falahi, F. 2020. Vermicompostingof grass and newspaper waste mixed with cow dung using Eisenia fetida: physicochemicalchanges. Global NEST J, 22(1): 8-14.

Nagar, R., Titov, A., andBhati, P. 2017. Vermicomposting of Leaf litters: Way to convertwaste in to Best. INT J CURR SCI, 20(4): 17-25.

Noble, R., and Coventry, E. 2005. Suppression of soil-borne plant diseases with composts: a review. Biocontrol Science and Technology, 15(1), 3-20.

Pillai, S., Peter, A. E., Sunil, B. M., and Shrihari, S. 2014. Soil pollution near a municipal solid waste disposal site in India. In International conference on biological, civil and environmental engineering (BCEE-2014) march (Vol. 1718).

Quadar, J., Chowdhary, A. B., Dutta, R., Angmo, D., Rashid, F., Singh, S., ... andVig, A. P.2022. Characterization of vermicompost of coconut husk mixed with cattle dung: physicochemical properties, SEM, and FT-IR analysis. Environmental Science and PollutionResearch, 1-12.

Quadar,J.,Chowdhary,A.B.,Khan,M.A.,Singh, S.,Kumar,R.,andSingh,J.2022.Role of Earthworms in Agro-Industrial Waste Management and Sustainable Agriculture. LifeSciences Research and Development, 83.

Rajput, R., Prasad, G., and Chopra, A. K. 2009. Scenario of solid waste management in present Indian context.

Ramnarain, Y. I., Ansari, A. A., and Ori, L. 2019. Vermicomposting of different organicmaterials using the epigeic earthworm Eisenia foetida. International Journal of Recycling ofOrganic Waste in Agriculture, 8(1): 23-36.

Sharma, K., and Garg, V. K. 2018. Comparative analysis of vermicompost quality producedfrom rice straw and paper waste employing earthworm Eisenia fetida (Sav.). Bioresourcetechnology, 250: 708-715.

Sharma, S., Kumar, A., Singh, A. P., and Vasudevan, P. 2009. Earthworms and vermitechnology–A review. Dynamic soil, Dynamic plant, 3(2), 1.

Sharma, S., Pradhan, K., Satya, S., and Vasudevan, P. 2005. Potentiality of earthworms for waste management and in other uses–A review. The Journal of American Science, 1(1): 4-16.

Siddiqua, A., Hahladakis, J. N., and Al-Attiya, W. A. K. 2022. An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. Environmental Science and Pollution Research, 1-23.

Silva, J. C., Siqueira, A. J. N., Maia, H. B., and Nunes, R. R. 2021. Vermicomposting cornwaste under cultural and climatic conditions of the Brazilian Backwoods. BioresourceTechnology Reports, 15, 100730.

Singh, J., Kaur, A., and Vig, A. P. 2014. Bioremediation of distillery sludge into soil-enriching material through vermicomposting with the help of Eisenia fetida. Applied biochemistry and biotechnology, 174(4): 1403-1419.

Singh, J., Kaur, A., Vig, A. P., and Rup, P. J. 2010. Role of Eisenia fetida in rapid recycling of nutrients from bio sludge of beverage industry. Ecotoxicology and Environmental Safety, 73(3): 430-435.

Singh, J., Kaur, A., Vig, A. P., and Rup, P. J. 2010. Role of Eisenia fetida in rapid recycling of nutrients from bio sludge of beverage industry. Ecotoxicology and Environmental

Singh, R. P., Embrandiri, A., Ibrahim, M. H., and Esa, N. 2011. Management of biomassresidues generated from palm oil mill: Vermicomposting a sustainable option. Resources,Conservation and Recycling, 55(4): 423-434.

Singh, R., Sharma, R. R., Kumar, S., Gupta, R. K., and Patil, R. T. 2008. Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry (Fragaria x ananassa Duch.). Bioresource Technology, 99(17), 8507-8511.

Singh, S. I., Singh, W. R., Bhat, S. A., Sohal, B., Khanna, N., Vig, A. P., ... and Jones, S.2022. Vermiremediation of allopathic pharmaceutical industry sludge amended with cattledung employing Eisenia fetida. Environmental Research, 214, 113766.

Singh, S., Bhat, S. A., Singh, J., Kaur, R., andVig, A. P. 2016. Vermistabilization of thermalpower plant fly ash using Eisenia fetida. J IndustPollutCont, 32: 554-561.

Singh, S., Bhat, S. A., Singh, J., Kaur, R., and Vig, A. P. 2017. Earthworms converting milk processing industry sludge into biomanure. The Open Waste Management Journal, 10(1).

Singh, S., Singh, J., and Vig, A. P. 2016. Earthworm as ecological engineers to change the physico-chemical properties of soil: soil vs vermicast. Ecological Engineering, 90: 1-5.

Sohal, B., Singh, S., Singh, S. I. K., Bhat, S. A., Kaur, J., Singh, J., and Vig, A. P. 2021. Vermicomposting of thermal fly ash using Eisenia fetida. Environmental Science and Pollution Research, 28(35): 48154-48170.

Sonowal, P., Khwairakpam, M., and Kalamdhad, A. S. (2014). Vermicomposting of solid pulp and paper mill sludge (SPPMS) using Eudrilus Eugeniae Earthworm. International Journal of Environmental Sciences, 5(3), 502.

Suthar, S. (2008). Bioremediation of aerobically treated distillery sludge mixed with cowdung by using an epigeic earthworm Eisenia fetida. The Environmentalist, 28(2): 76-84.

Suthar, S. (2010). Recycling of agro-industrial sludge through vermitechnology. EcologicalEngineering, 36(8): 1028-1036.

Suthar, S., Mutiyar, P. K., and Singh, S. (2012). Vermicomposting of milk processing industrysludge spiked with plant wastes. Bioresource technology, 116:214-219.

Termorshuizen, A. J., Van Rijn, E., Van Der Gaag, D. J., Alabouvette, C., Chen, Y., Lagerlöf, J., ... andZmora-Nahum, S. (2006). Suppressiveness of 18 composts against 7 pathosystems: variability in pathogen response. Soil Biology and Biochemistry, 38(8): 2461-2477.

Trillas, M. I., Casanova, E., Cotxarrera, L., Ordovás, J., Borrero, C., andAvilés, M. (2006). Composts from agricultural waste and the Trichoderma asperellum strain T-34 suppress Rhizoctonia solani in cucumber seedlings. Biological control, 39(1), 32-38.

Trivedi, P., Singh, K., Pankaj, U., Verma, S. K., Verma, R. K., and Patra, D. D. (2017). Effect of organic amendments and microbial application on sodic soil properties and growth of an aromatic crop. Ecological engineering, 102: 127-136.

Turan, N. G., Çoruh, S., Akdemir, A., and Ergun, O. N. 2009. Municipal solid waste management strategies in Turkey. Waste Management, 29(1): 465-469.

Vig, A. P., Singh, J., Wani, S. H., and Dhaliwal, S. S. 2011. Vermicomposting of tannerysludge mixed with cattle dung into valuable manure using earthworm Eisenia fetida (Savigny). Bioresource technology, 102(17): 7941-7945.

Wang, D., Shi, Q., Wang, X., Wei, M., Hu, J., Liu, J., and 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(7): 689-696.

Yadav,A.,andGarg,V.K.2011.Recyclingoforganicwastesbyemploying Eiseniafetida. Bioresource technology, 102(3): 2874-2880.

Zhi-Wei, S., Tao, S., Wen-Jing, D., and Jing, W. 2019. Investigation of rice straw and kitchen waste degradation through vermicomposting. Journal of environmental management, 243: 269-272.