Chapter I

INTRODUCTION

VERMI TECHNOLOGY AND WASTE MANAGEMENT

The global scientific community today is searching for a technology, which should be economically viable, environmentally sustainable, and socially acceptable (beneficial to the society with no adverse effect on human health). Vermiculture Technology combines all these virtues and qualities together.

A revolution is unfolding in vermiculture studies (rearing of useful earthworms species) for multiple uses in environmental protection and sustainable development. Earthworms have over 600 million years of experience as ecosystem engineers. Vermiculture scientists all over the world knew about the role of earthworms as waste managers, as soil managers and fertility improvers for long time. But some comparatively new discoveries about their role in wastewater treatment, contaminated soil remediation, have brought a revolution in the vermiculture studies (Sinha, 2009). About 4,400 different species of earthworms have been identified, and quite a few of them are versatile waste eaters and bio-degraders and several of them are bio-accumulators and bio-transformers of toxic chemicals.

VERMITECHNOLOGY IN SUSTAINABLE DEVELOPMENT

Bioengineering technologies based on earthworms are self-promoted, self-regulated, self-improved and self-enhanced, low or no-energy requiring zero-waste technologies, easy to construct, operate and maintain. They excel all bioconversion, bio-degradation and bio-production technologies by the fact that they can utilize organics that otherwise cannot be utilized by others. They excel all bio-treatment technologies because they achieve greater utilization than the rate of destruction achieved by other technologies. They involve about 100-1000 times higher value addition than other biological technologies (Appelhof 1997; Wang, 2000). Technologies based on earthworms are also environmentally and economically sustainable as the worms are highly renewable resources regenerating at a rapid rate (by \(2^8\) i.e. 256 worms every 6 months from a single individual and each of the 256 worms multiplying in the same proportion) and the products are completely biodegradable.
The best part is that vermi-agroproduction, vermi-protection and vermi-production technologies are based on the by-products (worm biomass and vermicompost) generated in the operation of other three technologies and therefore, more sustainable. It is like killing several birds in one shot.

Vermitechnology for sustainable development with environmental protection can be envisaged by the use of useful earthworm species which promises to provide cheaper solutions to several social, economic, environmental and health problems plaguing the human society, these can be further narrowed down as vermi–composting technology, vermi–filtration technology, vermi–remediation technology, vermi–agroproduction technology:

- The Vermi-Composting Technology
- The Vermi-Filtration Technology
- The Vermi-Remediation Technology
- The Vermi-Agro-Production Technology
- The Vermi Protection Technology
- The Vermi Production Technology

**Vermi-Composting Technology** for efficient management of municipal and industrial solid wastes (organics) by biodegradation and stabilization and converting them into useful resource (vermicompost-nutritive biofertilizer).

**Vermi-Filtration Technology** for treatment of municipal and some industrial wastewater, their purification and disinfection for reuse

**Vermi-Remediation Technology** for cleaning up chemically contaminated sites (lands) while also improving their physical, chemical, and biological properties for reuse

**Vermi-Agro-Production Technology** for restoring and improving soil fertility to produce safe and chemical-free food for the society by the use of vermicompost and without recourse to the destructive agro-chemicals;
**Vermi Protection Technology** for use of earthworms to develop potential modern vermimedicines to combat some chronic and deadly diseases and protect human health;

**Vermi Production Technology** for use of earthworms to produce some valuable raw materials to be used in rubber, lubricant, soaps, detergent and cosmetics industries and use of rich worm proteins as feed materials (vermimeals) to promote fishery, dairy and poultry industries to produce more nutritive foods for the society. Of these, four predecessors are of our major interest.

**BIOMANAGEMENT OF ENVIRONMENTAL WASTE BY VERMI TECHNOLOGY**

Earthworms have over 600 million years of experience as waste managers. The Greek philosopher Aristotle called them as the intestine of earth, meaning digesting a wide variety of organic materials including the waste organics, from earth (Darwin and Seward, 1903). They feed lavishly on the organic waste, and on the microorganisms (bacteria, fungi and the actinomycetes) that invade and colonize the waste biomass. Most earthworms consume, at the best, half their body weight of organics in the waste in a day. *Eisenia fetida* is reported to consume organic matter at the rate equal to their body weight every day (Viswanathan et al., 2005). Earthworms have real potential to both increase the rate of aerobic decomposition and composting of organic waste, and to stabilize the organic residues in them, while removing the harmful pathogens and heavy metals from the products.

Earthworm participation enhances natural biodegradation and decomposition of organic waste from 60 to 80%. The process becomes faster with time as the worms multiply rapidly doubling its population in every 60-70 days (Ismail, 2005). Waste degradation and composting by earthworms is proving to be environmentally preferred technology over the conventional microbial degradation and composting technology as it is rapid and nearly odorless process, reducing composting time by more than half. On an average, 2000 adult worms weigh 1 kg and one million worms approx. 1 ton. Given the optimum conditions of temperature (20-30°C) and moisture (60-70%), about 5 kg of worms can vermi-process 1 ton of MSW into vermicompost every month, 1000
worms can degrade 10 kg waste every month and 50 million worms can vermiprocess 90 tons of waste every week (Datar et al., 1997).

VERMICOMPOSTING OF COMMUNITY WASTES

Waste eater earthworms can physically handle a wide variety of organic wastes from both municipal (domestic and commercial) and industrial (livestock, food processing and paper industries) streams. They are highly adaptable to different types of organic wastes (even of industrial origin), provided, the physical structure, pH and the salt concentrations are not above the tolerance level (Loehr et al., 1984; Datar, 1997; Fraser-Quick, 2002; Sinha et al., 2005).

Municipal organic wastes

1) The food waste from homes (Some raw, but all cooked kitchen wastes - fruits and vegetables, grains and beans, coffee grounds, used tea leaves and bags, crushed egg shells) and restaurants and fried food wastes from fast-food outlets (Patil, 2005; Kristiana et al., 2005; Suther, 2009; Valani, 2009; Chauhan, 2009).

2) The garden (yard) wastes (leaves and grass clippings) from homes and parks constitute an excellent feed stock for vermi-composting. Grass clippings (high carbon waste) require proper blending with nitrogenous wastes (Valani, 2009; Chauhan, 2009).

3) The sewage sludge (biosolids) from the municipal wastewater also provides a good feedstock for the worms. The worms digest the sludge and convert a good part of it into vermi-compost (Vermitech, 1998; Sinha et al., 2009b).

4) Paunch waste materials (gut contents of slaughtered ruminants) from abattoir also make good feedstock for earthworms (Fraser-Quick, 2002).

Agriculture and animal husbandry wastes

Farm wastes such as crop residues, dry leaves and grasses. Livestock rearing waste such as cattle dung, pig and chicken excreta makes excellent feedstock for earthworms (Edwards et al., 1985; Hartenstein and Bisesi, 1989; Bansal and Kapoor, 2000; Munroe, 2007). Animal excreta containing excessive nitrogen component may require mixing of carbon rich bulking agents eg. Straw, saw dust, dried leaves and grasses, shredded paper waste etc. to maintain proper C/N ratio)
Some industrial organic wastes

Solid waste including the wastewater sludge from paper pulp and cardboard industry, textile mills, food processing industries including brewery and distillery; vegetable oil factory, potato and corn chips manufacturing industry, sugarcane industry, aromatic oil extraction industry. Sericulture industry, logging and carpentry industry also offers excellent feed material for vermi-composting by earthworms (Kale et al., 1993; Kale and Sunitha, 1995; Seenappa and Kale, 1993; Seenappa et al., 1995; Gunathilagragaj and Ravignanam, 1996; Elvira et al., 1998; Ceccanti and Masciandaro, 1999; Lakshmi and Vijayalakshmi, 2000; Kaushik and Garg, 2004; Visvanathan et al., 2005; Elvira et al., 1998; Lotzof, 2000; Ndegwa and Thompson, 2001; Fraser-Quick, 2002; Contreras-Ramos et al., 2006). Even the fly-ash from coal power plants considered to be a hazardous waste can be composted by earthworms (Saxena et al., 1998).

Worms can feed upon meat waste products if driven to starvation

Sinha et al., (2008b; 2009) found that worms can even eat chicken flesh (leaving the bones) if other feed materials are not available and driven to starvation. They are last food preferences. But the system is invaded with maggots and some foul odour for few days until worms eliminate them too by their anti-pathogenic actions.

Worms can even vermicompost human excreta (Feces)

Bajsa et al. (2004) studied vermicomposting of human excreta. It took six months to degrade. There was no re-growth of pathogens on storing the compost for longer period of time and the initial pathogen load did not interfere in the die off process, as the composting process itself seemed to stabilize the pathogen level in the system (Eastman, 1999; Eastman et al., 2001).

EARTHWORM SPECIES SUITABLE FOR WASTE DEGRADATION

Long-term researches into vermiculture have indicated that the Tiger Worm (*E. fetida*), Red Tiger Worm (*E. andrei*), the Indian Blue Worm (*P. excavatus*), the African Night Crawler (*E. eugeniae*) and the Red Worm (*Lumbricus rubellus*) are best suited for vermi-composting of variety of organic wastes (Graff, 1981; Beetz, 1999; Reinecke et al., 1992; Sinha et al., 2002; and Nair et al., 2007).
Critical factors affecting worm function and vermicomposting

a) Temperature: Vermicomposting is a mesophilic composting where temperature does not increase beyond 30°C. Most worms require moderate temperature between 20 and 30°C for best function.

b) Moisture: It is also a critical factor in vermicomposting process. It helps in the biochemical reaction and retains heat. Moisture content of 60-70% of total weight of waste is considered ideal for vermicomposting (Dynes, 2003).

c) Aeration: As vermi-composting is an aerobic process adequate flow of air in the waste biomass is also essential for worm function.

d) pH of medium: Earthworms are sensitive to pH change. Although they can survive in a pH range of 4.5 to 9, but functions is at neutral pH of 7.0 (Edwards, 1998). Worms and their vermicasts reduce the acid-forming carbon in the soil and help maintain neutral pH.

e) Calcium: Calcium appears to be important mineral in worm biology (as calcareous tissues) and biodegradation activity. Pramanik et al. (2007) found that application of lime at 5 g/kg of substrate not only enhances the rate of vermicomposting but also results into nutritionally better vermicompost with greater enzymatic (phosphatase and urease) activities.

f) C/N ratio: Nitrogen is a critical factor in any aerobic composting system. Generally 25 parts carbon to 1 part nitrogen by weight (C/N=25:1) is considered ideal for rapid vermicomposting.

g) Worm number and biomass: The number and quantity (biomass) of earthworms is also a critical factor for vermi-composting. More the number of worms, rapid is the decomposition and odor-free. A minimum of about 50-100 adult worms per kg of waste in the initial stage is considered ideal.

Mechanism of worm action in vermicomposting

Earthworms promote the growth of beneficial decomposer aerobic bacteria in waste biomass and act as an aerator, grinder, crusher, chemical degrader and a biological stimulator (Dash, 1978; Binet et al., 1998).
a) **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 μm and passed on to the intestine for enzymatic actions. The gizzard and the intestine work as a bioreactor.

b) **Enzymatic action:** The 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 (Dash, 1978).

c) **Worms reinforce decomposer microbes and act synergistically:** Worms promote the growth of beneficial decomposer microbes (bacteria, actinomycetes, and fungi) in waste biomass. Earthworms host millions of decomposer (biodegrades) microbes in their gut, which is, described as little bacterial factory (Singleton et al., 2003). Edwards and Fletcher (1988) 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 will in turn foster a microbial population of billions of millions. Under favorable conditions, earthworms and microorganisms act symbiotically and synergistically to accelerate and enhance the decomposition of the organic matter in the waste. It is the microorganisms, which break down the cellulose in the food waste, grass clippings, and the leaves from garden wastes (Morgan and Burrows, 1982).

d) **Humification of degraded waste organics:** The final process in vermi-processing and degradation of organic matter is the humification in which the large organic particles are converted into a complex amorphous colloid containing phenolic materials. Only about one-fourth of the organic matter is converted into humus.

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**VERMICOMPOST: A NUTRITIVE BIO-FERTILIZER AND MIRACLE GROWTH PROMOTER**

Vermicompost is a nutritive plant food rich in NKP, macro and micronutrients, beneficial soil microbes like nitrogen-fixing bacteria and mycorrhizal fungi and are excellent growth promoters (Krishnamoorthy and Vajranabhaiah, 1986; Edwards and Burrows, 1988; Buckerfield et al., 1999). It contains potassium (K), sulfur (S),
magnesium (Mg), manganese (Mn), copper (Cu), cobalt (Co), borax (Bo), iron (Fe) and carbon (C). Kale and Bano (1986) reports as high as 7.37% of N and 19.58% P as $P_2O_5$ in worm’s vermicast. UK Ministry of Agriculture reported 93 mg/L nitrate, 387 mg/L K, 53 mg/L P and 167 mg/L Mg in pure vermicast (Kangmin, 1998). Neilson 1965; Tomati et al., (1987) reported presence of plant growth hormones (auxins, gibberelins, and cytokinins) in vermicompost. Moreover, vermicompost contain enzymes like amylase, lipase, cellulase and chitinase, which continue to break down organic matter in the soil (to release the nutrients and make it available to the plant roots) even after they have been excreted (Chaoui et al., 2003).

Atiyeh et al. (2000) found that the vermicompost tended to be higher in nitrates, which is the more bio-available form of nitrogen for plants. Suhane (2007) found that exchangeable K was over 95% higher in vermicompost and a good amount of calcium (Ca) and zinc (Zn). He also studied about the beneficial and biologically active soil microorganisms in vermicompost and found that the total bacterial count was more than $10^{10}$/gm of vermicompost. It included *Actinomycetes, Azotobacter, Rhizobium, Nitrobacter*, and P solubilizing bacteria ranges from $10^2$-$10^6$/g of vermicompost.

Most significant is that earthworm’s vermicompost contains humus, which is not found in any other fertilizer – organic or inorganic. It is formed from the organic matters in soil over a long period of time. But the earthworms make it quickly in its metabolic process. Without humus and humic acids, plants cannot grow and survive. The humic acids (humic, ulmic and fulvic) are essential to plants in three basic ways. Humic acid enables plant to extract nutrients from the soil. Humic acid stimulates and increases root growth and fulvic acid helps plants overcome stress and helps dissolve unresolved minerals to make organic matter ready for plants to use (Canellas et al., 2002; Kangmin, 2009). Vermicompost has also been found to reduce the incidences of pest and disease attacks on crops besides promoting good growth (Edwards and Arancon, 2004). Even foliar spray of vermicompost solution on crop plants induces excellent impacts on growth and quality of fruits and disease suppression (Zaller, 2006).