Vermicomposting: Recycling Wastes into Valuable Organic Fertilizer

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Background

Environmental degradation is a major threat confronting the world, and the rampant use of chemical fertilizers contributes largely to the deterioration of the environment through depletion of fossil fuels, generation of carbon dioxide (CO_2) and contamination of water resources. It leads to loss of soil fertility due to imbalanced use of fertilizers that has adversely impacted agricultural productivity and causes soil degradation. Now there is a growing realization that the adoption of ecological and sustainable farming practices can only reverse the declining trend in the global productivity and environment protection (Aveyard 1988, Wani and Lee 1992, Wani et al. 1995).

On one hand tropical soils are deficient in all necessary plant nutrients and on the other hand large quantities of such nutrients contained in domestic wastes and agricultural byproducts are wasted. It is estimated that in cities and rural areas of India nearly 700 million t organic waste is generated annually which is either burned or land filled (Bhiday 1994). Such large quantities of organic wastes generated also pose a problem for safe disposal. Most of these organic residues are burned currently or used as land fillings. In nature's laboratory there are a number of organisms (micro and macro) that have the ability to convert organic waste into valuable resources containing plant nutrients and organic matter, which are critical for maintaining soil productivity. Microorganisms and earthworms are important biological organisms helping nature to maintain nutrient flows from one system to another and also minimize environmental degradation. The earthworm population is about 8–10 times higher in uncultivated area. This clearly indicates that earthworm population decreases with soil degradation and thus can be used as a sensitive indicator of soil degradation. In this report a simple biotechnological process, which could provide a 'win-win' solution to tackle the problem of safe disposal of waste as well as the most needed plant nutrients for sustainable productivity is described (Wani 2002).

What is Vermicomposting?

Vermicomposting is a simple biotechnological process of composting, in which certain species of earthworms are used to enhance the process of waste conversion and produce a better end product. Vermicomposting differs from composting in several ways (Gandhi et al. 1997). It is a mesophilic process, utilizing microorganisms and earthworms that are active at 10–32°C (not ambient temperature but temperature within the pile of moist organic material). The process is faster than composting; because the material passes through the earthworm gut, a significant but not yet fully understood transformation takes place, whereby the resulting earthworm castings (worm manure) are rich in microbial activity and plant growth regulators, and fortified with pest repellence attributes as well! In short, earthworms, through a type of biological alchemy, are capable of transforming garbage into 'gold' (Vermi Co 2001, Tara Crescent 2003).

Importance of vermicompost

Source of plant nutrients

Earthworms consume various organic wastes and reduce the volume by 40–60%. Each earthworm weighs about 0.5 to 0.6 g, eats waste equivalent to its body weight and produces cast equivalent to about 50% of the waste it consumes in a day. These worm castings 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 contain higher percentage (nearly twofold) of both macro and micronutrients than the garden compost (Table 1).

Table 1. Nutrient composition of vermicompost and garden compost.

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

From earlier studies also it is evident that vermicompost provides all nutrients in readily available form and also enhances uptake of nutrients by plants. Sreenivas et al. (2000) studied the integrated effect of application of fertilizer and vermicompost on soil available nitrozen (N) and uptake of ridge gourd (*Luffa acutangula*) at Rajendranagar, Andhra Pradesh, India. Soil available N increased significantly with increasing levels of vermicompost and highest N uptake was obtained at 50% of the recommended fertilizer rate plus 10 t ha^{-1} vermicompost. Similarly, the uptake of N, phosphorus (P), potassium (K) and magnesium (Mg) by rice (*Oryza sativa*) plant was highest when fertilizer was applied in combination with vermicompost (Jadhav et al. 1997).

Plant growth promoting activity

Growth promoting activity of vermicompost was tested using a plant bioassay method. The plumule length of maize (*Zea mays*) seedling was measured 48 h after soaking in vermicompost water and in normal water. The marked difference in plumule length of maize seedlings indicated that plant growth promoting hormones are present in vermicompost (Table 2).

Table 2. Plumule length of maize seedlings.

Treatment	Initial length (cm)	Final length (cm)
Tank water	16.5	16.6
Vermicompost water	17.6	18.6

Improved crop growth and yield

Vermicompost plays a major role in improving growth and yield of different field crops, vegetables, flower and fruit crops. The application of vermicompost gave higher germination (93%) of mung bean (*Vigna radiata*) compared to the control (84%). Further, the growth and yield of mung bean was also significantly higher with vermicompost application. Likewise, in another pot experiment, the fresh and dry matter yields of cowpea (*Vigna unguiculata*) were higher when soil was amended with vermicompost than with biodigested slurry (Karmegam et al. 1999, Karmegam and Daniel 2000).

The efficiency of vermicompost was evaluated in a field study by Desai et al. (1999). They stated that the application of vermicompost along with fertilizer N gave higher dry matter (16.2 g plant^{-1}) and grain yield (3.6 t ha^{-1}) of wheat (*Triticum aestivum*) and higher dry matter yield (0.66 g plant^{-1}) of the following coriander (C*oriandrum sativum*) crop in sequential cropping system. Similarly, a positive response was obtained with the application of vermicompost to other field crops such as sorghum (*Sorghum bicolor*) (Patil and Sheelavantar 2000) and sunflower (*Helianthus annuus*) (Devi and Agarwal 1998, Devi et al. 1998).

Application of vermicompost at 5 t ha^{-1} significantly increased yield of tomato (*Lycopersicon esculentum*) (5.8 t ha^{-1}) in farmers' fields in Adarsha watershed, Kothapally, Andhra Pradesh compared to control (3.5 t ha^{-1}). Similarly, greenhouse studies at Ohio State University in Columbus, Ohio, USA have indicated that vermicompost enhances transplant growth rate of vegetables. Amendment of vermicompost with a transplant grown without vermicompost had the highest amount of red marketable fruit at harvest. In addition, there were no symptoms of early blight lesions on the fruit at harvest. The yield of pea (*Pisum sativum*) was also higher with the application of vermicompost (10 t ha^{-1}) along with recommended N, P and K than with these fertilizers alone (Reddy et al. 1998). Vadiraj et al. (1998) reported that application of vermicompost produced herbage yields of coriander cultivars that were comparable to those obtained with chemical fertilizers.

The fresh weight of flowers such as C*hrysanthemum chinensis* increased with the application of different levels of vermicompost. Also, the number of flowers per plant (26), flower diameter (6 cm) and yield (0.5 t ha^{-1}) were maximum with the application of 10 t ha^{-1} of vermicompost along with 50% of recommended dose of NPK fertilizer. However, the vase life of flowers (11 days) was high with the combined application of vermicompost at 15 t ha^{-1} and 50% of recommended dose of NPK fertilizer (Nethra et al. 1999).

Reduction in soil C:N ratio

Vermicomposting converts household waste into compost within 30 days, reduces the C:N ratio and retains more N than the traditional methods of preparing composts (Gandhi et al. 1997). The C:N ratio of the unprocessed olive cake, vermicomposted olive cake and manure were 42, 29 and 11, respectively. Both the unprocessed olive cake and vermicomposted olive cake immobilized soil N throughout the study duration of 91 days. Cattle manure mineralized an appreciable amount of N during the study. The prolonged immobilization of soil N by the vermicomposted olive cake was attributed to the C:N ratio of 29 and to the recalcitrant nature of its C and N composition. The results suggest that for use of vermicomposted dry olive cake as an organic soil amendment, the management of vermicomposting process should be so adjusted as to ensure more favorable N mineralization-immobilization (Thompson and Nogales 1999).

Role in nitrogen cycle

Earthworms play an important role in the recycling of N in different agroecosystems, especially under *jhum* (shifting cultivation) where the use of agrochemicals is minimal. Bhadauria and Ramakrishnan (1996) reported that during the fallow period intervening between two crops at the same site in 5- to 15-year *jhum* system, earthworms participated in N cycle through cast-egestion, mucus production and dead tissue decomposition. Soil N losses were more pronounced over a period of 15-year *jhum* system. The total soil N made available for plant uptake was higher than the total input of N to the soil through the addition of slashed vegetation, inorganic and organic manure, recycled crop residues and weeds.

Improved soil physical, chemical and biological properties

Limited studies on vermicompost indicate that it increases macropore space ranging from 50 to 500 μm, resulting in improved air-water relationship in the soil which favorably affect plant growth (Marinari et al. 2000). The application of organic matter including vermicompost favorably affects soil pH, microbial population and soil enzyme activities (Maheswarappa et al. 1999). It also reduces the proportion of water-soluble chemical species, which cause possible environmental contamination (Mitchell and Edwards 1997).

Types of earthworms

Earthworms are invertebrates. There are nearly 3600 types of earthworms in the world and they are mainly divided into two types: (1) burrowing; and (2) non-burrowing. The burrowing types *Pertima elongata* and *Pertima asiatica* live deep in the soil. On the other hand, the non-burrowing types *Eisenia fetida* and *Eudrilus eugenae* 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; these convert the organic waste into vermicompost faster than the burrowing earthworms. They can tolerate temperatures 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. The burrowing type of earthworms come onto the soil surface only at night. These make holes in the soil up to a depth of 3.5 m and produce 5.6 kg casts by ingesting 90% soil and 10% organic waste.

Earthworm multiplication

Numerous organic materials have been evaluated for growth and reproduction of earthworms as these materials directly affect the efficacy of vermicompost. Nogales et al. (1999) evaluated the suitability of dry olive cake, municipal biosolids and cattle manure as substrates for vermicomposting. They reported that larger weights of newly hatched earthworms were obtained in substrate containing dry olive cake. In another study, maize straw was found to be the most suitable feed material compared to soybean (*Glycine max*) straw, wheat straw, chickpea (C*icer arientinum*) straw and city refuse for the tropical epigeic earthworm, *Perionyx excavatus* (Manna et al. 1997).

Zajonc and Sidor (1990) evaluated and compared various non-standard materials for the preparation of vermicompost. A mixture of cotton waste with cattle manure in the ratio of 1:5 was found to be the best. The use of grape cake alone increased earthworm weight slightly. Tobacco (*Nicotiana tabacum*) waste, used as substrate, increased earthworm weight but the earthworms failed to reproduce. A mixture of tobacco waste with rabbit manure in the ratio of 1:5 was found to be lethal to the earthworms.

A multiplication trial was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh with three kinds of earthworm cultures (*Eisenia fetida*, *Eudrilus eugenae* and *Perionyx excavatus*) using wheat straw, chickpea straw, tree leaves (*Peltophorum* sp) and *Parthenium* mixed with cow dung as feed materials. There was an increase in earthworm population and size during incubation for 90 days. The three types of earthworms multiplied 12 to 18 times when grown individually using legume tree leaves and cow dung mixture as raw material (Table 3). However, mixed culture (of all three species) showed higher multiplication rate (27 times) than the individual species.

Further studies on earthworm multiplication were also conducted at ICRISAT using tree leaves and *Gliricidia* stems mixed with cattle manure as feed material (Table 4). The earthworm population decreased when grown in mixture of *Gliricidia* stems and cattle manure. These results indicated that *Gliricidia* loppings could not be used for multiplication of earthworms. *Gliricidia* bark is known to possess toxic properties as it is used as rat poisoning bait.

In another multiplication study at ICRISAT, there was maximum increase in earthworm population (570%) and weight (109%) when grown in a feed material containing tree leaves (3 kg) and cow dung (6 kg). In contrast, mortality of earthworms (about 7 to 22%) was observed by growing them in a feed material containing soil (Table 5).

All these studies indicated that *Gliricidia* and tobacco leaves are not suitable for multiplication of earthworms. Perhaps the alkaloids and other principal compounds present in these leaves may effect the survival of earthworms. Also, soil and rabbit manure should not be mixed with earthworm feed material.

Table 3. Multiplication trial of earthworm species at ICRISAT, Patancheru, India in 2000[1].

Earthworm species	Initial population	Final population	Increase (%)
Mixed culture	900	15950	1612 (27)[2]
Eisenia fetida	90	1036	1051 (12)
Eudrilus eugenae	55	1007	1731 (18)
Perionyx excavatus	85	1192	1302 (14)

1. Mixture of legume tree leaves and cow dung was used as substrate.
2. Values in parentheses indicate increase in number of times at 90 days after incubation.

Table 4. Multiplication trials of earthworms using different organic materials at ICRISAT, Patancheru, India during 2000–02.

		Initial		Final[1]	
Earthworm species	Feed material	Population	Weight (g)	Population	Weight (g)
Eisenia fetida	Tree leaves (15 kg)	345	20	2510	207
	Cattle manure (15 kg)	510	207	1159	207
	Cattle manure (3 kg) + *Gliricidia* stem (6 kg)	1255	101	1000	50
Eudrilus eugenae	Tree leaves (15 kg)	311	21	2986	334
	Cattle manure (15 kg)	2986	334	1522	216
	Cattle manure (3 kg) + *Gliricidia* stem (6 kg)	2707	230	2249	100
Perionyx excavatus	Tree leaves (15 kg)	409	29	2707	230
	Cattle manure (15 kg)	2707	230	2650	187
	Cattle manure (3 kg) + *Gliricidia* stem (6 kg)	3356	365	1000	50

1. At 90 days after incubation.

Table 5. Multiplication trials of mixed culture of earthworms using soil and other organic substrates at ICRISAT, Patancheru, India, 2000–02.

	Initial		Final		Increase[1] (%)	
Feed material	Number	Weight (g)	Number	Weight (g)	Number	Weight
Cow dung (15 kg)	500	89	750	163	50	83
Tree leaves (3 kg) + cow dung (3 kg)	500	95	1545	125	21	32
Tree leaves (3 kg) + cow dung (6 kg)	500	110	3351	230	570	109
Pigeonpea leaves + pod shells + tree leaves (2 kg) + cow dung (2 kg)	500	98	2230	187	346	90
Pigeonpea leaves + pod shells + tree leaves (2 kg) + cow dung (4 kg)	500	115	1490	193	198	68
Soil (5 kg) + cow dung (5 kg)	1000	90	784	87	–22	–3
Soil (5 kg) + cow dung (5 kg) + pigeonpea leaves (1 kg)	1000	75	1023	241	2	223
Soil (5 kg) + cow dung (5 kg) + tree leaves (1 kg)	1000	160	929	170	–7	–6

1. At 90 days after incubation

Temperature changes during the process

Change in temperature was observed during the process of vermicomposting (from 5 to 65 days) with different farm residues (*Parthenium* and grass). In the beginning of the process, ie, up to 15 days, the temperature was high (32 to 33°C) in both *Parthenium* and grass substrates when compared to outside temperature (26 to 30°C). Later, there was a gradual decrease in temperature, which reached a minimum of about 24°C. However, higher temperature was recorded in *Parthenium* compost (decline from 32.8 to 27.5°C) than in grass compost (decline from 31.5 to 26.8°C) during the whole period of digestion process. Generally more heat was evolved from control treatment (without earthworms) than the vermicompost treatments (with earthworms). From these studies, it was suggested that the most suitable period for releasing the earthworms into organic residues would be between 15 and 20 days after heaping of the organic residues when the temperature is about 25°C (Fig. 1).

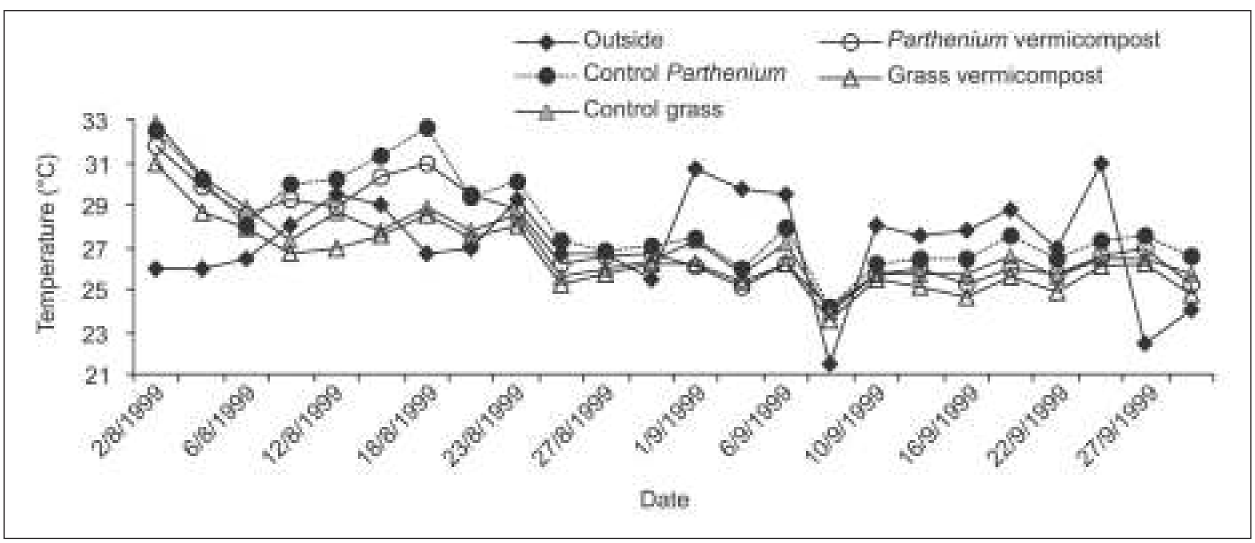

Figure 1. Temperature changes during biodigestion.

Methods of Vermicomposting

Pits below the ground

Pits made for vermicomposting are 1 m deep and 1.5 m wide. The length varies as required.

Heaping above the ground

The waste material is spread on a polythene sheet placed on the ground and then covered with cattle dung. Sunitha et al. (1997) compared the efficacy of pit and heap methods of preparing vermicompost under field conditions. Considering the biodegradation of wastes as the criterion, the heap method of preparing vermicompost was better than the pit method. Earthworm population was high in the heap method, with a 21-fold increase in *Eudrilus eugenae* as compared to 17-fold increase in the pit method. Biomass production was also higher in the heap method (46-fold increase) than in the pit method (31-fold). Consequent production of vermicompost was also higher in the heap method (51 kg) than in the pit method (40 kg).

Tanks above the ground

Tanks made up of different materials such as normal bricks, hollow bricks, shabaz stones, asbestos sheets and locally available rocks were evaluated for vermicompost preparation. Tanks can be constructed with the dimensions suitable for operations. At ICRISAT, we have evaluated tanks with dimensions of 1.5 m (5 feet) width, 4.5 m (15 feet) length and 0.9 m (3 feet) height. The commercial biodigester contains a partition wall with small holes to facilitate easy movement of earthworms from one tank to the other.

Cement rings

Vermicompost can also be prepared above the ground by using cement rings (ICRISAT and APRLP 2003). The size of the cement ring should be 90 cm in diameter and 30 cm in height. The details of preparing vermicompost by this method have been described in a later section.

Commercial model

The commercial model for vermicomposting developed by ICRISAT consists of four chambers enclosed by a wall (1.5 m width, 4.5 m length and 0.9 m height) (Fig. 2). The walls are made up of different materials such as normal bricks, hollow bricks, shabaz stones, asbestos sheets and locally available rocks. This model contains partition walls with small holes to facilitate easy movement of earthworms from one chamber to another. Providing an outlet at one corner of each chamber with a slight slope facilitates collection of excess water, which is reused later or used as earthworm leachate on crop. The outline of the commercial model is given in Figure 3.

The four components of a tank are filled with plant residues one after another. The first chamber is filled layer by layer along with cow dung and then earthworms are released. Then the second chamber is filled layer by layer. Once the contents in the first chamber are processed the earthworms move to chamber 2, which is already filled and ready for earthworms. This facilitates harvesting of decomposed material from the first chamber and also saves labor for harvesting and introducing earthworms. This technology reduces labor cost and saves water as well as time.

Figure 2. Commercial model for vermicomposting at ICRISAT.

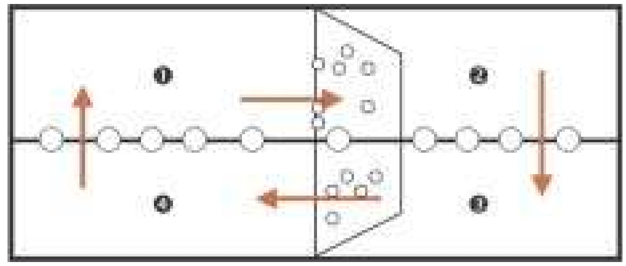

Figure 3. Diagrammatic representation of the commercial model with four chambers for vermicomposting.

Materials Required for Vermicomposting

A range of agricultural residues, all dry wastes, for example, sorghum straw and rice straw (after feeding cattle), dry leaves of crops and trees, pigeonpea (C*ajanus cajan*) stalks, groundnut (*Arachis hypogaea*) husk, soybean residues, vegetable wastes, weed (*Parthenium*) plants before flowering, fiber from coconut (C*ocos nucifera*) trees and sugarcane (*Saccharum officinarum*) trash can be converted into vermicompost. In addition, animal manures, dairy and poultry wastes, food industry wastes, municipal solid wastes, biogas sludge and bagasse from sugarcane factories also serve as good raw materials for vermicomposting.

The quantity of raw materials required using a cement ring of 90 cm in diameter and 30 cm in height or a pit or tank measuring 1.5 m × 1 m × 1 m is given below:

Dry organic wastes (DOW)	50 kg
Dung slurry (DS)	15 kg
Rock phosphate (RP)	2 kg
Earthworms (EW)	500–700
Water (W)	5 L every three days

The various ingredients are used in the ratio of 5:1.5:0.2:50–75:0.5 of DOW:DS:RP:EW:W. In the tank or pit system 100 kg of raw material and 15–20 kg of cow dung are needed for each cubic meter of the bed.

Vermicompost Preparation

Steps in the process

Vermicomposting involves the following steps which are depicted in Figure 4(a–k):

- Cover the bottom of the cement ring with a layer of tiles or coconut husk or polythene sheet (Fig. 4a).
- Spread 15–20 cm layer of organic waste material on the polythene sheet (Fig. 4b). Sprinkle rock phosphate powder if available (it helps in improving nutritional quality of compost) on the waste material and then sprinkle cow dung slurry (Fig. 4c and d). Fill the ring completely in layers as described. Paste the top of the ring with soil or cow dung (Fig. 4e). Allow the material to decompose for 15 to 20 days.
- When the heat evolved during the decomposition of the materials has subsided (15–20 days after heaping), release selected earthworms (500 to 700) through the cracks developed (Fig. 4f).
- Cover the ring with wire mesh or gunny bag to prevent birds from picking the earthworms. Sprinkle water every three days to maintain adequate moisture and body temperature of the earthworms (Fig. 4g).

- The vermicompost is ready in about 2 months if agricultural waste is used and about 4 weeks if sericulture waste is used as substrate (Fig. 4h).
- The processed vermicompost is black, light in weight and free from bad odor.
- When the compost is ready, do not water for 2–3 days to make compost easy for sifting. Pile the compost in small heaps and leave under ambient conditions for a couple of hours when all the worms move down the heap in the bed (Fig. 4i). Separate upper portion of the manure and sieve the lower portion to separate the earthworms from the manure (Fig. 4j). The culture in the bed contains different stages of the earthworm's life cycle, namely, cocoons, juveniles and adults. Transfer this culture to fresh half decomposed feed material. The excess as well as big earthworms can be used for feeding fish or poultry. Pack the compost in bags and store the bags in a cool place (Fig. 4k).
- Prepare another pile about 20 days before removing the compost and repeat the process by following the same procedure as described above.

Precautions during the process

The following precautions should be taken during vermicomposting:

- The African species of earthworms, *Eisenia fetida* and *Eudrilus eugenae* are ideal for the preparation of vermicompost. Most Indian species are not suitable for the purpose.
- Only plant-based materials such as grass, leaves or vegetable peelings should be utilized in preparing vermicompost.
- Materials of animal origin such as eggshells, meat, bone, chicken droppings, etc are not suitable for preparing vermicompost.
- *Gliricidia* loppings and tobacco leaves are not suitable for rearing earthworms.
- The earthworms should be protected against birds, termites, ants and rats.
- Adequate moisture should be maintained during the process. Either stagnant water or lack of moisture could kill the earthworms.
- After completion of the process, the vermicompost should be removed from the bed at regular intervals and replaced by fresh waste materials.

How to Use Vermicompost?

- Vermicompost can be used for all crops: agricultural, horticultural, ornamental and vegetables at any stage of the crop.
- For general field crops: Around 2–3 t ha^{-1} vermicompost is used by mixing with seed at the time of sowing or by row application when the seedlings are 12–15 cm in height. Normal irrigation is followed.
- For fruit trees: The amount of vermicompost ranges from 5 to 10 kg per tree depending on the age of the plant. For efficient application, a ring (15–18 cm deep) is made around the plant. A thin layer of dry cow dung and bone meal is spread along with 2–5 kg of vermicompost and water is sprayed on the surface after covering with soil.
- For vegetables: For raising seedlings to be transplanted, vermicompost at 1 t ha^{-1} is applied in the nursery bed. This results in healthy and vigorous seedlings. But for transplants, vermicompost at the rate of 400–500 g per plant is applied initially at the time of planting and 45 days after planting (before irrigation).
- For flowers: Vermicompost is applied at 750–1000 kg ha^{-1}.
- For vegetable and flower crops vermicompost is applied around the base of the plant. It is then covered with soil and watered regularly.

Plastic sheet placed below the ring

Layer of raw material placed on polythene sheet

Rock phosphate powder sprinkled on organic material

Cow dung slurry

Cement ring sealed with cow dung

Earthworms are released near cracks

Figure 4(a–k). Vermicomposting process.

Cement ring covered with gunny bag

Processed vermicompost

Heaping of vermicompost

Compost sieved

Bag filled with vermicompost

Biodiversity in Vermicompost

In the present study, vermicompost samples were collected and analyzed for microbial diversity and population studies. The vermicompost samples were collected in sterile containers from the rings before harvesting the compost. To compare microbial diversity, samples from the partially decomposed dry organic waste material, ready for the release of the earthworms, were also collected and checked for diversity and population counts.

Total mircobial populations of bacteria, fungi and actinomycetes from the substrates were determined by using dilution plate techniques with suitable media (Nutrient Agar, Potato Dextrose Agar, Actinomycetes Isolation Agar-HI Media). The number of colony forming units (CFU) was expressed as CFU g^{-1}.

Several authors have noted that the earthworms play a major role in affecting populations of soil organisms, especially in causing changes in the soil microbial community (Coleman 1985, Parmelee 1998). The present work recorded higher microbial populations in the partially decomposed dry organic waste material for vermicompost than the vermicompost (Table 6). This may be due to the existing temperatures and pH in the partially decomposed raw material. But compared to conventional thermophilic composts, vermicompost is much richer in microbial diversity, populations and activities (Subler et al. 1998).

Table 6. Microbial populations from the samples of vermicompost.

	Bacteria (CFU g^{-1})	Fungi (CFU g^{-1})	Actinomycetes (CFU g^{-1})
Vermicompost	54×10^6	8×10^4	1×10^4
Partially decomposed dry organic waste material for vermicompost	69×10^6	11×10^4	2×10^4

The fungal isolates from the samples were identified upto species level (Table 7). Much diversity was observed between the two samples collected. *Aspergillus*, *Fusarium*, *Mucor*, *Cladosporium*, and *Trichoderma* were the common genera observed in both the samples. Genera like *Absidia*, and *Stachbotrys* were recorded in vermicompost. Genera like *Alternaria*, *penicillium*, and *Thermomyces* were isolated from partially decomposed dry organic waste material for vermicompost. This clearly indicates that the fungal diversity is more in the decomposed material than in the vermicompost. The digestive epithelium of the simple straight tubular gut of worms is known to secrete cellulase, amylase, invertase, protease, phosphatase (Ranganathan and Vinotha 1998). Earthworms inevitably consume the soil microbes during the ingestion of litter and soil. It has been recently estimated that earthworms necessarily have to feed on microbes, particularly fungi for their protein/nitrogen requirement (Ranganathan and Parthasarathi 2000). This may be the reason for the less diversity of fungi and microbial counts seen in the vermicompost collected.

In both the samples percentage of *Aspergillus* was more when compared with other genera. *Tricoderma* and *Penicillium* have antibiotic activities and can also be used as biological control on soil borne pathogens. Only a few studies have investigated that the suppression of soil borne plant pathogens by vermicompost (Szczech et al. 1993), or disease suppression in the presence of earthworms (Stephens and Davoren 1997, Stephens et al. 1994). Disease suppression by compost has been attributed to the activities of competitive or antagonistic microorganisms as well as the antibiotic compounds present in the vermicompost.

Table 7. List of fungi isolated from partially decomposed dry organic waste for vermicompost and vermicompost.

Partially decomposed dry organic waste for vermicompost	Vermicompost
Alternaria citri	*Absidia cylindrospora*
Aspergillus fumigatus	*Aspergillus fumigatus*
Aspergillus niger	*Aspergillus niger*
Aspergillus cervinus	*Aspergillus clavoto nanicus*
Aspergillus terreus	*Aspergillus terreus*
Aspergillus sydowii	*Aspergillus sydowii*
Aspergillus niveus	*Aspergillus nidulans*
Aspergillus sclerotiorum	*Cladosporium herbarum*
Cladosporium cladosporioides	*Fusarium oxysporum*
Cladosporium herbarum	*Fusarium semitactum*
Fusarium samucinum	*Fusarium nivale*
Fusarium dimerum	*Mucor circinelloides*
Mucor racemosus	*Stachbotrys chartarum*
Penicillium chrysogenum	*Trichoderma viride*
Penicillium thomii	
Penicillium citrinum	
Trichoderma viride	
Thermomyces lanuginous	

Vermicomposting: A Livelihood Micro-enterprise for Rural Women

ICRISAT with support from the Asian Development Bank (ADB), Philippines, District Water Management Agency (DWMA), Government of Andhra Pradesh and Tata-ICRISAT-ICAR project in northeastern regions of India was keen to promote the vermiculture technology. The primary objective of this project was to help women from rural areas to set up micro-enterprises based on vermiculture technology and also to improve crop productivity by increasing soil fertility through ecological methods of farming (Wani 2002).

The training program conducted by ICRISAT for DWACRA (Development of Women and Child in Rural Area) group of women and other women self-help groups (SHGs) covered technical aspects of multiplying earthworms, managing and collection of organic wastes, application of vermicompost for various crops, accounting and marketing. At the same time a noxious weed, *Parthenium hysterophorus* (locally referred as *vayyari bhama* or congress weed), was found abundantly in the fields as well as on field bunds, which inhibited crop growth and caused environmental pollution. Hence, the women have come forward to utilize this weed as raw material for vermicomposting, which is a safe weed disposal mechanism and an opportunity to convert into valuable compost.

Case Studies

Adarsha watershed, Kothapally

Ms Lakshmamma and four other women have set up a vermicomposting enterprise in a common place under one roof. Having begun with a population of 2,000 earthworms of three epigeic species, they regularly harvest around 400 kg of vermicompost every month collectively. Their work in making vermicompost is shared collectively and the unique marketing strategy involves meeting potential customers. Sometimes, they even get customers from distant places. They earn a net income of around Rs 500 each month. By becoming an earning member of the family, they are involved in the decision-making process in the family. This has also raised their status in the society.

APRLP watershed village

Ms Padmamma living in Sripuram, one of the thousand non-descript villages of Mahbubnagar district in Andhra Pradesh, leads a routine life and has never dreamt of a different life. She joined the women's SHG at the begining of the Andhra Pradesh Rural Livelihoods Programme (APRLP) project. Though reluctant during the initial stage, she started taking active part in the weekly meetings and showed interest in the discussions about raising income through small initiatives like adopting the vermicompost scheme. This scheme was introduced to enhance crop productivity in the fields and enable the farmers to get more per-hectare yield. Ms Padmamma is able to get higher yield from different crops such as maize and vegetables with the application of vermicompost in her own field. She now proudly displays the vermiculture beds to any visitor who comes to meet her.

Tata-ICRISAT-ICAR project

The farmers of Bundi nucleus watershed in Rajasthan, India have shown lot of interest in vermicomposting. Two farmers have built a multiple compartment system (commercial model) of vermicomposting while many are following the regular vermicomposting. In Guna nucleus watershed in Madhya Pradesh, nearly 35 farmers from all the three microwatersheds are practicing vermicomposting. Most of them are producing vermicompost on a large scale and are applying to their own fields for vegetable crops and getting higher yields with low-cost technology. A few farmers have already started selling their extra produce of vermicompost at the nearby market at the rate of Rs 5–7 per kg.

Conclusions

The production of degradable organic waste and its safe disposal becomes the current global problem. Meanwhile the rejuvenation of degraded soils by protecting topsoil and sustainability of productive soils is a major concern at the international level. Provision of a sustainable environment in the soil by amending with good quality organic soil additives enhances the water holding capacity and nutrient supplying capacity of soil and also the development of resistance in plants to pests and diseases. By reducing the time of humification process and by evolving the methods to minimize the loss of nutrients during the course of decomposition, the fantasy becomes fact. Earthworms can serve as tools to facilitate these functions. They serve as "nature's plowman" and form nature's gift to produce good humus, which is the most precious material to fulfill the nutritional needs of crops. The utilization of vermicompost results in several benefits to farmers, industries, environment and overall national economy.

To farmers:

- Less reliance on purchased inputs of nutrients leading to lower cost of production
- Increased soil productivity through improved soil quality
- Better quantity and quality of crops
- For landless people provides additional source of income generation

To industries:

- Cost-effective pollution abatement technology

To environment:

- Wastes create no pollution, as they become valuable raw materials for enhancing soil fertility

To national economy:

- Boost to rural economy
- Savings in purchased inputs
- Less wasteland formation

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