Potentiality of Earthworms for Waste Management and in Other Uses – A Review

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Abstract: Scientific investigations have established the viability of using earthworms as a treatment technique for numerous waste streams besides producing organic fertilizers. Vermicomposting results in the bioconversion of the waste stream into two useful products, earthworm biomass and vermicompost. The former can be used as a protein source whereas vermicompost is considered as an excellent product since it is homogenous, has desirable aesthetics, has reduced level of contaminates, has plant growth hormones, higher level of soil enzymes, greater microbial population and tends to hold more nutrients over a longer period without adversely impacting the environment. Earthworm while ingest organic waste and soil, consume heavy metals through their intestine as well as through their skin, wherefore concentrating heavy metals in their body. The present paper review the current state of knowledge on biology and species of earthworm, vermiculturing, earthworm interaction with microflora; and on the use of earthworms for waste stabilization, vermicompost production for plant growth and heavy metal accumulation. [The Journal of American Science. 2005;1(1):4-16].

Key Words: Vermicomposting; organic waste; earthworms

1. Introduction

With the advent of industrialization and energy based intensive agriculture, chemical pathways for raw materials conversion became predominant with extensive use of petrochemical based feedstock. The damaging long-term environmental impacts and resource depletion indicate un-sustainability of the current methods. Attention is once again on biochemical pathways with the intervention of appropriate biological organisms. There are numerous sources of waste where degradable organic matter is either partially or fully generated. In India, most of the MSW is dumped and only a fraction (less than 10%) is intermittently processed in mechanical compost plants (Shekdar, 1999). Although the composting plants are found to be technically feasible, but due to competition from other manures and uncertainty over the utilization in the farms, very few plants are working at the designed capacity.

The degradable organic matter from these wastes when dumped in open undergoes either aerobic or anaerobic degradation. These un-engineered dumpsites permit fine organic matter to become mixed with percolating water to form leachate. The potential for this leachate to pollute adjoining water and soil is high. India where a lot of solid organic waste is available in different sectors with no dearth of manpower, the environmentally acceptable vermicomposting technology using earthworms can very well be adopted for converting waste into wealth. Considerable work has been carried out on vermicomposting of various organic materials and it has been established that epigeic forms of earth-worms can hasten the composting process to a significant extent, with production of a better quality of composts as compared with those prepared through traditional methods. The viability of using earthworms as a treatment or management technique for numerous organic waste streams has been investigated by a number of workers (Hand, 1988; Logsdon, 1994; Madan, 1988; Singh, 2002). Similarly a number of industrial wastes have been vermicomposted and turned into nutrient rich manure (Sundaravadivel, 1995). Hand et al. (1988) defined vermicomposting as a low cost technology system for the processing or treatment of organic wastes.

The plant protection practices and recommendations for applications of heavy doses of pesticides to control some soil insects and weeds have made the soil barren. A growing awareness of some of the adverse economic and environmental impacts of agrochemicals in crop production has stimulated greater interest in the utilization of organic amendments such as compost or vermicompost for crop production (Follet, 1981). Therefore, the sustainability has to be restored by some means of regular food security. Utilization of earthworms may be an answer as an ecologically sound, economically viable and socially acceptable technology. The present paper reviews the research work done on various aspects involved in vermicomposting of organic waste and various uses of vermicompost.

2. Biology of earthworm

Earthworms are natural invertebrates of agro ecosystem belonging to the family lumbricidae and dominant in the temperate and tropical soils. They are hermaphrodites, both male and female reproductive organs are present in every single earthworm but self-fertilization does not generally occur. At the time of laying eggs, the sexually mature worms have a distinctive epidermal ring shaped area called, the clitellum, which has gland cells that secrete material to form a viscid, girdle like structure known as cocoon. Cocoons are small, with their size varying according to species. The colour of the cocoon changes gradually as it develops from the freshly laid stage to the hatching stage. Though the number of fertilized ova in each cocoon ranges from one to twenty for lumbricid worms (Stephenson, 1930), often only one or two survive and hatch (Edwards, 1972).

Cocoon production starts at the age of 6 weeks and continues till the end of 6 months. Under favourable conditions one pair of earthworms can produce 100 cocoons in 6 weeks to 6 months (Ismail, 1997). The incubation period of a cocoon is roughly about 3-5 weeks, in temperate worms it ranges between 3-30 weeks and in tropical worms within 1-8 weeks. Earthworms also have the power to regenerate segments, which are lost. The doubling time i.e. the time taken by a given earthworm population to double its number or biomass, specifically depends upon the earthworm species, type of food, climatic condition etc. For example, the mean doubling time, with reference to density and biomass of *Lampito mauritii* in different organic inputs is 38.05 and 33.77 days respectively while in case of *Perionyx excavatus* it is 11.72 and 16.14 days respectively (Ismail, 1997). The most effective use of earthworms in organic waste management requires a detailed understanding of biology of all potentially useful species (Edward, 1998) population dynamics and productivity in earthworms can not be fully understood unless the life cycle of each earthworm is known. There are studies on life cycle and reproductive strategies of earthworms on temperate species (Lavelle, 1979), Indian species (Julka, 2001) and tropical species (Dash, 1980). Knowledge of reproductive strategies of earthworms comes predominately from studies on temperate species (Jimeneg, 1999). Studies on the life cycles i.e. cocoons production, morphology, hatching pattern and fecundity of seven tropical earthworm species have been done by Battacharjee and Chaudhari (2002) for effective vermiculture. Quality of organic waste is one of the factors determining the onset and rate of reproduction (Dominguez, 2000). The quantity of food taken by a worm varies from 100 to 300 mg/g body weight/ day (Edwards, 1972). Earthworms derive their nutrition from organic materials, living micro organisms and by decomposing animals. Surface living earthworms feed on food material selectively while deep soil living worms ingest soil as such. The type and amount of material available influence the size of earthworms, population, species diversity, growth rate and cocoons production.

Earthworms voraciously feed on organic wastes and while utilizing only a small portion for their body synthesis they excrete a large part of these consumed waste materials in a half digested form. Since the intestines of earthworms harbour wide ranges of microorganisms, enzymes, hormones, etc., these half digested material decompose rapidly and is transformed into a form of vermicompost within a short time (Edwards, 1972; Kale, 1986).

3. Species of earthworms

There are about 3000 species of earthworms distributed all over world and about 384 species are reported in India (Julka, 1986). Most earthworms are terrestrial organisms, which live in the soil. But some species like *Pontodrilus burmudensis* lead a comfortable life in estuarine water. Taxonomic studies on the Indian earthworms species have been carried out mainly by Julka (1983). Earthworms vary greatly in size, In India some peregrine species like *Microscotex phosphoreus* (Duges) are even 20 mm long while some endemic geophagous worms such as *Drawida grandus* (Bourus) may reach up to one meter in length.

Earthworm occur in diverse habitats, organic materials like manures litter, compost etc are highly attractive for earthworms but they are also found in very hydrophilic environment close to both fresh and brachish water, some species can survive under snow. Most of the earthworms are omnivorous, however *Agastrodrilus*, a carnivorous genus of earthworms from the Ivory Coast of Africa has been reported to feed upon other earthworms of the family Eudrilidae (Levelle, 1983).

4. Vermiculturing Process

Earthworms are generally classified as saprophages but based on their feeding habits they are classified into detrivores and geophages (Lee, 1985). Detrivores feed at or near the soil surface on plant litter or dead roots and other plant debris or on mammalian dung. These worms are called humus formers and comprise the *epigeic* and *anecic* forms. *Perionyx excavatus, Eisenia fetida, Eudrilus euginae, Lampito mauritii, Polypheretima elongata, Octochaetona serrata and Octochaetona curensis* are few examples of detrivorous earthworms (Ismail, 1997). Geophagous worms, feeding beneath the surface, ingest large quantities of organically rich soil and comprise the endogeic earthworms, *Metaphire posthuma* and *Octochaetona thurstoni* are two common examples of geophages.

Epigeics are surface dwellers and feed on organic matter on soil surface. Endogeic earthworms spend most of their time in the minerals layer of soil and burrow predominantly. Anecic earthworms like *Lumbricus terrestris* predominantly make vertical burrows. Of these three ecological varieties of earthworms, the epigeics and anecics have been harnessed for use in the vermicomposting process. Although a number of earthworm species have been used, one of the most commonly used world wide is *Eisenia fetida,* the tiger or brandling worm (Haimi, 1990). Other suitable species include *Lumbricus rubelus*, *Eudrilus eugeniae* and *Perionyx excavatus* an Asian species (Edwards, 1995) and *Eisenia andrei* (Haimi, 1990). As local species of earthworms are excellently adapted to local conditions, Ismail (1993) recommended the 'in-situ' soil community comprising the epigeic and anecic varieties, for the combined process of litter and soil management. He studied the distribution of earthworms in 50 locations. *Lampito mauritii* and *Octochaetona serrata* were found to be the dominating species in the sandy loams and clay loams respectively. The endogeic and anecic earthworms associate with free living soil bacteria to constitute the drilosphere (Ismail, 1995).

The selection of the correct earthworm species for particular vermiculture application is important (Appelhof, 1996). Also the vermicomposts produced - using different species of earthworms show variation in nutrient composition. A study was conducted on the effect of moisture on the growth, maturation and cocoon production of *Dendrobaena venera,* an earthworm species from Europe. It was considered as less successful species for vermicomposting as it requires relatively high moisture content (Muyima, 1994). Also in a comparative study, *Drawida nap1ensis* showed relatively slow growth in comparison to other earthworms species although population was not a prerequisite for the production of viable cocoons, indicating that it may be parthenogenetic (Kaushal, 1992). Shanthi et al. (1993), in India, evaluated the potential of three species of earthworms namely *Metaphire posthuma, Eisenia* species and *Perionyx excavatus* in degradation of vegetable waste. Among all three, *P. excavatus* was able to withstand greater ranges of moisture and temperature than other species and thus most suited for use in vermicomposting. Contrary to this, Reinecke et al. (1992) reported that *E. fetida* had a wider tolerance for temperature than *Eudrilus eugeniae* and *P. excavatus.* It tolerates as high as 42°C as well as low soil temperature below 5^0 C. The quality and amount of food material influences not only the size of earthworm population but also the species present and their rate of growth and fecundity (Dominguez et al., 2000, Chaudhari and Battacharjee 2002). Hendriksen (1990) suggested that C:N ratio and particularly polyphenol concentration are the most important factor determining litter palatability in detrivorus earthworms.

Earthworms can be cultured and put to various uses i.e. to improve and maintain soil fertility, to convert organic waste into manure, to produce earthworm based protein food (earthworm meal) for livestock, drug and vitamins source, as natural detoxicant (Paoletti, 1991) and a bait for fish market (Ghosh, 2004). Culturing of earthworms is done in humid places with proper protection from predators like ants, rats, bandicoots, frogs and toads. Shelter is provided to avoid direct sunlight and water logging conditions due to rain.

The first step in vermiculture is to select suitable feed materials for the earthworms. These can be nitrogen rich material like cattle dung, pig manure, poultry manure etc. or other organic materials like leguminous agro waste. The feed material should not have C:N ratio more than 40. Using carbon material with a very high C: N ratio, like paper and soaked cardboards, may just fatten the worms (Ismail, 1997). A variety of non-standard materials for vermiculturing have been compared. The greatest weight increase of earthworms *Eisenia fetida* was obtained with 50g soil mixed with 150g cellulose waste. Reproduction was most intensive in substrate consisting of 100g cattle manure, 50g soil and 50g cellulose waste. The best results obtained with cotton waste were in combination with cattle manure in the ratio 1:5. Grape cake and tobacco waste gave only marginal increase and the earthworms did not reproduce. An outdoor study conducted using polythene containers to assess the suitability of different organic residues, i.e. soyabean, wheat, maize strover, chickpea straw and city garbage, with *Perionyx excavatus*, showed best growth of earthworms with maize strover (Manna, 1997). Mba (1989) observed that rearing of *Eudrilus euginae* on fermented *Paspalum digitatus* (Dallis grass) is possible otherwise this medium as raw substrate is toxic to the worms.

Wooden boxes, cemented tanks, earthen pots, earthen pits lined with either stones or plastics can be used for vermiculturing. Humid and slightly dark places, 40-50% moisture in beds, 20-30°C temperature, pH of 7 and partially decomposed organic matter rich in nitrogen help earthworms to grow faster and produce more cocoons (Kale, 1995). Vermiculturing is also being employed to produce castings for use as agricultural fertilizer. Cuba has developed more than 170 vermiculture centres for the above purpose. Data are also available on the chemical composition of earthworms castings from worms fed with different feed stocks (Werner, 1996).

It is widely believed that organic fertilizers, by providing a nutrient rich substrate, support higher earthworm population, whether they feed directly upon the organic matter or upon the microorganisms, which colonize the organic materials. Inorganic fertilizers may also contibute indirectly to an quality of crop residues returned to the soil (Edwards, 1995), although the long term use of inorganic nitrogen fertilizers may some times cause a decrease in earthworm abundance and biomass, particularly if it is ammonia based (Ma, 1990). Warner and Dindal (1989) reported that manure amendments supported higher earthworm densities and biomass than inorganic ferilisers after 5 years of soyabean-corn-legume rotations. Edwards and Lofty (1982) stated that in long term condition cereal production, earthworm abundance and biomass was greatest in plot receiving a combination of manure and inorganic fertilizers.

5. Vermicomposting process

The term "vermicomposting" refers to the use of earthworms for composting organic matter and the latest biotechnology which helps in giving biofertilizers in the term of vermicompost, for agricultural uses and a high quality protein (earthworm biomass) for supplementing the nutritional energy needs of animals, at a faster rate. Vermicomposts, specifically earthworm casts, are the final product of vermicomposting. It is an aerobic, bioxidation and stabilization non- thermophilic process of organic waste decomposition that depends upon earthworms to fragments, mix and promote microbial activity (Gaundi, 2002).

Vermicomposting as a principle originates from the fact that earthworms in the process of feeding fragment the substrate thereby increasing its surface area for further microbial colonization (Chan, 1988). During this process, the important plant nutrients such as nitrogen, potassium, phosphorus and calcium present in the feed material are converted through microbial action into forms that are much more soluble and available to the plants than those in the parent substrate (Ndegwa, 2001). Earthworms are voracious feeders on organic waste and while utilizing only a small portion for their body synthesis they excrete a large part of these consumed waste material in a half digested form. Since the intestine of earthworms harbour wide range of microorganisms, enzymes hormones, etc., these half digested substrate decomposes rapidly and are transformed into a form of vermicompost with in a short time (Lavelle, 1988).

This process takes place in the mesophilic temperature range (35-40^{o} C). Earthworm prepares organic manures, through their characteristic functions of breaking up organic matter and combines it with soil particles. The final product is a stabilized, well humidified, organic fertilizer, with adhesive effects for the soil and stimulator for plant growth and most suitable for agricultural application and favourable environmentally. The action of earthworms in this process is both physical/mechanical and biochemical. Physical participation in degrading organic substrates results in fragmentation, thereby increasing the surface area of action, turnover and aeration. Biochemical changes in the degradation of organic matter are carried out through enzymatic digestion, enrichment by nitrogen excrement and transport of organic and inorganic materials. About 5- 10 percent of ingested material is absorbed into the tissue for their growth and metabolic activity and rest is excreted as vermicast. The vermicast is mixed with mucus secretion of the gut wall, and of the microbes and transformed into vermicompost (Edwards, 1972). The decomposition process continues even after the release of the cast by the establishment of microorganisms. The studies on the effects of vermicomposting on some components of organic waste showed that vermicompost enhances degree of polymerization of humic substances along with a decrease of ammonium N and an increase of nitric N (Cegarra, 1992).

Vermicomposting facilities are reported to be already in commercial operation in Japan, Canada, USA and is also being efficiently practised in the Philippines and in Asia. Ghosh (2004) reported that vermicomposting at commercial level was started at Ontario (Canada) only in 1970 and is now processing about 75 tones of refuse per week, American earthworm company (AEC) began a farm in 1978-1979 with about 500 tones capacity per month and Aoka Sangyo Co. Ltd., Japan has three 1000 tones per month plants processing waste from pulp and food industries. Beside these, there are about 3000 other vermicomposting plants in Japan with 5- 50 tones capacity per month. Advanced systems for vermicomposting are based on top feeding and bottom discharge of a raised reactor, thus providing stability and control over the key areas of temperature, moisture and aerobicity (Price, 1988). An improved mechanical separator for removing live earthworms from vermicomposts has also been introduced having a novel combing action by Price at al. (1990).

6. Characteristics of vermicompost

Vermicompost, a product of a non- thermophilic biodegradation of organic material through interactions between earthworms and micro organisms, is a peat like material with high porosity, aeration, drainage, water holding capacity and microbial activity, (Edwards, 1998; Atiyeh, 2000d). It contains most nutrients in plant available forms such as nitrates, phosphates, exchangeable calcium, soluble potassium etc (Edward, 1998) and has large particular surface area that provides many microsites for microbial activity and for the strong retention of nutrients. The plant growth regulators and other plant growth influencing materials i.e. auxins, cytokinins, humic substances etc, produced by micro organisms have been reported from vermicompost (Atiyeh, 2002b; Muscolo, 1999). The humic materials extracted from vermicomposts have been reported to produce auxin- like cell growth and nitrate metabolism of carrots (*Daucus carota*) (Muscolo, 1999). However humic substances can occur naturally in mature animal manure, sewage sludge or paper – mill sludge but their amount and rates of production are increased dramatically by vermicomposting.

The nutrient status of vermicompost produced with different organic waste is; organic carbon 9.15 to 17.98 %, total nitrogen 0.5 to 1.5 %, available phosphorus 0.1 to 0.3 %, available potassium 0.15, calcium and magnesium22.70 to 70 mg/100g, copper 2 to 9.3 ppm, Zinc 5.7 to 11.5 ppm and available sulphur, 128 to 548 ppm (Kale, 1995).

Several researchers have compared vermicasts with the surrounding soils and reported their results (Lavelle, 1978). The vermicasts have been reported with a higher Base Exchange capacity and are rich in total organic matter, phosphorus potassium and calcium with a reduced electrical conductivity, large increase in oxidation potential and significant reductions in water-soluble chemicals which constitute possible environmental contaminants. Humic acid like components (HAL) were isolated by conventional procedures from various organic wastes including animal manures, a municipal solid refuse and a sewage sludge that were composted for 2-3 months with the earthworms *E. fetida* or *Lumbricus rubellus* by Senesi et al. (1992). Vermicompost HAL containing appreciable amounts of Fe and Cu in inner sphere complexes of definite chemical and geometrical forms, similar to those found in humid acid (HA) from soil and other sources, can be considered adequate analogues of soil HA with respect to their metal complexion properties and behavior. Vermicompost is rich in microbial diversity, population, and activity (Subler, 1998) and vermicast contains enzymes such as *proteases, amylases, lipase, cellulase and chitinase* which continue to disintegrate organic matter even after they have been ejected. The chemical analysis of casts shows 2 times the available magnesium, 5 times the available nitrogen, 7 times the available phosphorus and 11 times the available potassium compared to the surrounding soil (Bridgens, 1981). The vermicompost is considered an excellent product since it is homogenous, has reduced level of contaminants and tends to hold more nutrients over a longer period without impacting the environment (Ndegwa, 2001).

7. Waste stabilization by vermicomposting

Agricultural waste, horticultural waste, animal waste, silkworm litter, plant biomass (leaf litter), weeds, kitchen waste abiding, foul, acidic, spicy and spoilt food, city refuse after removing non-degradable waste material such as glass, plastic, strong rubber and metal can be vermicomposted (Kale, 1995). Vermicomposting of pre - treated pig manure using *E. fetida* produced a humus rich odour free vermicast (Chan, 1988). *Pheretima asiatica* could stabilize most of the solids arising from the treatment waste including raw pig manure (Wong, 1991). Dominguez at al. (1997) studied the total and available content of Zn and Cu during the vermicomposting process, because these are problematic minerals in pig manure. Although as a consequences of the carbon losses by mineralization during process the total amount of heavy metals increase (between 25-30%), the amounts of bioavailability heavy metals tend to decrease by 35 – 55 % in two months. Dominguez (1997) vermicomposted pig manure and observed 50-60 % higher nutrients in the earthworm treatments than in the control. Further on the basis of his preliminary studies he also added that human pathogens do not survive during vermicomposting. After 60 days *of* vermicomposting; faecal coliform bacteria in biosolids dropped from 39000 MPN/g to 0 MPN/g that same time period, *Salmonella* sp. dropped from < 3 MPN/g to < l MPN/g. The suitability of cowslurry substrate for vermicomposting, the changes brought about in slurry by *E. fetida* and on the special beneficial relationships between *E. fetida* and micro organisms isolated from the slurry are discussed by Hand at al (1988b). A comparison of two methods of vermicomposting showed that top feeding of slurry was more efficient in promoting earthworm growth and cocoon production than the mixing of slurry with solid materials.

Various workers have suggested that *E. fetida* could be used in sludge management (Mitchell, 1980; Neuhauser, 1980 b) but there have been few large scale field trials of the concept. The city of Lufkin, Texas (USA) initiated the use of earthworms in processing liquid sludge and predicted that 4500 kg of *E. fetida* would consume 900kg dry sludge daily. The whole output of this plant served a population of 10,000 to 15,000 (Prince, 1981). The potential of different kinds and combinations of wastes to support the biomass of *E. fetida* capable of processing a given amount of waste in a period of 1 month was tested by Haimi and Huhta 1986. Miscellaneous waste mixed with activated sewage sludge for a long period produced good compost with odour less castings. The use of the California worm *Lumbricus rubellus* in the transformation of partially decomposed and non-decomposed sewage sludge into compost for agricultural purpose was studied. The end product of partially decomposed had an improved humus composition and higher content of P and K (Delgado at al., 1995). It also previously observed that earthworms *(Eisenia fetida)* accelerate mineralization and degree of humification (Albanell, 1988). Further Saciragic at al. (1990) reported that *E. fetida* worms could only grow in aerated sludge.

The sludge which was not suitable for direct foodland application could involve the use of worms for vermicomposting (Frank, 1983). In Australia and New Zealand a number of composting toilets of various designs using earthworms were seen. The most sophisticated of these, the Dowmus Composting Toilet had fan aeration and a compost extraction auger (Edwards, 1997). Similarly in India both solid waste and sewage from a colony of 500 homes were processed with vermiculture at the Indian Aluminium Co. Ltd. Site in Belgaum. The colony's sewage was fed to a 200 sq. mt. vermifilter, designed for processing up to 100 m^3/day and the purified water was used for garden irrigation (White, 1996).

Kaviraj and Sharma (2003) reported comparative study of *E. fetida* (exotic) and *P. excavatus* (local) species of earthworms in vermicomposting of MSW. Singh and Sharma (2002) studies the role of bioinoculants i.e. *Pleurotus sajor-caju, Trichoderma harzianum, Aspergillus niger and Azotobacter chroococcum,* in predecomposition of a mixed solid waste i.e MSW and horticulture waste (70:30) for it's subsequent vermicomposting and observed that this system not only improved the quality of product but also reduced stabilization period.

Paper pulp has been suitability utilized to produce vermicompost. In Spain, *E. endrei* transformed paper pulp mill substrate by process of aerobic and mesophilic hydrolysis (Elvira, 1995). A comparative study, on the quality of organic matter and heavy metal in different mixtures of paper mill sludge and sewage sludge before and after vermicomposting *(E. endrei)* reported that a 1:6 mixture of paper mill sludge to sewage sludge was the most effective mixture for increasing the weight of *E. andrei* during the vermicomposting period. Total and OTPA extractable metals increased during vermicomposting but the concentration did not exceed the maximum limits pennitted in sludge for agricultural use. The degree of extractability of Mn, Cu and Zn decreased during vermicomposting implying reduced availability for plants (Elvira, 1995). Further in an another study conducted by Elvira et al. (1998) on vermicomposting of pulp mill sludge mixed with garbage sludge, pig slurry and poultry slurry at different ratios showed highest growth and highest mortality of *E. andrei* in all the mixtures considered. Butt (1993) utilized solid paper mill sludge and spent yeast as a feed for soil dwelling earthworms *(Lumbricus terrestris).* Zharikov et al. (1993) reported work on utilizing the wastes of the microbiology industry (Sewage sludge, husks, and low quality bacterial preparations) by red earthworms.

In an another study Iegnocellulosic waste of Maple (Acer) was composted aerobically and vermicomposting method for 10 months under controlled conditions and chemical analysis and C-13 CPMAS NMR Spectrosco py was done to study the transformation of organic matter. Initially the bulk of organic matter and polysaccharides, including cellulose underwent a relatively rapid decomposition whereas the degradation of aromatic compound and lignin occurred only after composting for 1 month with the greatest rates occurring in the following 3 months (Vinceslas, 1997).

8. Potential applications of earthworms and vermicompost in plant growth

Being rich in macro and micro nutrients, the vermicompost. has been found an ideal organic manure enhancing biomass production of a number of crops (Vasudevan, 1997b; Hidalgo, 1999; Pashanasi, 1996). The importance of vermicompost in agriculture, horticulture, waste management and soil conservation has been reviewed by many workers (Edwards, 1995; Riggle, 1994, Kaviraj, 2003). Darwin (1881) stated that the earthworms prepare the ground in an excellent manner for the growth of fibrous-rooted plants and for seedlings of all kinds. The beneficial effect of earthworms on plant growth may be due to several reasons apart from the presence of macro nutrients and micronutrients in vermicasts and in their secretions in considerable quantities. It is believed that earthworm produce certain metabolites, vitamins and similar substances into the soil which may be the B or D group vitamins (Nielson, 1965). The use of earthworm compost in commercial production of *Chrysanthemum morifolium* was advocated by Martinez and Gomez (1995).

Edwards (1995) reported that in a Rothamsted study with 25 types of vegetables, fruits or ornamentals, earthworm casts (EW) performed better than compost or commercial potting mixture amendments. The beneficial effects of earthworm cast utilization in other horticulture settings have also been reported (Hidalgo, 1999). Fresh casts often contain high ammonium levels, but rapid nitrification results in stable levels of both nitrogen forms due to organic matter protection in dry casts (Decaens, 1999). Nutrients in casts are initially physically protected, but this is reduced as the aggregate structure weakens over time (McInerney, 2000). In addition to increased N availability, C, P, K, Ca and Mg availability in the casts is also greater than in the starting feed material (Orozco, 1996). Earthworm cast amendment has been shown to increase plant dry weight (Edwards, 1995) and plant N uptake (Tomati, 1994). Cantanazaro (1998) demonstrated the importance of the synchronization between nutrient release and plant uptake and showed that slower release fertilizers can increase plant yield and reduce nutrient leaching.

The growth of vesicular - arbuscular mycorrhizal fungi is enhanced in the presence of earthworms (Kale, 1992). Earthworms are known to act as vectors of viable propagules of mycorrhizal fungi (Redell, 1991). Soil quality is affected by soil aggregates and these aggregates often determine the retention and movement of water, diffusion of gases, growth and development of roots in the soil. Earthworms play a vital role in preventing soil erosion and soil aggregates formation directly as well as indirectly by transmitting the AM fungi which are involved in water stable aggregate formation (Wright, 1998). Inoculation of earthworms in nursery pots enhanced the growth of three tree species with improved mycorrhizal infection possibly due to dispersion of fungi in large root area by worms (Patrick, 1998). Galli et al. (1992) reported an increase of 30% in protein synthesis in *Lactuca sativa* seedling following the application of vermicompost. The compost .produced by earthworms from municipal wastes (CPEMW) caused a reduction in the pH of soil and increase in the dry matter production of maize (Ferreira, 1992). This increase was significant when CPEMW was used in combination with lime or mineral fertilizer or both. Casts present enhanced nitrogen fixing power and a greater amount of auxins in comparison to conventional composting. Without N at sowing, 15 tons manure or 3 tons vermicompost applied at the earlier stage of winter oilseed rape increased survival by 9-23 percentage units (Bury, 1996). *Lumbricus terrestris* released into irrigated apple orchard soils speeded up decomposition of surface mulch and made the soil fertile in California (Werner, 1997). Cuba has been reported to have more than 170 vermiculture centres producing earthworm castings for the use as agricultural fertilizer (Werner, 1996). Throughout the island, the primary vermiculture feedstock is cow manure, although pig and sheep manure, coffee pulp, sugarcane pulp, other crdp-residues and garbage are increasingly used as well. Manure and crop residues are predecomposted for 15 to 30 days in piles that are turned twice a week before feeding to earthworms. Coffee pulp is pre-decomposed for at least 45 days. In Australia, vermicomposted organics from grape processing when added to vines under shadow mulches, increased grape yield by 20-50% at the first harvest (Edwards, 1997). In Pinar del. Rio province Cuba, castings are used to replace manure as a fertilizer in tobacco. Castings at the rate of 4 t/ha replace 45 t/ha of cow manure formerly used. This has improved production by 31 percent and enhanced quality by reducing leaf chlorine content from one percent to 0.4 percent (Werner, 1996). The growth of plants with vermicompost, as reported by Dominguez (1997) is also influenced by reduction of bioavailable heavy metals and elimination of pathogens (Riggle, 1994). On the other hand floriculture industry did not seem to use worm castings. The reason given by several floriculturists was that high amount of organic matter contribute to crop diseases. However, trimmings from the floriculture industry is regarded a very common feed stock for the worms (Logsdon, 1994). Data are also available on the enhanced net production and nitrogen content of birch seedlings due to inoculation of earthworms (Haimi, 1992). A technology using earthworms to stimulate growth of tea and enhance soil quality was practiced in India in association with Parry Agro Ltd. involving inoculation of earthworms in trenches with organic inputs in between tea plantations, thereby increasing production between 75 and 240% (Patrick, 1998).

9. Earthworms' interaction with microflora

The burrowing and casting activities of earthworms contribute to the activity of soil micro organisms (Edwards, 1996) and nutrient enriched earthworm casts are good media supporting microbial growth (Lee, 1985). Many authors have studied the microbial community in the gut of earthworms (Fisher, 1995; Karsten, 1997). It is well known that Gram-negative bacteria are common inhabitants of the intestinal canal of earthworms (Reyes, 1976). Number of *Vibro sp.* and *Aeromonas hydrophila* were reported to frequent in the gut of earthworms *Eisenia lucens* (Marialigeti, 1979) and *Pheretima sp.* respectively. Daane et al. (1998) found, by scaning electrone microscopy, that there were numerous rod shaped bacteria in egg capsule of *E. fetida,* and suggested a mutualistic association. Edwards (1998) reported that vermicompost is rich in microbial populations and diversity, particularly fungi, bacteria and actinomycetes.

The digestive system of earthworms consists of a pharynx, oesophagus and gizzard followed by an anterior intestine that secretes enzymes and a posterior intestine that absorbs nutrients. During progress through digestive system there is a dramatic increase in number of micro organisms of upto 1000 times. There is an experimental evidence that micro organisms provide food for earthworms. Bacteria are of minor importance in the diet, algae are of moderate importance and protozoa and fungi are major source of nutrients. Worms, produced under sterile conditions could live on individual cultures of certain bacteria, fungi and protozoa but grew best on various mixtures of micro organisms. In order to study the modification of microflora during vermicomposting of rabbit manure the numbers of micro-organisms of various groups were determined during and after the process and compared with those resulting from a parallel spontaneous maturation process of the same material. Actual vermicomposting brought out less change in microbial counts analogous to during a prolonged spontaneous maturation of rabbit manure (Allievi, 1987). However, specific nutritional interactions were observed between *E. fetida* and micro-organisms. The earthwoms were found to be feeding directly upon the cells of certain micro-organisms. Other species were found to be toxic to *E. fetida.* The seeding of vermiculture beds with the bacterium *Acinetobacter calcoaceticus* stimulated earthworm growth and consumption of the substrate (Hand, 1988), while no difference was observed for *Acetobacter diazotrophicus* inoculation over the worm reproductivity (Aquino, 1994).

Studies (Kale, 1991) on incidence of cellulolytic and lignolytic organisms in earthworm worked soils showed that symbiotic microflora of worms are involved in lignin degradation. The total microbial load in the different regions of the gut of worms has also shown more intense colonization of microbes in the anterior part of the intestine than the other region. Bisesi (1990) found that application of earthworm biotechnology in conjunction with indegenous microbial activity, under ambient conditions of temperature and seasonal changes enhance the rate of stabilization and turnover of biological sludge. Earthworm have been shown to selectively consume different type of plant material (Piearce, 1989), and to select different fungal species when offered on filter paper disc (Cooke, 1983). The presence of fungal propagules in the earthworm gut, and in cast material, has been known for some time (Parle, 1963) and earthworm have been implicated in both the reduction and dispersal of soil- borne animal and plant fungal disease and the spread of beneficial group such as mycorrhizal fungi (Gange, 1993). Parle (1963) reported that population of yeast and fungi did not proliferate during passage through the gut, although actinomycetes and bacteria did.

10. Metals and agrochemicals accumulation from soil by earthworms

Earthworms are often preferred subject in soil ecotoxicological research because they are quite easy to handle and measure their different life cycle parameters, in accumulation and excretion of metals and biochemical responses. Earthworms ingest large amount of soil and are therefore exposed to heavy metals through their intestine as well as through the skin, wherefore concentrating heavy metals from the soil in their body (Morgan, 1999). Earthworms may serve as bioindicators of soil contaminated with pesticides i.e. polychlorinated biphenyls, polycyclic hydrocarbons (Saint-Denis, 1999), and heavy metals (Spurgeon, 1999a). Lead, cadmium, zinc and copper are accumulated and, under some environmental conditions, bioconcentrated in earthworms (Cortet, 1999). It is presumed that in many cases zinc is the critical toxic metal for these organisms (Spurgeon, 2000). Mortality and fecundity of earthworms as bio indicating organisms may serve as reliable, however ultimate and time consuming, indices of environmental pollution (Morgan, 1999).

Suppression of labile aluminium in acidic soils by the use of vermicompost extract (VCE) was observed by chelation combined with pH induced precipitation. (Mitchell, 1993). The same authors in 1992 also reported that in solutions above pH 6, a 98% reduction of total Al was obtained due to pH effects, whereas at pH 4, a reduction of 90% was obtained due to chelation (Alter, 1992). Ireland (1977) reviewed the effect of various pesticides and heavy metals on earthworms. This will bring down the risk of entry of these pollutants into plant system and then into sequential food chain. When worms are used for this purpose, they should be prevented from entering into food chain as they are found to concentrate very high levels of these toxins in their tissue.

11. Other uses

In experiments with tomatoes and cabbages in Poland it was found that vermicompost could be used as biopesticides and it protected the three vegetable plants from a number of microbes (Szczech, 1994). Medicinal value of earthworms was known as far back as 1340 A.D. and covering a range of diseases from pyorrhea to postpartal weakness, from small pox to jaundice to rheumatism (Reynolds, 1972). Hori et al. (1974) have reported significant anti-pyretic activity of a medicine derived from the earthworms. Earthworms have been used for reducing fever due to its antipyretic activity and for testing pregnancy in human females (Hassenbein, 1951). They were also found useful for curing chronic cough, jaundice, diarrhoea and also for facilitating delivery (Wahid, 1961).

Earthworms are known as a protein rich source of cattle feed. The dry matter of earthworms has been found to be around 20 to 25 percent of the fresh weight. This contains around 60 % protein, 7-10 % fat, 8-10 % ash, 0.55 % Ca and 1 % phosphorus. *Eudrilus eugeniae* has been successfully used for this purpose in India and abroad. Converting 1 tone of cattle dung into 450 kg of usable humus and 40 kg of earthworms, 6.5 kg of worm meal with 70% protein content for animal feed was produced (Hennuy, 1986). When vermicompost, produced with *E. fetida,* was given as feed for chick, it reduced caecal colonization *by Salmonella tphimurium* and *S. enteritidis* (Spencer, 1995). Earthworms' meal has been experimentally fed to pigs (Harwood, 1978), mice and rats (Schulz, 1977). According to Harwood (1976) chickens fed on earthworms meal had better feed conversion ratios.

Earthworm can be used as bio-indicators for the monitoring of ecosystem state and changes. Various workers identified the earthworms for evaluating the effect of soil contamination with heavy metals and pesticides, agricultural practices, and acid rain etc. (Paoletti, 1991). There are numerous studies about the heavy metal influence on the growth, reproduction and mortality of earthworms.

Ghosh (2004) used the earthworm as fish feed and observed the higher biomass of fish as compare to the inorganic fertilizer, used to increase the fish biomass. Marcel et al. (1997) reported that earthworm increase the water infiltration rate of the soil and observed a mean rate of 150 mm h^{-1} per 100 g m^{-2} of earthworms however the anecic species shows maximum infiltration (282 mm h^{-1} per 100 g m^{-2}).

12. Conclusion

Vermicomposting technology involves harnessing earthworms as versatile natural bioreactors playing a vital role in the decomposition of organic matter, maintaining soil fertility and in bringing out efficient nutrient recycling and enhanced plants' growth. A variety of organic solid wastes, domestic, animal, agro-industrial, human wastes etc can be vermicomposted. The value of vermicompost is further enhanced as it has simultaneously other benefits: excess worms can be used in medicines and as protein rich animal feed provided they are not growing on polluted wastes and can be used as an anti soil pollutant.

Hence, mass rearing and maintaining worm cultures and tapping of organic wastes for their maintenance has a good scope for developing it as a cottage industry in developing countries like India where there is no girth of organic wastes.

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