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Vermicomposting Biotechnology: An Eco-Loving Approach for Recycling of Solid Organic Wastes into Valuable Biofertilizers

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Abstract

Day by day vigorous changes in the human population, indiscriminate growth of urban cities, industrialization, and agricultural practices have led to an increased accumulation of solid organic waste materials in the environment. The recovery of nutrients by modification of wastes like municipal solid waste, industrial solid waste, agricultural residues, and animal wastes, etc. is important for their management and for reducing environmental degradation. Recycling of organic wastes through vermicomposting biotechnology is an emerging trend as an “environmentally sustainable”, “economically viable” and “socially acceptable” technology all over the world. The review assesses the following topics in detail: Vermicomposting biotechnology, earthworm species for waste management, raw materials for vermicomposting, environmental factors effecting vermicomposting, applications of vermicompost and future prospects.

Keywords: Solid organic wastes; Earthworm species; Environmental factors; Vermicomposting

Introduction

In past 20 years population pressure, urbanization, industrialization, and mechanized agricultural activities have increased, due to which organic waste materials have been accumulated in the environment as Solid Organic Waste (SOW). On one hand tropical soils are deficient in all necessary plant nutrients and on the other hand large quantities of such nutrients available in SOW. Treatment of Solid Organic Wastes has therefore become an essential part of life almost all over the world, the alarming increase in their quantity and the mixing of biodegradable and non-biodegradable wastes at the generation points make it complicated to handle them with limited resources. The overall objective of SOW management is to minimize the adverse environmental effects caused by the indiscriminate disposal of SOWs [1]. Further, the disposal of wastes through the use of earthworms also upgrade the value of original waste materials in situ and allows a final product to be obtained free of chemical or biological pollutants [2,3]. Vermicomposting is a decomposition process involving the joint action of earthworms and microorganisms. Although microorganisms are responsible for the biochemical degradation of organic matter, earthworms are crucial drivers of the process, by fragmenting and conditioning the substrate and dramatically altering its biological activity. Earthworms act as mechanical blenders and by comminuting the organic matter they modify its physical and chemical status, gradually reducing its C:N ratio, increasing the surface area exposed to micro-organisms and making it much more favorable for microbial activity and further decomposition. Greatly during passage through the earthworm gut, they move fragments and bacteria-rich excrements, thus homogenizing the organic material. Earthworms involved directly or indirectly in organic matter decomposition, stabilization, and nutrient turn-over [4-8]. The cast produced after bioremediation of organic wastes through earthworm is a special type of Bio-fertilizer (Vermicompost). The term “Biofertilizer” or more appropriately a “Microbial inoculants” can generally be defined as preparation containing live or latent cells of efficient strains of Nitrogen fixing, Phosphate solublising or cellulolytic microorganisms used for application to seeds, soil with the objective of increasing the number of such microorganisms and accelerate those microbial process which augment the availability of nutrients that can be easily assimilated by plants. It is generally accepted that microbial biomass and respiration are greater in earthworm casts/vermicompost than in the parent soil [9,10]. However earthworms can feed on these selective raw materials [11,12], resulting in an increase in culturable aerobic microorganisms and micro & macro nutrients in the cast of earthworms, as seen with studies on *Lumbricus terrestris* and *Lumbricus rubellus* [13-15]. Earthworms are therefore considered as potential for use in SOW management through the use of Vermicomposting Technology.

Vermicomposting Biotechnology

Millions of tons of solid waste (SW) generated from the modern society are ending up in the landfills every day, creating extraordinary economic and environmental problems for the local government to manage and monitor them (may be up to 30 years) for environmental safety (emission of GHG, toxic gases and leach ate discharge into ground water & soil). Another serious cause of concern today is the emission of greenhouse gases (GHG) methane (CH4) & nitrous oxides (N2O) resulting from the disposal of SW either in the landfills or from their management by conventional composting systems. We are facing the escalating socio-economic and environmental cost of dealing with current and future generation of mounting solid wastes (SW). A considerable portion of SW consist of “Organic Wastes” that are “biodegradable” and can be vermicomposted into a highly “nutritive bio-fertilizer” 4-5 fold more powerful than conventional composts and even superior to chemical fertilizers for better crop growth and safe food production. Waste degradation & composting by earthworms is proving to be economically & environmentally preferred technology over the conventional microbial degradation & composting technology

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as it is rapid and nearly odorless process, reducing composting time by more than half and the end product is both "disinfected" and "detoxified" [16,17]. One million worms doubling every two months can become 64 million worms at the end of the year. Considering that each adult worm (particularly *Eisenia fetida*) consume organics waste equivalent to its own body weight everyday, 64 million worms (weighing 64 tons) would consume 64 tons of waste everyday and produce 30-32 tons of vermicompost per day at 40-50% conversion rate.

Types of Solid Organic Wastes (SOW) and Earthworm Species used in Vermicomposting Biotechnology

Solid Organic Substrates have been classified by Thomas and Trivedy [18] on the basis of physical and chemical characteristics is presented in Table 1. The use of different organic substrates and species of earthworms employed and their suitability in vermicomposting is presented in Table 2. Substrates, especially agricultural residues, have been tested extensively in combination with an easily biodegradable substrate such as Cow Dung (CD). Kale et al. [19] reported the suitability of neem cake as an additive in earthworm feed and its significance in the establishment of micro flora. *E. eugeniae* was tolerant to neem cake in the culture medium up to a concentration of 1.6-6.4% and had a positive effect on earthworm biomass production.

Sl no	Types of Substrates	C:N Ratio	Suitability
1	Fish, scrap poultry manure, night soil, activated sludge, pig manure, sheep dropping, meat scraps, cotton seed meal and other oil seed residues	1-19	Most suitable due to high Nitrogen content
2	Garbage, sea weed, butter cup, amaranthus, lettuce, cabbage and vegetable waste which are fresh, green and succulent including wastes from food processing industries	19-27	Moderately suitable
3	Saw dust flax, waste straw, coir waste, etc. including all crop residues with high lignocelluloses content, high carbon and low moisture	27-208	Less suitable

Table 1: Rating of substrates for vermicomposting.

Sl no	Solid Organic Waste (SOW)	Species employed	Reference
1	Potato peels	*Pheretima elongate*	[80]
2	Press mud	*Pheretima elongate* *Eudrilus eugeniae, Eisenia fetida* *Megascolex megascolex*	[45] [44] [76]
3	Canteen waste	*Eisenia fetida*	[81,37]
4	Tomato skin seed	*Pheretima elongate*	[7]
5	Onion residue	*Eisenia fetida/Eudrilus eugeniae*	[82]
6	Sericulture waste	*Perionyx excavates*	[25]
7	Sericulture waste	*Phanerochaete chrysosporium*	[83]
8	Board mill sludge	*Lumbricus terrestris*	[84]
9	Sugar cane residues	*Pheretima elongate*	[85]
10	Gaur gum	*Eudrilus eugeniae*	[86,87]
11	Agricultural residues	*Eudrilus eugeniae*	[81]
16	Sago waste	*Lampito mauritii*	[88]
17	Sago waste	*Eisenia fetida*	[89]
18	Onion waste	*Eudrilus eugeniae*	[90]
19	Garlic waste	*Eisenia fetida*	[90]
20	Source separated from human feces	*Eisenia fetida*	[91]
21	Paper mill sludge	*Eisenia fetida*	[92]
22	Press mud, bagassi, sugar cane trash	*Drawida willsi*	[64]
23	Press mud	*Perionyx ceylanensis*	[93]

Table 2: Earthworm species employed for vermicomposting of Solid Organic Wastes (SOW).

E. eugeniae was mass cultured on 6 different feed formulate prepared by mixing CD, sheep and horse dung with other OWs such as rice polish, wheat barn and green gram bran vegetable waste and eggshell powder in various combinations [20]. A laboratory-scale study was conducted to access the suitability of powdered rubber leaf litter as vermiculture substrate for *P. excavatus*, *E. eugeniae*, and *E. fetida*.

Some important studies on vermicomposting biotechnology

- Visvanathan et al. [21] studied vermicomposting in great details and found that most earthworms consume, at the best, half their body weight of organics in the waste in a day. *Eisenia fetida* can consume organic matter at the rate equal to their body weight every day. Earthworm participation enhances natural biodegradation and decomposition of organic waste from 60 to 80% over the conventional aerobic & anaerobic composting. Given the optimum conditions of temperature (20-30°C) and moisture (60-70%), about 5 kg of worms (numbering approx. 10,000) can vermiprocess 1 ton of waste into vermicompost in just 30 days. Upon vermi-composting the volume of solid waste is significantly reduced from approximately 1 cum to 0.5 cum of vermi-compost indicating 50% conversion rate, the rest is converted into worm biomass.
- Kale [22]; Kale et al.[23]; Seenappa et al. [24]; Gunathilagraj [25] and Lakshmi et al. [26] studied the degradation and composting of "wastewater sludge" from paper pulp and cardboard industry, brewery and distillery, sericulture industry, vegetable oil factory, potato and corn chips manufacturing industry, sugarcane industry, aromatic oil extraction industry, and logging and carpentry industry by earthworms. These organic wastes offer excellent feed materials for vermi-composting by earthworms. Kale et al. [27] also studied the vermicomposting of waste from the mining industry which contains sulfur residues and creates disposal problems. They can also be fed to the worms mixed with organic matter. Optimum mixing ratio of the sulfur waste residues to the organic matter was 4%.
- Saxena et al. [28] studied the vermicomposting of "fly-ash" from the coal power plants which is considered as a hazardous waste and poses serious disposal problem due to heavy metal contents. As it is also rich in nitrogen and microbial biomass it can be vermi-composted by earthworms. They found that 25% of fly-ash mixed with sisal green pulp, parthenium and green grass cuttings formed excellent feed for *Eisenia fetida* and the vermicompost was higher in NKP contents than other commercial manures. The earthworms ingest the heavy metals from the fly-ash while converting them into vermicompost.
- Bajsa et al. [29] successfully studied vermicomposting of "human excreta" (feces). It was completed in six months, with good physical texture, odourless and safe pathogen quality. Sawdust appeared to be the best covering material that can be used in vermicomposting toilets to produce compost with a good earthy smell, a crumbly texture and dark brown colour.

Mechanism of Earthworm action during Vermicomposting of Solid Organic Wastes

Grinding action

The waste feed materials ingested is finely ground (with the aid of stones in their muscular gizzard) into small particles to a size of 2-4 microns and passed on to the intestine for enzymatic actions. The gizzard and the intestine work as a "bioreactor".

Enzymatic action

The gizzard and the intestine work as a "bioreactor". Worms secrete enzymes proteases, lipases, amylases, cellulases and chitinases in their gizzard and intestine which bring about rapid biochemical conversion of the cellulosic and the proteinaceous materials in the waste organics. They ingest the food materials, cull the harmful microorganisms, and deposit them mixed with minerals and beneficial microbes as "vermicasts" in the soil [30].

Worms reinforce decomposer microbes & act synergistically

Worms promotes the growth of "beneficial decomposer microbes" (bacteria, actinomycetes & fungi) in waste biomass [30,31]. They hosts millions of decomposer microbes in their gut which is described as "little bacterial factory". They devour on microbes and excrete them out (many times more in number than they ingest) in soil along with nutrients nitrogen (N) and phosphorus (P) in their excreta. The nutrients N and P are further used by the microbes for multiplication and vigorous action [32]. Edwards et al. [33] showed that the number of bacteria and "Actinomycetes" contained in the ingested material increased up to 1000 fold while passing through the gut. A population of worms numbering about 15,000 wills in turn faster a microbial population of billions of millions. Earthworms and microbes act "symbiotically & synergistically" to accelerate and enhance the decomposition of the organic matter in the waste. It is the microorganisms that break down the cellulose in the food waste, grass clippings and the leaves from garden wastes [34].

Humification

Dominguez and Edwards [35] reported that organic wastes, to be compatible with their agricultural uses and to avoid adverse effects on plant growth, must be transformed into a humus-like material and become stabilized, decreases in the carbon from fulvic acids (FA) and increases in the percentages of the carbon from humic acids (HA) were observed throughout the vermicomposting process, and this was also much more marked at the end of the process, so clearly earthworm activity accelerates humification of organic matter. Moreover, during Vermicomposting, the humic materials increased from 40 to 60 percent, which was more than the values obtained in a composting process using the same materials. Humification processes are enhanced not only by the fragmentation and size reduction of the organic matter, but also by the greatly increased microbial activity within the intestines of the earthworms and by aeration of the soil through earthworm movement and feeding.

Parameters Change during Vermicomposting of Solid Organic Waste

pH

Earthworms are very sensitive to pH, thus pH of soil or waste is sometimes a factor that limits the distribution, numbers and species of earthworms. In a vermicomposting experiment with different soil proportions (1:3, 1:4, 1:5, 1:6) of CD the earthworms reduced the pH: *E. fetida*, 6.7 to 6.1; *E. eugeniae*, 6.7 to 6.0 and *M. megascolex,* 6.7 to 6.4 [36]. Several researchers have stated that most species of earthworms prefer a pH of about 7.0 [7,37,38,39]. Edwards [40] reported a wide pH range (5.0-9.0) for maximizing the productivity of earthworms in SOW management. Bhawalkar [41] suggested a neutral substrate pH for vermicomposting using deep burrower species *Pheritima elongata*. Satchell [42] reported that *Bimastos eiseni, Dendrobaena octaedra* and *Dendrobaena rubida* were acid-tolerant species, while *Allolobophora caliginosa, Allolobophora nocturna, Allolobophora longa* were acid-tolerant. Singh et al. [43] reported that *P. excavatus* performs well in a wide range of substrate pHs. The decrease in pH values when press mud was treated with *M. megascolex*, *E. eugeniae* and *E. fetida* showed a decreasing trend in pH from 8.6 to 6.7 during vermicomposting over a period of 60 days [44]. A decrease in pH was recorded in CD vermicomposting using *E. fetida* and *L. mauritti* [39] and *Pheritima elongate* using tomato skin seed waste as substrate [45] or kitchen waste [37].

Moisture

In the natural soil-earthworms interaction, when there is a loss of soil moisture, earthworms tend to move to a safer area with more moisture. When the whole area is dry the earthworms adjust themselves and survive through large water loss from the body: *L. terrestris* can lose up to 70% and *A. caliginosa* 75% [4]. Experiments conducted using *P. elongata* showed optimum moisture of 70% for the treatments of potato peel waste [46] whereas press mud required 60-70%. Trials for vermicomposting CD showed optimum moisture of 60-70% with a higher number of *E. eugeniae*, *E. fetida* and *M. megascolex* earthworms [36,44]. Strains associated with endospore-forming Bacillus survive extreme weather conditions and become active when favorable soil moisture conditions are regained [44]. Evans and Guild [47] reported that *A.chlorotica* produced more cocoons at moisture contents of 28 to 48%. Juveniles, who show high tolerance to low moisture, when transferred to a new environment with favorable moisture, adjust faster than adult worms [4,45]. Such experiments were also carried out with the cocoons of *E. fetida* and *E. eugeniae*, which were transferred to culture boxes containing CD while adult earthworms were separately transferred. More juveniles were found in culture boxes with cocoons than in culture boxes with adults [44-46]. Therefore, moisture level is a significant factor in the set-up of a vermicomposting unit [48-50] in village environments units need to be carefully designed to hold water without causing water logging.

Temperature

Evans and Guild [47] reported that the activity, metabolism, growth, respiration, reproduction, fecundity and growth period from hatching to sexual maturity of earthworms are greatly influenced by temperature. Cocoons hatch sooner at higher temperatures [4]. A temperature range of 20-30°C for vermibeds was suggested using *E. fetida*, *E. eugeniae* and *P. excavatus* [51,52]. The optimum temperature range for earthworm activity and for setting vermicomposting units are presented in Table 3 and 4 respectively.

Organic matter

Earthworms use a wide variety of organic materials for food and even in adverse conditions; extract sufficient nourishment from the waste or soil to survive. The kind and amount of food available influences not only the size of an earthworm population but also the species present and their rate of growth and fecundity. Zezonc and Sedor [53] reported that greatest weight increase in *E. fetida* was obtained when 50 g of soil was mixed with 150 g cellulose waste. Nayak and Rath [70] claimed that organic residues comprising city, industrial, agricultural farms, household and kitchen wastes with dead or decaying materials can be used as bedding materials for vermicomposting. Joshi [55] suggested that animal manure, dairy and poultry waste, food industry waste;

slaughterhouse waste or biogas sludge could be used for recycling through vermicomposting. The best results of vermicomposting were obtained from paper and food manufacturing industries when treated with *E. fetida*, *E. andrei* and *P. excavatus* [56].

Micro and macro nutrients status and microbial population in earthworm's cast

There are varying reports on the nutrient contents of vermicasts [37,57] whereas Ranganath et al. [49] ascertained nutrient values for a good VC based on their study on urban wastes also suggested the rate of application of VC in Table 5. Ghilarov [58] claimed that the number of microorganisms in earthworm casts was 1.64, 1.35 and 1.97 fold higher than in regular soil in three different fields, namely oak forest, rye and grass, respectively. A 5 and 40 fold higher level of bacterial counts was reported in vermicast more than the surrounding soil in the case of potato peel waste [46] and paper industry sludge [59] respectively. An increase in hydrolytic microflora in vermicomposting of organic solid wastes was reported by Singh [45] and Munnoli [44]. Monson et al. [60] reported an increase in nutrients of kitchen waste vermicomposted by *E. eugeniae*: in N, from 1.31 to 2.12%; in P, from 0.121 to 0.7%; in K, from 0.45 to 0.48% and the C:N ratio decreased from 32.45 to 13.66%. A higher microbial load was also observed in paddy fields to which VC was applied [23]. An increase in the microbial population was recorded with potato waste using *Pheretima elongata* [46] and with press mud waste using *E. fetida*, *E. eugeniae* and *Megascolex megascolex* when compared with the surrounding soil [44]. Meena and Renu [59] reported an increase in nutrients when press mud was blended with saw dust and treated using three different earthworm species *E. fetida*, *E. eugeniae* and *P. excavatus* individually (Monocultures) and in combination (Polycultures). Kale et al. [23] reported that earthworm's burrows lined with earthworm casts are an excellent medium for harbouring N-fixing bacteria; Loquet et al. [62] and Bhattacharya et al. [63] also recorded an increase in the microbial count of VCs compared to traditional compost in Table 6. Kumar et al. [64] reported the contents of VCs in Table 7. *E. fetida* vermicasts from sheep manure alone or mixed with cotton wastes were analyzed for their properties and chemical composition every 2 weeks for 3 months and compared with the same manure without earthworms. Earthworms accelerated the mineralization rate and resulted in castings with a higher nutritional value and degree of humification, suggesting that this kind of industrial wastes can be used in vermicomposting [65]. Madhukeshwar et al. [66] claimed that any kind of organic waste generated in an agro-based industry or biotechnology unit when treated with earthworms would be resourceful VC. When *E. fetida* was used for vermicomposting it resulted in an increase in P, Ca, Mg and a decreased of K [67]. Giraddi and Tippanavar [68] studied the biodegradation of waste from the fruit-pulp, biscuit and sugar industries were bio-degradable in field designs using *E. eugeniae*, *E. fetida* and *Perionyx excavatus*, for waste management. The wastes were bio-converted to compost in 40-90 days.

The quality of compost obtained had increased micro and macro nutrients. Butt [69] explored the possibility of treating paper mill sludge with spent yeast from the brewery industry using *L. terrestris* whereas

Sl no	Temp. Range (ºC)	Species	Reference
1	26-35	*Pheretima californica*	[94]
2	22-29	*Eudrilus eugeniae*	[95]
3	25	*Eisenia fetida; Eudrilus eugeniae*	[96]
4	20-35	*Perionyx excavates*	[97]
5	25-35	*Perionyx excavates*	[5]
6	15-35	*Eudrilus eugeniae; Eisenia fetida; Pheretima elongate*	[46]
7	28-32	*Perionyx excavatus; Lampito mauritii; Drawida nepalensis*	[98]
8	25-34	*Eisenia fetida*	[99]
9	25	*Eisenia fetida*	[100]
10	20	*Eisenia fetida; Eisenia Andrei*	[101]
11	20	*Eudrilus eugeniae*	[102]
12	15-35	*Eudrilus eugeniae; Eisenia fetida; Megascolex megascolex*	[44]
13	28.9	*Eisenia fetida; Lampito mauritii*	[39]
14	26-35	*Eisenia fetida; Eudrilus eugeniae*	[90]
15	5-25	*Eisenia fetida*	[91]
16	28-32	*Lampito mauritii*	[103]
17	27-28	*Octochatona serrata*	[103]

Table 3: Optimum Temperature range for activity of earthworm species.

Sl no	Temperature range (°C)	Species	Reference
1	25-35	Eudrilus eugeniae	[44]
2	20-35	Eisenia fetida	[44]
3	20-35	Megascolex megascolex	[44]
4	20-30	Eisenia fetida, Eudrilus eugeniae	[51,52]
5	20-34	Pheretima elongate	[46]

Table 4: Optimum Temperature range for setting vermicomposting units.

Sl no	Parameter	Vermicompost	Crop	Rate/Th^{-1}
1	pH	7-8.5	Cereals	5
2	Organic Carbon (%)	20-30	Pulses	5
3	Nitrogen (%)	1.5-2.0	Oil seeds	12.5
4	Phosphorus (%)	1-2	Spices	10
5	Potassium (%)	1-2	Vegetables	12.5
6	Calcium (%)	1-3	Fruits	7.5
7	Manganese (pap)	1-2	Cash crop	15-17.5
8	Sculpture (%)	<1	Plantations	7.5
9	Moisture (%)	15-20	*Horticulture Crops	100-200 g/tree
10	C/N ratio	15-20:1	*Kitchen garden and pots	50 g/pot
11	Micronutrients (pap)	200		

Table 5: Composition of good quality vermicompost and rate of application for various crops.

Sources: [104,105] I no	Type of microbes	Traditional compost	Vermicompost
1	Bacteria	$143 \times 10^3 \times 2$ /g	$167.29 \times 10^3 \times 2$ /g
2	Fungi	$39.61 \times 10^2 \times 2$ /g	$96.25 \times 10^2 \times 2$ /g
3	Actinomycetes	$365.27 \times 10^3 \times 2$ /g	$419.62 \times 10^3 \times 2$ /g
4	PP solution	$195.61 \times 10^2 \times 2$ /g	$168.20 \times 10^2 \times 2$ /g
5	N2 Fixing bacteria	$92.58 \times 10^2 \times 2$ /g	$96.62 \times 10^2 \times 2$ /g
6	Thio-sulphate oxidizer	$315.38 \times 10^2 \times 2$ /g	$569.29 \times 10^2 \times 2$ /g

Table 6: Comparison of microbial count of traditional and vermicomposts.

Sl no	Contents	Percentage (%)
1	Humus	30-50
2	N	0.72
3	K	0.74
4	Carbon	40-57
5	Hydrogen	4-8
6	Oxygen	35-54
7	pH	4 to 9
8	C/N	20

Table 7: Vermicompost Contents.

the same industrial waste was treated with *E. andrei* by Elvira et al. [70]. They also investigated the vermicomposting of sludge from paper mill and dairy industries mixed with cattle manure using *E. Andrei* in 6-months pilot scale experiments where the number of earthworms and biomass increased significantly. The VCs were rich in N, P, and K and had good structure, a low level of heavy metals, lower conductivity, high humic acid contents and good stability and maturity. They also reported the growth of *E. andrei* by using paper mill and dairy mill sludges in pure wastes by mixing with different proportions of cattle manure [70]. Studies of the possible use of paper and dairy mill sludge during vermicomposting confirmed that such material might be a valuable component of breeding medium for *E. fetida* earthworms. But the content of mineral N and total K were low [71].

Applications of Vermicomposting Biotechnology

Vermicomposting and pathogen destruction

Dominguez and Edwards [35] showed that vermicomposting involves a great reduction in populations of human pathogenic microorganisms, as in composting. It is generally accepted that the thermophilic stage of the composting process eliminates pathogenic organisms, but we have shown that human pathogens do not survive vermicomposting. After 60 days of vermicomposting, amounts of faecal coliform bacteria in biosolids dropped from 39,000 MPN/g to 0 MPN/g. In that same time period, *Salmonella* sp. dropped from <3 MPN/g to <1 MPN/g. Similar results have been reported by Eastman (1999) and also for faecal coliforms, *Salmonella* sp., for enteric viruses, and for helminth ova.

Water holding capacity

The major losses of soil water are through the process of transpiration by plants and evaporation from the soil surface and the combined process is known as evapo-transpiration [72]. If the organic content in a given soil/waste is more than about 10% the max dry density of compaction decreases considerably. The optimum moisture content increases with an increase in organic content [73]. A similar experiment on compaction conducted by adding 200 g of VC of press mud prepared by *E. fetida, E. eugeniae* and *M. megascolex* to 3 kg of soil showed lower densities compared to the density of soil indicating an increase in voids and water holding capacity [44]. Therefore adding VCs with aggregation properties and higher water holding capacities will not only increase the yield of crops but also provide nutrients required for growth. When applied to the surface it takes part in maintaining the soil evaporation to a minimum by absorbing atmospheric moisture as a good adsorbent and influences the energy balance [4,74-76].

Carbon mineralization during vermicomposting

As other members of the organic matter decomposer community, earthworms can assimilate carbon from the most recently deposited organic matter fractions, consisting mainly of easily-degradable substances. In all cases the degradation process resulted in carbon losses by mineralization which produced a decrease in the amounts of total organic carbon and in the carbon contributions to the organic matter, which was much higher in the final stages of decomposition when the earthworm populations were bigger and more active [35]. Although earthworms consume and process large amounts of organic matter, their contributions to the total heterotrophic respiration is very low due to their poor assimilation efficiency and only when there are large active earthworm populations, as in vermicomposting systems, can they contribute to an appreciable extent to the heterotrophic respiration.

Role in nitrogen cycle

Earthworms had a great impact on nitrogen transformations in the pig manure by enhancing nitrogen mineralization, so that most mineral nitrogen was retained as nitrate. The net total nitrogen, in all treatments and times, decreased; losses being more marked during the final stages when earthworm activity was higher. The different nitrogen fractions followed trends similar to the total nitrogen. In all treatments, during the final stages of the process, when the earthworm population was bigger and more active, important reductions in organic nitrogen content and a high nitrification rate were noted [35]. This implies that earthworm (*Eisenia andrei* in this case), modified conditions in the manure that favoured nitrification, resulting in the rapid conversion of ammonium into nitrates. Similar results have been reported by Hand et al. [77] who found that *Eisenia fetida* in cow slurry increased the nitrate concentration of the substrate.

Vermicomposting and heavy metal availability

It is important to know the changes in total and available contents of heavy metals in the organic matter during the vermicomposting process, because they may cause problems in some animal manures, sewage sludges, and industrial organic wastes. Dominguez et al. [35] studied that consequence of carbon losses by mineralization during vermicomposting, the total amounts of heavy metals increased (between 25 and 30%), the amounts of bioavailable heavy metals tended to decrease with a decrease of between 35 and 55% in the bioavailable metals in two months. Similar results were reported in other studies for both composting and vermicomposting and this implies a lower availability of these elements for plants from vermicomposts. During vermicomposting, heavy metals tend to form complex aggregates with the humic acids and the most polymerized organic fractions.

Conclusion

Vermicomposting Biotechnology used for waste and land management and for improving soil fertility to promote crop productivity and production of valuable bioactive compounds of great medicinal values has grown considerably in recent years all over the world and has been scientifically improved (UNSW 2002). It is like getting "gold from garbage" (solid organic waste to highly nutritive biofertilizer). The three versatile species *E. fetida, E. euginae* and *P. excavatus* performing wide social, economic & environmental functions occur almost everywhere.

The vermi-composting maintain the "global human sustainability cycle" & "circular economy" "using food wastes (negative economic & environmental value) of the society to produce food (positive socio-economic value) for the society again" while also protecting farm soil and improving its fertility (positive economic & environmental value) and if vermicompost can "replace" the "chemical fertilizers" for production of "safe organic foods" which has now been proved worldwide, it will be a giant step towards achieving global social, economic & environmental sustainability. With the growing global popularity of "organic foods" which became a US $ 6.5 billion business every year by 2000, there will be great demand for vermicompost in future. US Department of Agriculture estimates 25% of Americans purchase organically grown foods at least once a week [78]. In any vermiculture practice, "worm biomass" comes as a valuable by-product. It is finding that uses and applications of earthworms in modern medicine and in several industries for sustainable production of essential goods for societal use and consumption [79]. On commercial scale tons of worm biomass can result every year as under favorable conditions worms "double" their number at least every 60-70 days.

All infrastructure based on vermicomposting biotechnology using earthworms are easy to construct, install and operate with minimum engineering considerations. They are highly economical and cost effective with highly valued by-products and end-products. It is basically a "one-time investment" technology as the earthworms multiply at a fast rate under favorable conditions of temperature and moisture and increase the pace and rapidity of the technological process. Besides the advantages of this technique there are some disadvantages also; It can be quicker, but to make it so generally requires more labour; It requires more space because worms are surface feeders and won't operate in material more than a meter in depth; It is more vulnerable to environmental pressures, such as temperature, freezing conditions and drought; Perhaps most importantly, it requires more start-up resources, either in cash (to buy the worms) or in time and labour.

It is also justifying the beliefs of Great Russian scientist Dr. Anatoly Igonin who said "Nobody and nothing can be compared with earthworms and their positive influence on the whole living Nature. They create soil & improve soil's fertility and provide critical biosphere's functions: disinfecting, neutralizing, protective and productive". Future of mankind on earth beholds with the earthworms and our relationship must be maintained.

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