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Earthworms and Vermitechnology – A Review

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ABSTRACT

Vermicomposting is a suitable means for waste remediation and organic manure (vermicompost) production. Earthworms occur in diverse habitats, vary greatly in size and feed upon a variety of organic materials. Most earthworms are terrestrial but may be estuarine. They are omnivorous but mostly feed on dead organic matter, living bacteria, rotifers, nematodes, fungi, and other microorganisms. Out of about 3000 species of earthworms found worldwide, in India about 500 species have been reported. Earthworms eject humus-rich castings and form water-stable aggregates, which improve soil physical and chemical properties. Casting also contains enzymes like protease, amylase, lipase, cellulase and chitinase to decompose organic matter. Vermiculture is feasible in suitable containers and can be done indoors or outdoors depending on local climatic conditions. A tremendous amount of work has been done worldwide on solid waste management employing different epigeic and anecic earthworm species. Use of earthworms as a source of human protein has also been advocated. They can also be utilized to feed fish, pigs and poultry. The action of earthworms in vermicomposting is by physical and biochemical processes. Physical processes include substrate aeration, mixing and grinding while biochemical processes involve decomposition of waste by various enzymes present in the gut of earthworms and is influenced by microbes present in their intestine. Earthworms have several medicinal properties and are also known to accumulate toxic residues from soil/substrates. The role of earthworms in sustainable farming is immense. The present paper reviews the information on various aspects of earthworms and vermitechnology.

Keywords: flyash, vermiculturing, vermicompost, vermiwash, vermiremediation

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INTRODUCTION

Over the last few years, the problem of efficient disposal and management of organic solid wastes has become more rigorous due to rapidly increasing population, intensive agriculture, and industrialization (Garg *et al.* 2006). Production of large quantities of organic wastes all over the world poses major environmental (offensive odors, contamination of ground water and soil) and disposal problems (Edwards and Bater 1992). Appropriate disposal of waste is most essential and beneficial from ecological and economical point of view. Although, there are many ways of organic waste treatment, composting is one of the best acceptable ways for quality environment and organic farming. Organic farming involves the use of natural organic inputs like farm yard manure, compost, green manure, oil cakes, press mud, etc. (Purohit and Gehlot 2006). Decomposers like earthworms stimulate composting and are useful both in enhancing manurial value and decreasing time. Earthworm is physically an aerator, crusher and mixer, chemically a degrader and biologically a stimulator in the decomposition system. In recent years the farmers are again realizing the worth of highly beneficial animals like earthworms and are making all possible efforts to culture and subsequently release them in field and garden. The beneficial role of earthworms in increasing the soil fertility has been documented since ancient times.

The combination of composting and vermicomposting has recently been considered as a way of achieving stabilized substrates (Tognetti *et al.* 2007) for improving soil fertility. Composting enables sanitization of the waste and elimination of toxic compounds, and the subsequent vermicomposting reduces particle size and increases nutrient availability. In addition, inoculation of microbial cultures along with earthworms reduces the duration of the treatment process (Ndegwa and Thompson 2001; Lazcano *et al.* 2008). Earthworms have been used in the vermiconversion of urban, industrial and agro-industrial wastes to produce biofertilizers (Elvira *et al.* 1998; Suthar 2006; Gupta and Garg 2008). It is well established that a large number of

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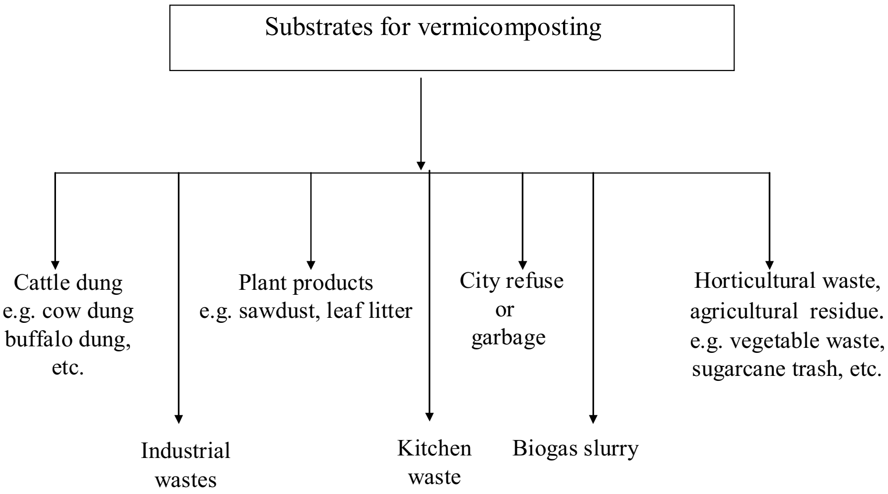

Fig. 1 Different kinds of substrates utilized in vermicomposting.

organic wastes can be ingested by earthworms and egested as peat like material termed as the vermicast. The vermicast is much more fragmented, porous and microbially active than parent material (Edwards and Bohlen 1996a; Edwards *et al*. 1998) due to humification and increased decomposition.

Vermicomposting involves the bio-oxidation and stabilization of organic material by the joint action of earthworms and microorganisms. Although it is the microorganisms that biochemically degrade the organic matter, earthworms are the crucial drivers of the process, as they aerate, condition and fragment the substrate, thereby drastically altering the microbial activity (Lazcano *et al*. 2008). Earthworms act as mechanical blenders and by commuting the organic matter they modify its physical and chemical status by gradually reducing the ratio of C: N and increasing the surface area exposed to microorganisms thus making it much more favourable for microbial activity and further decomposition (Domínguez *et al*. 1997). Vermicompost is a mixture of worm castings, organic material, humus, living earthworms, cocoons and other organisms. Vermicompost is homogenous with desirable aesthetics plant growth hormones and high levels of soil enzymes and tends to hold more nutrients over longer periods without adverse impacts on the environment (Ndegwa and Thompson 2001). Considerable amount of work has been carried out on vermicomposting of various organic materials such as animal dung, agricultural waste, forestry wastes, city waste, leaf litter and food wastes (Hand *et al*. 1988; Logsdon 1994; Singh and Sharma 2002). Similarly, industrial wastes such as guar gum, paper pulp and distillery wastes have been vermicomposted and turned into nutrient rich manure (Sundaravadivel and Ismail 1995; Suthar 2006, 2007a). Different kinds of substrate which can be utilized for vermicomposting process are summarized in **Fig. 1**. Vermicomposting is not fully adopted on the industrial scale (Domínguez *et al*. 1997) since the temperature is always in the mesophilic range, pathogen removal is not ensured, although some studies have provided evidence of suppression of pathogens (Monroy *et al*. 2008).

Vermicomposting is defined as a low cost technology system for processing or treatment of organic waste (Hand *et al*. 1988b). Vermicomposting decomposes organic materials through the joint action of earthworms and microorganisms that inhabit gut or composting substrates. The rapid transformation in physicochemical and biochemical properties makes vermicomposting suitable for management of industrial wastes (Garg *et al*. 2006; Vivas *et al*. 2009). Epigeic form of earthworms can hasten the composting process to a significant extent (Kale *et al*. 1982; Tomati *et al*. 1983; Senapati 1988), with the production of better quality of compost, compared with those prepared through traditional methods (Tripathi and Bhardwaj 2004). Certain epigeic earthworm species such as *Eisenia foetida*, *Perionyx excavatus* and *Eudrilus eugeniae* are voracious feeders of organic wastes (Kale and Bano 1985). All aspects of the worm biology such as feeding habits, reproduction and biomass production potential must be known (Senapati *et al*. 1980; Bouche and Ferriere 1986) in order to utilize the earthworms successfully in vermiculture. Since the diversity of earthworm species varies with different soil types and different agro climatic conditions, the species suited to a particular region must be identified. The present paper reviews the current status of knowledge on biology, ecology, distribution and enemies of earthworms, vermiculture and use of earthworms for various applications such as vermicompost production (with and without inoculation of efficient micro flora), bioremediation (heavy metal and agrochemical accumulation), medicinal importance and earthworm interactions with micro flora.

BIOLOGY OF EARTHWORMS

The earthworms are simple, cylindrical, coelomate and segmented animals. They have a long, rounded body with a pointed head and slightly flattened posterior. They are characterized by lacking bones or cartilage. They lack any appendages but have a few hooks like chaetae for gaining hold on the substratum. Rings that surround the moist, soft body allow the earthworm to twist and turn. With no true legs, bristles (setae) on the body move back and forth, allowing the earthworm to crawl. The cavity between the internal organs and dermal layer is filled with the coelomic fluid. The pressure of this fluid against the dermal layer gives the worm its shape (Ravindran *et al*. 2008).

Earthworms vary greatly in size though not in shape. In India some peregrine species like *Microscolex phosphoreus* (Duges), *Dichogester saliens* (Beddard) and *Bimastos parvus* (Eisen) are even less than 20 mm long (Bano *et al*. 1987) while some endemic geophagous forms such as *Drawida nilamburensis* (Bourne) and *D. grandis* may reach up to 1 m in length. The world's largest known worm *Microchaetus microchaetus* (Rapp), found in South Africa, has length of about 7 m. Earthworm occurs in diverse habitats. Organic materials are highly attractive for some species. They all are also found in very hydrophilic environments close to both fresh and brackish waters. Some species can survive under snow and few are arboreal inhabiting accumulated detritus in the axils of banana, palm and bamboo trees.

Earthworms are hermaphrodites, which mean they have both male and female sex organs, but they require another worm to mate. The sexually mature worms have a distinctive epidermal ring shaped area called clitellum which has gland cells that secrete material to form cocoons. The wide band (clitellum) that surrounds a mature breeding earthworm secretes mucus (albumin) after mating. Sperm from another worm is stored in sacs. As the mucus slides over the worm, it encases the sperm and eggs inside. After slipping free from the worm, both ends seal, forming a lemon-shape cocoon approximately 31 cm long. The three layered wall of cocoons is secreted by a type of cliteller gland cell containing large granules. It contains protein and a chitinoid material (Needham 1969). Because of presence of chitin, initially formed colourless cocoon darkens with exposure to air. Two or more baby worms will hatch from one end of the cocoon. Cocoon production starts at the age of 6 weeks and continues till the end of 6 months, the incubation period of a cocoon is roughly about 3-5 weeks and in temperate worms it ranges between 3-30 weeks and in tropical worms 1-8 weeks. The incubation period varies from species to species. It may be 14-30 days for some Indian species as compared to 8-30 days in European species. Baby worms are 1.27 to 2.54 cm long and whitish to almost transparent in color. The red worms take 4 to 6 weeks to become sexually mature. Reproduction and cocoon production is possible throughout the year, although maximum cocoon production by Indian species of worms in pasture soils has been recorded in late October and early November (Senapati and Julka 1993). The gut of the earthworm is inhabited by millions of microbial decomposers. A wide range of microorganisms including bacteria, algae, fungi, protozoa, actinomycetes, fungi and even nematodes are found commonly throughout the length of earthworm gut. Doube and Brown (1998) reported more than 50 species of bacteria from the earthworm gut. The species of microbes in the gut are usually very similar to those in surrounding soil or organic matter upon which the earthworms feed (Edwards *et al.* 1985). The digestive system of earthworm consists of a pharynx, oesophagus and gizzard followed by intestine. The anterior intestine secretes enzymes and posterior intestine absorbs nutrients during progress through digestive system. There is a dramatic increase in number of microorganisms of up to 1000 times (Edwards and Fletcher 1988). Earthworms have 'chemoreceptor' which aid in search of food. The main activity of earthworm involves the ingestion of soil, mixing of different soil components and production of surface or subsurface castings. Within 24 hrs they can pass soil/organic material almost equivalent to their own weight through alimentary canal. The annual worm cast production has been estimated to be between 1.4 and 77.8 tonnes/ha at some Indian sites (Garg and Kaushik 2005). The largest quantities of 2100-2600 tonnes/ha have been reported in Africa (Edwards and Lofty 1977). The style and shape of the released cast vary with species to species; however, it can not be taken as criteria for identifying the worms. *Lampito mauritii* deposits granular casts on the soil surface whereas the cast released by *Pontoscolex corethrurus* and *Polyphretima elongata* are thick and sticky mounds. The largest cast of *Pheretima* species in northern Thailand was reported to be 35 cm in height, 5 cm in diameter and weighed 975 g (Masciandaro and Garcia 2002). Surface castings released by *P. excavatus* and *E. eugeniae* are thin and loose granular on soil surface.

Earthworm's body contains 65% protein (70–80% high quality 'lysine-rich protein' on a dry weight basis), 14% fats, 14% carbohydrates and 3% ash (Graff 1981). They weigh over 1400–1500 mg after 8–10 weeks. On an average, 2000 worms weigh 1 kg and 1-2 million worms weigh approximately 1 tonnes (Visvanathan *et al*. 2005). Studies on the life cycle i.e. cocoon production, morphology, hatching pattern and fecundity of several tropical species have been done by Bansal and Kapoor (2002). Earthworms form a major component of soil biota and they together with a large number of other organisms constitute the soil community. The type and amount of organic substrate available influence the size of earthworms, population, species, diversity, growth rate and cocoon production.

The earthworm has many enemies, including mites, ants, centipedes, nematodes, fly larvae, termites, springtails, snails, slugs, millipedes, spiders, birds, rats, mice, moles, gophers, toads and snakes (Edwards and Lofty 1977; Edwards 2004). A wide variety of parasitic and pathogenic organisms have been reported from earthworms. These include bacteria, fungi, protozoa, platyhelmenthes, nematodes and diptera larvae. Birds, moles, shrew are major consumers of earthworm. Moles feed largely on worms, the latter constitute of 100% of their diet in winter and 50% in summer. They store worms in their burrows in paralysed conditions by cutting off their few anterior segments (Macdonald 1976). Mites, beetles, centipede feed on and destroy developing earthworm and their cocoons (Edwards and Bohlen 1996). A carnivorous earthworm *Agastrodrilus* sp. reportedly feeds upon other earthworms. Bengston *et al.* (1976) recorded that the predations of golden plover (*Pluvialus apricaria*) on worms in a hay field in Iceland brought down the prey population to less than 50% when grass cover was short.

ECOLOGY AND DISTRIBUTION OF EARTHWORMS

Earthworms are burrowing animals and form tunnels by literally eating their way through the soil. The distribution of earthworms in soil depends on factors like soil texture and aeration, temperature, moisture, availability of organic matter, pH of the soil, dung and litter. The reproductive potential and dispersive power of the species are important. Organic materials like humus, cattle dung and kitchen wastes are highly attractive sites for some species. Earthworms are generally absent or rare in soil with a very coarse texture, and high clay content, or soil with pH < 4 (Gunathilagaraj 1996). They are very sensitive to touch, light and dryness. Water-logging in the soil can cause them to come to the surface. Worms can tolerate a temperature range between 5 to 29°C. A temperature of 20 to 25°C and moisture of 50–60% is optimum for earthworm function (Hand 1988). Earthworms are very sensitive to hydrogen ion concentration. Many species of earthworms prefer soils with a pH of about 7. However, some like *Lumbricus terrestris* occurs in soil with a pH of 5.4 whereas *Megascolex* thrives well in soils with a pH ranging from 4.5 to 4.7. *E. foetida* dominates in the soils of pH 7 to 8. Some genera like *Dendrobaena exatedra* and *D. rutrida* are acid tolerant species and *Allolobophora caliginosa*, *A. nocturna*, *A. longa* and *A. rosea* are acid intolerant species. The temperate soils have higher percentage of earthworms which feed directly on organic matter and lower percentage of humus feeders. The Lumbricids and *P. posthuma* distributed all over the world are called peregrine.

Earthworms are invertebrates. There are nearly 3600 types of earthworms in the world and they are mainly divided into two types: (1) burrowing (2) non-burrowing. The burrowing types are *P. elongata* and *P. asiatica* live deep in the soil. On the other hand, the non-burrowing types *E. foetida* and *E. eugeniae* live in the upper layer of soil surface. The burrowing types are pale, 20 to 30 cm long and live for 15 years. The non-burrowing types are red or purple and 10 to 15 cm long but their life span is only 28 months. The non-burrowing earthworms eat 10% soil and 90% organic waste materials. They convert the organic waste into vermicompost faster than the burrowing earthworms. They can tolerate temperature ranging from 0 to 40°C but the regeneration capacity is more at 25 to 30°C and 40–45% moisture level in the pile.

According to Card *et al*. (2004) earthworms are classified into anecic, endogeic and epigeic categories.

Anecic (Greek for "out of the earth") – These are burrowing worms that come to the surface at night to drag food down into their permanent burrows deep within the mineral layers of the soil. They have long life cycle and are large in body size slightly pigmented at anterior and posterior ends. They are phytophagous in nature, e.g. *L. terrestris.*

Endogeic (Greek for "within the earth") – These are also burrowing worms but their burrows are typically more shallow and they feed on the organic matter already in the soil, so they come to the surface only rarely. They have intermediate life cycles with limited regenerative capacity and small to large in body size. They are geophagous, e.g. *Metaphire posthuma* and *Octochaetona thurstoni.*

Epigeic (Greek for "upon the earth") – These worms live in the surface litter and feed on decaying organic matter. They do not have permanent burrows. They are phytophagous, very small in size, very active and have high regenerative capacity within a short period of time. Normally they are richly pigmented worms. These "decomposers" are the type of worm used in vermicomposting. The commonly employed species in vermicomposting are *E. foetida*, *E. eugeniae* and *P. excavatus*.

VERMICULTURING

It is not very difficult to raise and maintain earthworms. They can be successfully raised in small containers filled with the suitable food material (organic material). The rainy season seems to be best for culturing them. Sufficient moisture and adequate organic residues are considered ideal for growth and multiplication. Within a period of about twelve months, under suitable conditions the multiplication may be 50 times greater. Vermiculture (derived from the Latin *vermis* meaning worm) involves the mass production of earthworms for waste degradation, and composting with 'vermicast' production. Earthworms feed on organic matter and utilize only a small amount for their body synthesis and excrete a large part of the consumed materials in a partially digested form as worm casts. The process involves physical/mechanical and biochemical activities. The physical and mechanical process includes mixing and grinding, whereas biochemical process includes microbial decomposition in the intestines of the earthworms. Feeding is required every 3–5 days in vigorously growing worm beds, with an optimal daily feeding rate of 0.75 kg feed/kg worm/day. Overfeeding must be avoided as it can lead to excessive fermentation in the bed and cause the worms to shrink and eventually die. In addition, overfeeding can attract mites, which compete with worms for food (Ndegwa *et al*. 1999). In vermiculturing and vermicomposting processes a leachate commonly known as vermiwash is obtained as a result of the constant application of water to maintain the substrate moisture in the range of 65–70%. The chemical composition of this leachate depends mainly on the chemical composition of the substrates used in vermiculturing and this can be used for agriculture purposes. Earthworms could be raised commercially for recycling biodegradable organic wastes, production of biofertilizers and animal protein for poultry and fish feed. The technology involved, in raising of earthworm is simple. It is possible to culture worms both indoor and outdoor depending upon local climatic conditions. Vermiculturing is feasible in suitable containers. A mixture of 1/3 soil and 2/3 organic matter is considered to be more useful in culture containers (Reynolds 1977). Kale (1986) carried out trials of various mixtures of organic matters to study the dietary influence on biomass and size of population *E. eugeniae.* Young worms fed upon a feed combination of cow dung and gram gained maximum population and dry weight bran. Various combinations of soil and organic matter have been tried for raising worms. The common organic substrates are decayed leaves, hay, straw, rice, wheat bran, cow dung, vegetable waste, poultry droppings, biogas, sludge etc. Indoors cultures are kept preferably in cool building at temperature between 10 to 15°C for *E. foetida* and 20°C for tropical species i.e. *E. eugeniae* and *P. excavatus.* Within a period of one year, if the cultures are properly maintained, the multiplication may be more than fifty times. First step in vermiculture is to select suitable feed material for earthworms. The nature of food and its availability and other physical parameters like temperature, light and moisture content, biological parameters like density, pressure, environmental conditions created by their own activity influence their growth and fecundity (Neuhauser *et al.* 1989).

Culturing of earthworms is done indoors in humid places with proper shelter to avoid direct sunlight or heavy down pour (Kale and Bano 1985). Earthworms can be cultured in wooden boxes, cement tanks, plastic trays or earthen pots with small holes at the bottom for discharge of excessive water to prevent water-logging and with a capacity to accommodate from 100 to 500 worms over a period of 6 to 8 weeks. At the bottom of the bed about 3–4 cm of moist coconut coir waste or saw dust is placed. Above that about 5–6 cm of cattle dung or poultry droppings or any other organic material is placed as feed material. The worms feed on partially degraded cattle dung and this allows a smooth transition to other organic waste subsequently placed on top. Water is regularly sprinkled to maintain the moisture content. The container is kept covered, preferably with a moist jute bag. This provides darkness for the worms and protects them from predators. It also retains moisture, maintains stability of temperature of the immediate environment, and also allows sufficient aeration. After the waste is degraded and converted into a loose, black, granular mass, the worms start aggregating at the base of the container. The upper layer of odourless compost is then removed and dried in the shade.

Earthworms feed on nitrogen rich organic wastes. They feed easily on partially degraded materials like cattle dung, primarily acted upon by microbes. The various categories of wastes are very effectively degraded and managed by the earthworms. These include kitchen wastes, garden waste, dairy farm wastes, sugar mill residues (pressed mud-cake, spoiled bagasse and trash), slaughterhouse wastes (residues such as the flesh, feathers and blood), distillery and hatchery wastes, municipal waste (all organic residues in municipal wastes including garbage and sewage sludge), etc.

VARIOUS APPLICATIONS OF EARTHWORMS

Organic manure and other agriculture organic wastes are important sources for maintenance of soil organic matter and to sustain soil productivity. In intensive livestock farming, there is a huge amount of animal excreta being generated. Proper utilization of these wastes can improve soil physical condition and environmental quality besides providing the nutrients for the plants (Mishra *et al.* 1989; Bhardwaj 1995; Sharma *et al.* 2005). Earthworms have been extensively used in the stabilization of urban, industrial and agricultural wastes. They can also be used in soil detoxification and vermicompost production (Gupta and Garg 2008). Different types of earthworms such as *E. foetida*, *E. andrei*, *L. terrestris*, *P. excavatus* and *E. eugeniae* have been used for the vermicomposting of different types of organic and industrial wastes. Earthworms accelerate the transformation of organic waste material into more stabilized form by aeration and bioturvation, by their excreta and qualitative or quantitative influence upon the telluric microflora (Suthar 2007b). The utility of epigeic earthworms for successful degradation of organic wastes is well documented for different industries such as paper and pulp (Elvira *et al.* 1997, 1998), dairy (Gratelly *et al.* 1996), sugar processing (Kale 1998; Reddy and Shantaram 2005), winery and distillery (Nogales *et al.* 2005), wood and wood chips (Maboeta and Van Rensburg 2003), textile mills (Kaushik and Garg 2004; Garg and Kaushik 2005), oil (Benitez *et al.* 2004) and power (fly ash) (Gupta *et al.* 2005). Muthukumaravel *et al.* (2008) studied the role of *Megascolex mauritii* in composting of vegetable waste along with cow dung and found encouraging results. However, compared to thermal composting, vermicomposting with earthworms often produces a product with a lower mass, lower processing time, humus content and more N content greater fertilizer value. Moreover vermicomposting also generates additional earthworms which can have other uses.

Therefore, vermicomposting seems to be more appropriate and an efficient technology to convert different types

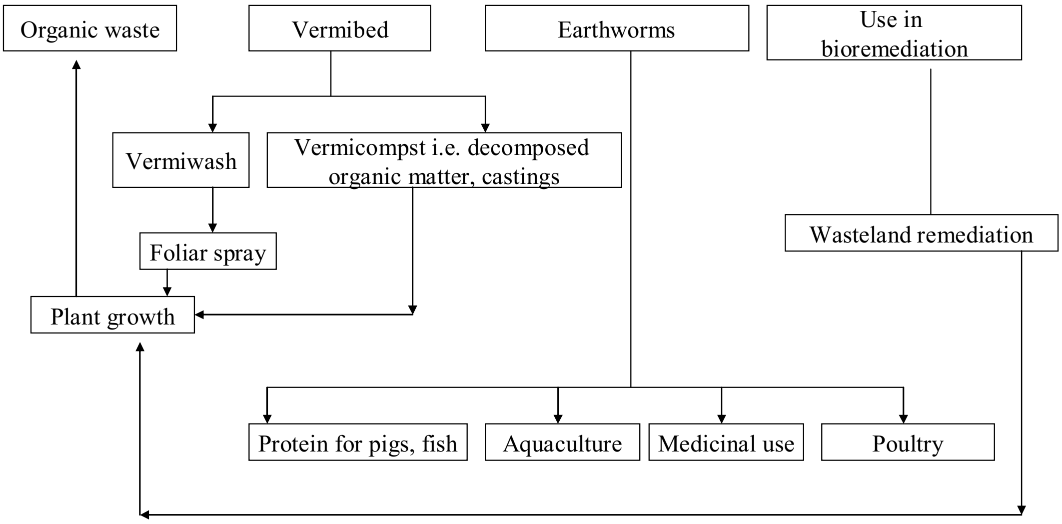

Fig. 2 Recycling of organic waste through vermitechnology.

of organic waste in to a valuable community resource at low input basis. Vermicompost application also suppresses the growth of many fungi, like *Pythium*, *Rhizoctonia* and *Verticillium*, etc. causing many diseases in plants (Hoitink and Fahy 1986). Sometimes it also controls the population of plant parasitic nematodes (Johnston *et al*. 1995; Arancon *et al*. 2006). Muscolo *et al*. (1999) have reported that vermicompost exhibits similar effects on growth and yield of plants as shown by soil-applied inorganic fertilizers or plant growth regulators or hormones.

Role of earthworms in vermicomposting

During vermicomposting, earthworms eat, grind, and digest organic wastes with the help of aerobic and some anaerobic micro flora, converting them into a much finer, humified, and microbially active material (**Fig. 2**). The generated product is stable and homogeneous, having desirable aesthetics such as reduced levels of contaminants (Ndegwa and Thompson 2001).

Environmental pollution problems originating from municipal solid waste (MSW) call for more sustainable waste management systems (Nass *et al* 1993). Solid waste is defined as the organic and inorganic waste materials produced by different sources and have lost value in the eye of their owner (Aalok *et al.* 2008). It has been estimated that India, as a whole, generates as much as 25 million tones of urban solid waste of diverse composition per year but per capita waste production in India is minisculous compared to the per capita production of wastes in the industrialized countries. It is estimated that the per capita waste generated in India is about 0.4 kg/day with the compostable matter approximately 50-60%. Management of solid waste has become one of the biggest problems we are facing today. The rapid increase in the volume of waste is one aspect of the environmental crisis, accompanying recent global development. Most common practices of waste processing are uncontrolled dumping which causes mainly water and soil pollution. Besides dumping or sanitary land filling, the final disposal of solid waste can be carried out by other methods like incineration and composting. Earthworm farming (vermiculture) is another bio-technique for converting the solid organic waste into compost (Ranganathan and Vinotha 1998).

1. Characteristics of earthworm species suitable for vermicomposting

The worm species to be utilized for vermicomposting should have high consumption, digestion, and assimilation rate. They should be efficient converter of plant or animal biomass to body proteins so that their growth rates are high. They should have wide adaptability to environmental factors (varying temperature conditions) and tolerance to disease, produce large number of cocoons, also cocoons should not have long hatching time so that multiplication and organic matter conversion is fast (Purohit and Gehlot 2006).

The rate of decomposition depends on the type of the waste material. If physical conditions are suitable then the number of earthworm's increase until the food becomes a limiting factor. It is generally known that the epigeic species *E. eugeniae*, *P. excavatus* and *E. foetida* have a potential as waste decomposers (Kale *et al.* 1982). Presently, California red hybrid *E. foetida* with a high production capacity and efficient processing of a wide range of organic materials is the main source for industrial vermicultural forms. At the same time, several other species apart from *E. foetida* (*Dendrobaena veneta* Rosa, *E. eugeniae* Kinberg, *Drawida willsi* Michaelsen, *L. mauritii* Kinberg, and *P. excavatus* Perrier) applicable for vermiculture have been found. Extending the range of species and search for new earthworm forms with valuable technological properties is substantiated by a relatively narrow temperature and humidity limits where *E. foetida* and other industrial species can maintain high activity (Barne and Striganova 2004). Earthworms of different species and ecological categories differ greatly in their ability to digest various organic residues. Several epigeic (*E. foetida*, *E. andrei*, *E. eugeniae*, *P. excavatus* and *P. sansibaricus*) and few anecic earthworms (*L. mauritii* and *L. terrestris*) have been identified as potential candidates to decompose organic waste materials (Garg and Kaushik 2005; Suthar 2007). As compared to epigeics, anecic (those that build semi-permanent vertical burrows in the substrate) earthworms show somewhat different patterns of biological activity in substrates, mainly due to their burrowing activity.

2. Genetic diversity of microbes in vermicomposting

In composting process, the importance of microbial communities is well established (Ryckeboer *et al.* 2003). The contribution of different microorganisms to various compost production phases have recently confirmed by using novel cultivation-independent techniques based on the direct analyses of phospholipids fatty acids (Vinceslas and Loquest 1997), quinolines (Tang *et al*. 2004), or the analyses of rRNA genes encoding for the small subunit ribosomal RNA (for bacteria, 16S rRNA) (Dees and Ghiorse 2001; Tebbe 2002). The vermicompost has been found to be mainly colonized by bacteria from the phyla Chloroflexi, Bacteroidetes and Gemmatimonadetes. In addition bacteria from the subclass Alphaproteobacteria and the phylum

Table 1 Earthworm species used for variety of substrate stabilization.

Earthworm species	Substrate	Reported by
Eudrilus eugeniae	Sago sludge	Banu *et al*. 2008
Lumbricus terrestris	Solid paper mill sludge	Butt 1990
Eisenia andrei	Paper-pulp mill sludge + primary sewage sludge	Elvira *et al*. 1996
Eisenia foetida	Textile mill sludge + cow dung and agricultural residues	Kaushik and Garg 2004
E. foetida	Aquaculture effluent sludge	Marsh *et al*. 2004
E. foetida	Livestock excreta	Garg *et al*. 2006
Perionyx excavatus, *Perionyx sansibaricus*	Cattle waste solids	Suthar 2008
E. foetida	Woodchip and sewage sludge	Maboeta and Rensburg 2003
Eudrilus eugeniae	Sago-sludge	Banu *et al*. 2008
E. foetida	Sugar mill sludge (press mud)	Sangwan *et al*. 2008
E. foetida	Sewage sludge	Vigueros *et al*. 2002
E. foetida	Fly ash	Gupta *et al*. 2005
E. foetida	Solid Waste (leather industries)	Ravindran *et al*. 2008
E. foetida, *E. andrei*	Spent mushroom compost	Tajbakhsh *et al*. 2006
Lumbricus rubellus	Coffee waste and kitchen waste	Adi and Noor 2009
E. foetida	Coffee pulp	Orozco *et al*. 2004
E. foetida	Biosolids (textile industries)	Contreras *et al*. 2005

Table 2 Composition of nutrient elements of vermicompost (Arancon *et al*. 2005).

Type of compost	N (%)	P (%)	K (%)	B (μg/g)	Ca (μg/g)	Fe (μg/g)	Mg (μg/g)	Mn (μg/g)	Na (μg/g)	S (μg/g)	Zn (μg/g)
Food waste vermicompost	1.3	2.7	9.2	23	18614	23264	4364	610	842	2587	279
Cow manure vermicompost	1.9	4.7	1.4	58	23245	3454	5802	160	3360	5524	516
Paper waste vermicompost	1.0	1.4	6.2	31	9214	17811	7661	447	613	1929	127
Biosolids compost	1.7	1.8	6.4	33	27965	7714	7185	364	930.0	6291	1281
Yard waste compost	0.5	1.8	6.6	50	89207	9031	21229	324	121	2860	120

Acidobacteria have been detected in vermicompost. The most striking difference between compost and vermicompost was that the 16S rRNA sequences from vermicompost were mainly related to yet-uncultured bacteria (83% of 23 sequences), whereas for the compost, this percentage was much lower (24%). Quantitatively higher diversity of microbes detected in vermicompost probably correlates well with a higher functional diversity that is caused by earthworm activities, i.e. digging and feeding. These perturbations modify the physico-chemical conditions and increase the number of microhabitats during the vermicompost process (Dominguez *et al*. 1997). Bacterial diversity measurements can only be acceptable indicators for a product quality in the future if the bacterial communities developing in the same products are consistent and stable during subsequent storage of the materials until use (Fracchia and Dohrmann 2006).

3. Vermicomposting of various types of substrates

Disposal of industrial sludge by environmentally acceptable means poses a very great challenge worldwide. Vermistabilization of different types of solid wastes including sludge can be achieved by using epigeic earthworms in the composting process with production of a better quality of compost as compared with those prepared through traditional composting methods (Neuhauser *et al*. 1988; Elvira *et al.* 1998; Masciandaro *et al.* 2002; Adi and Noor 2009). Suthar and Sushma (2008) stabilized the distillery industry sludge by mixing it with cow dung in different proportions which resulted in decrease in pH, organic C contents, and an increase in total N, available P, exchangeable K, Ca and Mg contents. Suthar (2009) amended vegetable solid waste with wheat straw, cow dung and biogas slurry converted them in to vermicompost using earthworm *E. foetida*. The vermicomposting caused a decrease in organic C and C: N ratio, while increase in total N, available P, and exchangeable K contents. Different types of organic waste vermicomposted by various species of earthworm are given in **Table 1**. Mitchell (1978) demonstrated that aerobic sewage sludge can be ingested by *E. foetida* and the sludge is decomposed and stabilized about 3 times faster than non-ingested sludge. Contreras-Ramos *et al*. (2005) reported that vermicomposting of sewage sludge with *E. foetida* resulted in reduction of *Salmonella* spp., faecal coliform, *Shigella* spp. and helminthes eggs. Bacterial communities and chitinase gene diversity of vermicompost were investigated by Yasir *et al.* (2009) to clarify the influence of earthworms on the inhibition of plant pathogenic fungi in vermicompost. The spore germination of *Fusarium moniliforme* was reduced in vermicompost aqueous extracts prepared from paper sludge and dairy sludge.

4. Characteristics of vermicompost

The quality of composts depends on several factors *viz.* type of substrate (organic residues), aeration, humidity, pH, temperature, and the earthworm species used during vermicomposting. Some workers have reported higher content of NPK and micronutrients in vermicompost (Jambhekar 1992; Ramanathan and Parthasarthi 1999; Bansal and Kapoor 2000), while some have reported similar nutrient content in the vermicompost and ordinary compost (Nedgwa and Thompson 2001). The vermicompost has been reported with a higher base exchange capacity and is rich in total organic matter, phosphorus, potassium and other nutrients. It is also known to enhance the degree of polymerisation of humic substances along with a decrease of ammonium N and increase of nitric N and total nitrogen (Bansal and Kapoor 2000).

Table 2 shows the composition of nutrient elements of vermicomposts generated from different substrates. Liming in vermicompost generally enhance microbial population as well as earthworm activities.

Earthworms consume various organic wastes and reduce the volume by 40–60%. The castings produced by the earthworms have been analyzed for chemical and biological properties. The moisture content of castings ranges between 32 and 66% and the pH is around 7.0. The worm castings have been reported to contain higher percentage (nearly two fold) of both macro and micronutrients than the garden compost**.** Nutrient composition of vermicompost and garden compost are shown in **Table 3**.

The greater nitrate availability in casts than the soil may be due to the mineralization of relatively nitrogen rich lucerne mixed in to the casts followed by the subsequent nitrification of the released ammonia (Hoitink and Fay 1986). The vermicompost contains humified organic matter

Table 3 Nutrient composition of vermicompost and garden compost (Nagavallemma *et al.* 2004).

Nutrient element	Vermicompost (%)	Garden compost (%)
Organic carbon	9.8-13.4	12.2
Nitrogen	0.51-1.61	0.8
Phosphorus	0.19-1.02	0.35
Potassium	0.15-0.73	0.48
Calcium	1.18-7.61	2.27
Magnesium	0.093-0.568	0.57
Sodium	0.058-0.158	<0.01
Zinc	0.0042-0.110	0.0012
Copper	0.0026-0.0048	0.0017
Iron	0.2050-1.3313	1.1690
Manganese	0.0105-0.2038	0.0414

Table 4 Physio-chemical characteristics of vermiwash (Purohit and Gehlot 2006).

Parameter	Conc. (ppm)
pH	6.90
Dissolved oxygen	1.14
Chloride	110.00
Alkalinity	70.00
Sulphates	177.00
Inorganic phosphate	50.9
Ammonical nitrogen	Below detectable limit
Potassium	69.00
Sodium	122.00
Total hardness	375.00
Calcium hardness	175.00
Magnesium hardness	200.00
BOD	4.60
COD	97.00

characterized by high molecular weight and an enzyme catalysed humic fraction which stimulates plant germination and growth (Macay and Gregg 1986). The fertilizer value of earthworm castings and beneficial effects on crops have been attributed to the presence of active mineral nutrients (Edwards 1988) and plant growth regulators with phytohormonal action. Humic substances have been found to possess phytohormonal properties which influence both growth of roots and shoots (Suthar 2007c).

5. Vermiwash

Vermiwash is a transparent pale yellow liquid biofertilizer. It is a mixture of excretory products and mucous secretion of earthworms (e.g. *L. mauritii* and *E. foetida*) and plant micronutrients. It may be promoted as a potent biofertilizer for better growth and yield of plants. Vermiwash is found to contain a number of enzymes *viz*. proteases, amylase, urease and phosphatase (Zambare *et al*. 2008), soluble plant nutrients (**Table 4**), organic acids and mucus of earthworms and microbes (Shivsubramanian and Ganeshkumar 2004). It has been found to be very effective on several plant species such as spinach (*Spinacia oleracea*), onion (*Allium cepa*) and potato (*Solanum tuberosum*) (Ansari 2008), and hence can be used as foliar spray, biofertilizer and biopesticide. If need be vermiwash may be mixed with cow's urine and diluted (1 l of vermiwash, 1 l of cow's urine and 8 l of water) and sprayed on plants to function as an effective foliar spray and pesticide. It has also been found to develop resistance in crops. Gulsar and IIyer (2006) have found nematicidal effect of vermiwash on plants.

Role of earthworm in improving soil fertility

Earthworms play an important role in improving soil fertility. They promote soil fragmentation and aeration and bring about soil turning and dispersion. Earthworms host millions of beneficial microbes (including the nitrogen fixers) in their gut and excrete them in soil along with nutrients N and P in their excreta (Singleton *et al*. 2003). The presence of earthworms also reduces 'soil salinity' and neutralizes pH of soil (Sinha *et al.* 2008). Application of vermicompost increases the total microbial population of N-fixing bacteria and actinomycetes (Alam *et al.* 2007)

Vermi-castings of earthworms containing enzymes like amylase, lipase, cellulase and chitinase etc 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 (Sinha *et al*. 2002). Benitez *et al.* (2004) reported the presence of β-glucosidase, phosphatase and urease from lignocellulytic vermicompost. Several experiments have demonstrated that vermicompost contains plant growth regulating materials including plant growth hormones and humic acids which are probably responsible for the increased germination, growth and yields of plants (Atiyeh *et al*. 2002, 2006b, 2005, 2008). Vermicomposting increases humic acids content and acid phosphatase activity in organic substrates and microbial inoculation further enhances the rate of humification and enzyme activity (Pramanik *et al.* 2009). Bachman and Metzger (2008) reported enhanced shoot and root weight, leaf area, and shoot:root ratios of both tomato and marigold when they incorporated of vermicompost of pig manure into germination media.

Role of earthworms in bioremediation

Modern agricultural practices have resulted in an increasing impact on environment, causing a serious decline in the natural resources. The land bioreclamation deals with processes related to the action of living organisms. The biological methods in land reclamation improve fertility on a sustainable basis.

Earthworms in general are tolerant to many chemical contaminants including heavy metals and organic pollutants in soil and can bio-accumulate them in their tissues. Earthworms species like *E. foetida*, *E. tetraedra*, *L. terrestris*, *L. rubellus* and *A. chlorotica* have been found to remove heavy metals (Cd, Pb, Cu, Hg, etc.) pesticides and lipophilic organic micropollutants like polycyclic aromatic hydrocarbons (PAH) from the soil (Sinha *et al.* 2008). Vermiremediation may prove to be a very cost-effective and environmentally acceptable way to treat polluted soils and sites contaminated with different types of pollutants.

1. Heavy metal

Heavy metal in the sewage sludge is of great concern to the public health. Heavy metals are those metals that have density > 5-6 g/cm^3 (Wild 1993). The heavy metal content in the sewage sludge depends greatly on the type of industry. In general municipal sludge is high in Al, Fe, Zn, Cu and Cr content. Certain species of earthworms such as *E. foetida*, *Aporrectodea tuberculata*, *L. terrestris*, *L. rubellus*, *Dendrobaena rubida*, *D. veneta*, *Eiseniella tetraedra* and *A. chlorotica* have been found to remove heavy metals, pesticides and lipophilic organic micro pollutants like polycyclic aromatic hydrocarbons (PAH) from the soil (Contreras-Ramos *et al*. 2005). Malley *et al*. (2006) measured bioaccumulation of copper (Cu) and zinc (Zn) in *E. foetida* after 10 weeks of experiment.

It is well known that earthworm can raise the level of plant nutrient availability (Tripathi and Bhardwaj 2004) as well as pH in the soil (Salmon 2001; Cheng and Wong 2002) which may lead to less availability of heavy metals. As a consequence, earthworm community is important in reducing soluble and mobile forms of heavy metals in soils.

Some species of earthworms are known to be potential accumulators of heavy metals and therefore they have been successfully demonstrated in mitigating the toxicity of industrial and municipal waste by vermicomposting technology (Saxena *et al*. 1998). Native species are also well adapted to local conditions (Goswami and Kalita 2000). *L. mauritii* is well equipped to metabolize electrophilic xenobiotics and thus get easily adapted to metal (Pb and Zn) stressed environment. Elvira *et al.* (1996) studied the efficiency of *E. andrei* in bio-converting paper–pulp mill sludge mixed with primary sewage sludge. Earthworms *L. terrestris* and *E. foetida* were shown to induce higher microbial activity and oil degradation (Schaefer *et al*. 2005). In addition, the earthworm *E. foetida* has been used as a test organism for different contaminants. Several reports indicate that *E. foetida* tolerates 1.5% crude oil while *L. terrestris* did not survive 0.5% of it (Safwat *et al*. 2002).The use of *E foetida* increases the PAH removal (Contreras-Ramos *et al*. 2006). Vermifiltration of wastewater using waste eater earthworms is a newly conceived novel technology. Earthworms' bodies work as a 'biofilter' and they have been found to remove the 5 days' BOD (BOD5) by 90%, COD by 80–90%, total dissolved solids (TDS) by 90–92%, and total suspended solids (TSS) by 90–95% from wastewater by the general mechanism of 'ingestion' and biodegradation of organic wastes, heavy metals, and solids from wastewater and also by their 'absorption' through body walls (Sinha *et al*. 2008). Earthworms collected from the roadsides and mining sites show higher amounts of heavy metals than those from the other sites and hence can be a 'bioindicator' of heavy metal contamination in soil.

2. Distillery waste

Distillery is an important sub-unit of sugar production industry. Studies have revealed that vermicomposting could be an appropriate technology to convert energy rich organic wastes to value-added products. It has been demonstrated that *E. eugeniae* can breakdown the waste generated from distilleries when mixed with other potting materials (Elvira *et al*. 1998; Kale 1998; Suthar 2006). Appreciable results during vermicomposting of distillery sludge mixed with press mud, water hyacinth, plant litter, and cow dung in different proportions have been reported (Suthar 2006).

3. Fly ash

Fly ash is the fine residue captured from flue exhausts when coal is burnt in power stations. With the consistently increasing number of coal-fired plants, the large-scale generation of fly ash is creating acute waste disposal problems in different parts of the world. To overcome this, various possible methods for the safe disposal and reuse of fly ash have been envisaged by different researchers, of which the composting process has received a particular interest (Bhattacharya and Chattopadhyay 2002; Venkatesh and Eevera 2008). Moreover, co-composting of sewage sludge and coal fly ash has been an effective way to transform the fly ash into nutrient-rich product (Fang *et al*. 1999). However, as the availability of many nutrients is very low in fly ash, available ranges of such nutrients must be improved to increase the effectiveness of fly ash as a soil amendment. Bhattacharya and Chattopadhyay (2002) used fly ash with organic matter in the form of cow dung at 1: 3, 1: 1 and 3: 1 ratios and incubated it with epigeic earthworm (*E. foetida*) for 50 d. Venkatesh and Eevera (2008) mixed fly ash with cow dung at 1: 3, 1: 1, and 3: 1 ratios and incubated with *E. eugeniae* for 60 days. The concentration of macro and micronutrient was found to increase in the earthworm-treated series of fly ash and cow dung combinations compared with the fly ash alone. The concentration of phosphate-solubilizing bacteria (PSB) was found to increase many fold and organic matter transformed considerable amounts of insoluble P from fly ash into more soluble forms. Also easily mineralizable NH_4^+ and NO_3^- tended to increase considerably in the treatment with earthworms (Bhattacharya 2004). Adoption of vermicomposting technology, which involves the degradation of organic materials with the help of earthworms, has been found to enhance the solubility of different major nutrients in fly ash. In addition the increased activities of different microorganisms in earthworm intestines increase the more solubility of nutrients (Bhattacharya and Chattopadhyay 2002).

4. Press mud

Press mud has significant fertilizer value as it is a rich source of organic matter, organic carbon, sugar, protein, enzymes, macronutrients (N, P and K), micronutrients (Zn, Fe, Cu, Mn, etc.) and microbes (Ranganathan and Parthasarathi 1999; Sangwan *et al.* 2008). Although press mud has significant fertilizer value but due to prohibitive cost of sludge disposal, it is dumped in open where it adversely affects environment. The management and nutrient recovery from press mud has been attempted by vermicomposting after mixing it with biogas plant slurry in appropriate quantities. Moisture plays a crucial role in vermicomposting of press mud. More and better worm biomass, cocoon production, hatchling number and rate of compost recovery were found in the 65-67% moisture (Parthasarathi 2007). The final product was nutrient rich, odour free, more mature and stabilized. The results showed that carbon content was decreased during the process and nitrogen content was enhanced (Parthasarathi 1999).

5. Bioaccumulation of pesticides

Earthworms in general are highly resistant to many pesticides and have been reported to concentrate the pesticides and heavy metals in their tissues. They also inhibit the soil borne pathogens and work as a detoxifying agent for polluted soil (Davis 1971; Ireland 1983). Earthworms can remove hydrocarbons and many other chemicals from contaminated soil, even benzo(a)pyrene, which is a PAH very resistant to degradation (Contreras-Ramos *et al*. 2006). A study showed that after only one application of the relatively persistent pesticide aldrin to soil, more than 34% was found to be present in the soil 5 years later. Several studies have revealed that earthworms can either accumulate or degrade 'organochlorine pesticide' and 'polycyclic aromatic hydrocarbons' (PAHs) residues in the medium in which they feed (Ireland 1983). Sinha *et al*. (2008a) showed that, nearly 80% (60–65% if the dilution factor is taken into account) of seven important PAHs were removed in just 12 weeks with a loading rate of about 50 worms per kg of soil. Vermiremediation leads to significant improvement in the quality of soil and land where they inhabit. During the vermiremediation process of soil, the population of earthworms increases significantly benefiting the soil in several ways.

Earthworm as a source of protein for poultry and fish feed

Earthworms rich in protein can be used to feed chickens, pigs, rabbits, and as a dietary supplement for aquarium fish *Poecilia reticulata*. Vermicompost is hazard free organic manure, which improves quality of pond base and overlying water (Chakrabarty 2008) as well as provides organically produced aqua crops. Common nutrient analysis showed that *E. foetida* meal has high protein content in the range of 54.6 to 71.0% dry matter. Casts of *E. foetida* had a protein content of 7.9% dry matter, which is similar to that of corn meal and hence worm casts could be used for partial replacement of corn meal or wheat bran in animal diets. Worm body fluid has been reported to be rich in protein (9.4%), vitamins and minerals, particularly iron. With proper management of vermiculture, the worm protein can supplement fish meal and the demand for animal protein can be studied (Gurrero 1983; Kale 1986; Nandeesha *et al.* 1988). There are also reports of worms being eaten by Maoris of New Zealand and native of New Guinea (Edwards and Lofty 1977).

Medicinal importance of earthworms

Earthworms have been used in Chinese medicine as an aphrodisiac and fertility treatment. Research is being done on earthworms' anti-inflammatory properties for treating arthritis and other joint ailments. Chen *et al*. (2007) isolated G-90 (a glycolipoprotein mixture) and fibrinolytic enzyme from the tissue homogenate of earthworm *E. foetida* (Annelida, Lumbricidae) which exhibited pleiotropic biological functions and anti-tumor activity, respectively. Earthworms have been used as anticoagulant and N fibrinolytic medicines in East Asia for several thousands of years (Mihara *et al*. 1991). According to the concepts of traditional Chinese medicine, earthworm is associated with the bladder, liver, lung and spleen meridians, and has salty and cold properties. It drains liver heat and clears lung heat, and can also clear heat in the collateral channels (Zhang *et al*. 2000). Typically earthworm is used with other herbs to treat a wide range of conditions, ranging from spasms and convulsions to pain relief, treatment of fevers and certain types of arthritis. It is also used to treat some types of asthma and bronchitis. Earthworm protein and its coelomic fluid were reported to exhibit cytolytic, agglutinating, proteolytic, haemolytic, mitogenic, tumor static and antibacterial activities (Edwards and Bohlen 1996; Popovi *et al*. 2001; Cooper 2005). Further extracts from the earthworm in different solvents were studied in carrageenin-induced oedema and cotton pellet granuloma in rats and showed anti-inflammatory property (Yegnanarayan *et al.* 1988). Very recently Prakash *et al.* (2007) and Balamurugan *et al.* (2007) have reported the anti-ulceral, anti-oxidative and antipyretic properties of earthworm *L. mauritii*. Traditional medicine practitioners in Tamilnadu (India) use the earthworm, in its decoction form, to treat fever, stomach pain, neck pain, neural disorders and digestive disorders (Balamurugan *et al.* 2007). However there are no scientific data available to prove the claim of the traditional medicine practitioners about the medicinal effectiveness of earthworms.

EARTHWORMS' INTERACTION WITH MICRO FLORA

Vermicomposting is an effective biological process for conversion of agro-industry residues into a stable end product, wherein microbial activity plays an essential role. Earthworms are mainly responsible for fragmentation and conditioning of the substrate, increasing surface area for microbial activity and significantly altering biological activity of the process (Domínguez *et al.* 2002). However, the role of earthworms in influencing the microbial community at functional and genetic level is still not well understood. Researchers have evaluated the effect of gut transit on the microbial population, biomass and enzyme activities of different organic residues (Zhang *et al.* 2000; Scheu *et al.* 2002; Aira *et al.* 2006) and Albanell *et al*. (1988) showed that earthworms can modify physiology of microbial community and trigger enzyme activities during vermicomposting of pig slurry.

Earthworms are considered ecosystem engineers (Lavelle *et al.* 1997) because they affect the physicochemical and biological properties of the soils that they inhabit through their activities such as casting and burrowing (Lavelle *et al.* 1997). Microbial biomass and respiration are greater in earthworm casts than in the parent soil (Zhang and Hendrix 1995). However, microorganisms may constitute an important part of the diet of earthworms, which can feed on them selectively (Edwards 2004). Some microorganisms are digested in their gut while others proliferate. An increase in culturable microorganisms in the gut of *L. terrestris* and *L. rubellus* has been reported (Fisher *et al*. 1995). The efficiency of vermicomposting may therefore, depend on number and types of microorganisms in the substrate (Hand *et al.* 1988). The increase in dehydrogenase activity at the 15 day sampling indicated increased microbial activity during vermicomposting of crop residue and cattle dung (Abbasi and Ramasamy 1999). Inoculation of nitrogen fixing bacteria namely *Azotobacter*, *Azospirillum* in vermicompost increased the contents of N and P. Enriching vermicompost with rock phosphate improved significantly the available P when inoculated with *Penicillum striata.* The inoculation of consortium of microorganisms *Aspergillus niger*, *P. sajor-caju*, *Azotobacter chroococum*, *Trichoderma harzianum* not only accelerated vermicomposting of crop residues and farm yard manure but also enriched the quality of product (Singh and Sharma 2002). During the incubation period the inoculated bacterial strains proliferated rapidly, fixed nitrogen and solubilised added and native phosphate (Kumar and Singh 2000). *E fetida* appears to be able to destroy human pathogens as well as non pathogenic microflora (Flack and Hartenstein 1984). Preliminary studies showed that human pathogens do not survive during vermicomposting (Domínguez 1997).

Vermicomposting is thus an enhanced form of composting (i.e. bioaugumented composting) which is cheaper as it does not require expensive physical /mechanical unit process associated with traditional microbial composting process (Hand *et al.* 1988a). Combining vermicomposting with existing composting operations can also accelerate stabilization compared to composting alone (Ndegwa and Thompson 2001). A combination of aerobic composting and vermicomposting has been proved to enhance the value of final product (Graziano and Casalicchio 1987) and the product also met the pathogen reduction requirements (Ndegwa and Thompson 2001). Frederickson and Knight (1988) have demonstrated that vermiculture and anaerobic system can be combined to enhance organic matter stabilization. Recently, Frederickson *et al.* (1997) showed that the vermicomposting of 2 week pre-decomposed yard waste reduced the volatile solid content significantly in 8 weeks, over the waste, which were not subjected to vermicompsting. To ensure that vermicomposting system operates at maximum efficiency, pre decomposition should be kept to minimum (Frederickson *et al.* 1997). Few studies have tested the influence of vermicomposts on arbuscular mycorrhiza. Kale *et al*. (1987) reported an increase in AMF colonization in *Salvia* and *Aster* roots growing in a garden soil mixture amended with vermicompost. Domínguez *et al.* (2002) studied the effect of the earthworm, *E. andrei*, on the nematode community and on the microbial activity during the vermicomposting of two organic wastes, cow manure and sewage sludge. Nematode abundance was dramatically affected by earthworm activity.

Singh and Sharma (2002) reported that earthworm growth rate was greatest in treatment with *A. flavus*. Doube and Brown (1992) concluded that the capability of earthworms to digest organic residues is minimal. They obtain their nutrients from the microorganisms associated with the ingested substrate. Further it has been demonstrated that the earthworm *L. terrestris* is able to alter the composition of the ingested microbiota, modifying both the bacterial and fungal communities of soils via casting (Egert *et al*. 2004). However on the other hand, there are reports stating that the types of microorganisms found in the castings are similar to those found in surrounding soil.

CONCLUSIONS

Management of solid waste has become one of the biggest problems we are facing today. Vermicomposting provides an alternative approach in waste management. A variety of organic solid wastes viz. domestic, animal, agro-industrial, human wastes, etc. can be vermicomposted and converted in to useful products, like earthworm biomass and vermicompost. Earthworm biomass generated could also be of great importance for various applications. Mass culturing and maintaining worm cultures and trapping of wastes not only for their maintenance but also getting quality product in form of vermicompost has a good scope as cottage industries for developing countries. Considering the potential of this technology for various applications beside enriching the soils and in turn increase of crop yield, there is much scope to expand vermiculture and vermicomposting in third world countries which still sustain on traditional organic farming. Overall, the widespread use of vermitechnology could result in increased employment opportunity and rapid development of the rural areas.

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