Vermicomposting technology for solid waste management

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Introduction

Aristotle called worms the "intestines of the earth" and stated that there may not be any other creature that has played so important a role in the history of life on earth. Earthworms constitute a large part of biomass (living bodies) inhabiting soil. In recent years efforts have been made to use the potential of earthworms in recycling of nutrients, waste management and development of vermicomposting systems at commercial scale. These are also called as "Ecosystem engineers" as they increase the numbers and types of microbes in the soil by creating conditions under which these creatures can thrive and multiply. The objective of this article is to present an overview of the vermicomposting technology.

In India, the integration of crops and livestock and use of manure as fertilizer were traditionally the basis of farming systems. But development of chemical fertilizer industry during the green revolution period created opportunities for low-cost supply of plant nutrients in inorganic forms which lead to rapid displacement of organic manures derived from livestock excreta. The deterioration of soil fertility through loss of nutrients and organic matter, erosion and salinity, and pollution of environment are the negative consequences of modern agricultural practices. In India, millions of tons of livestock excreta are produced annually (Table 1). Odour and pollution problems are of concern. Currently the fertilizer values of animal dung are not being fully utilized resulting in loss of potential nutrients returning to agricultural systems. The potential benefits of vermicomposting of livestock excreta include control of pollution and production of a value added product. Vermicomposting of different livestock excreta including cattle dung; horse waste; pig waste; goat waste; sheep waste; turkey waste and poultry droppings has been reported. Organic wastes can be ingested by earthworms and egested as a peat-like material termed "vermicompost". Recycling of wastes through vermicomposting reduces the problem of non-utilization of livestock excreta. During vermicomposting, the important plant nutrients such as N, P, K, and Ca, present in the organic waste are released and converted into forms that are more soluble and available to plants. Vermicompost also contains biologically active substances such as plant growth regulators. Moreover, the worms themselves provide a protein source for animal feed.

Table 1. Livestock population and quantity of waste generated in India

Animal species	Population (in million)	Daily average excreta $animal^{-1}$ Wet weight (kg)
Cow	185.18	11.6
Buffalo	97.92	12.2
Horse	0.75	-
Donkey	0.65	-
Sheep	61.47	0.76
Goat	124.35	0.70
Camel	0.63	-

Source: Livestock Census Report, 2003, Directorate of Economics and Statistics, Ministry of Agriculture, Government of India

Potential benefits of vermicomposting

Why should an organic farmer be interested in vermiculture and/or vermicomposting? The answers are several and simple. In summary, they are as follows:

- Vermicompost appears to be generally superior to conventionally produced compost in a number of important ways;
- Vermicompost is superior to most composts as an inoculant in the production of compost;
- Worms have a number of other possible uses on farms, including value as a high-quality animal feed;

- Vermicomposting and vermiculture offer potential to organic farmers as sources of supplemental income.

Vermicompost has the following advantages over chemical fertilizers.

- It restores microbial population which includes nitrogen fixers, phosphate solubilizers etc.
- Provides major and micro- nutrients to the plants.
- Improves soil texture and water holding capacity of the soil.
- Provides good aeration to soil, thereby improving root growth and proliferation of beneficial soil microorganisms.
- Decreases the use of pesticides for controlling plant pathogens.
- Improves structural stability of the soil, thereby preventing soil erosion.
- Enhances the quality of grains/ fruits due to increased sugar content.

At the same time, the beginning of vermicomposting process is a more complicated process than traditional composting:

- It can be quicker, but to make it so generally requires more labour;
- It requires more space because worms are surface feeders and won't operate in material more than a meter in depth;
- It is more vulnerable to environmental pressures, such as temperature, freezing conditions and drought;

Perhaps most importantly, it requires more start-up resources, either in cash (to buy the worms) or in time and labour (to grow them).

Composting, Vermicomposting and Vermiculture

Composting is bioconversion of organic matter by heterotrophic microorganisms (bacteria, fungi, actinomycetes and protozoa) into humus-like material called compost. The process occurs naturally provided the right organisms, moisture, aerobic conditions, feed material and nutrients are available for microbial growth. By controlling these factors the composting process can occur at a much faster rate.

Vermicomposting is the process by which worms are used to convert organic materials (usually wastes) into a humus-like material known as vermicompost. The goal is to process the material as quickly and efficiently as possible.

Vermiculture is the culture of earthworms. The goal is to continually increase the number of worms in order to obtain a sustainable harvest. The worms are either used to expand a vermicomposting operation or sold to customers who use them for the same or other purposes.

If the goal is to produce vermicompost then we want to have maximum worm population density all of the time. If the goal is to produce worms then we keep the population density low enough that reproductive rates are optimized.

Species Suitable for Vermicomposting

Epigeic species viz., *Eudrilus eugeniae, Eisenia foetida and Perionyx excavatus* are appropriate for vermicomposting. The desirable attributes of appropriate vermicomposting species are given in Box 1.

Box 1. Desirable attributes of worms suitable for vermicomposting

1. Worm should exhibit high biomass consumption together with a high efficiency of conversion of ingested biomass to body proteins, a physiological trait required for achieving high growth rate.
2. Worm should have wider range of tolerance to environmental factors including adaptation to feed on a variety of organic residues
3. Worm should produce large numbers of cocoons with short hatching time enabling rapid population growth and, linked to this rapid growth, faster composting of organic residues.
4. Life cycle of the worm should be such that mature/adult phase is quickly reached.
5. Using a mixture of species is likely to be more useful than use of single species.
6. Worm should be disease resistant.

The life cycle of three earthworm species which are widely used in vermicomposting is given below:

(1) Eisenia foetida

Eisenia foetida, popularly known as red wriggler, red worm, tiger worm etc is perhaps the most widely used earthworm for vermicomposting. The species has also been in wide usages for various toxicological studies as test worm. Mature individuals can attain up to 1500 mg body weight. Each mature worm on an average produces one cocoon every third day and from each cocoon on hatching within 23 days emerge from 1 to 3 individuals.

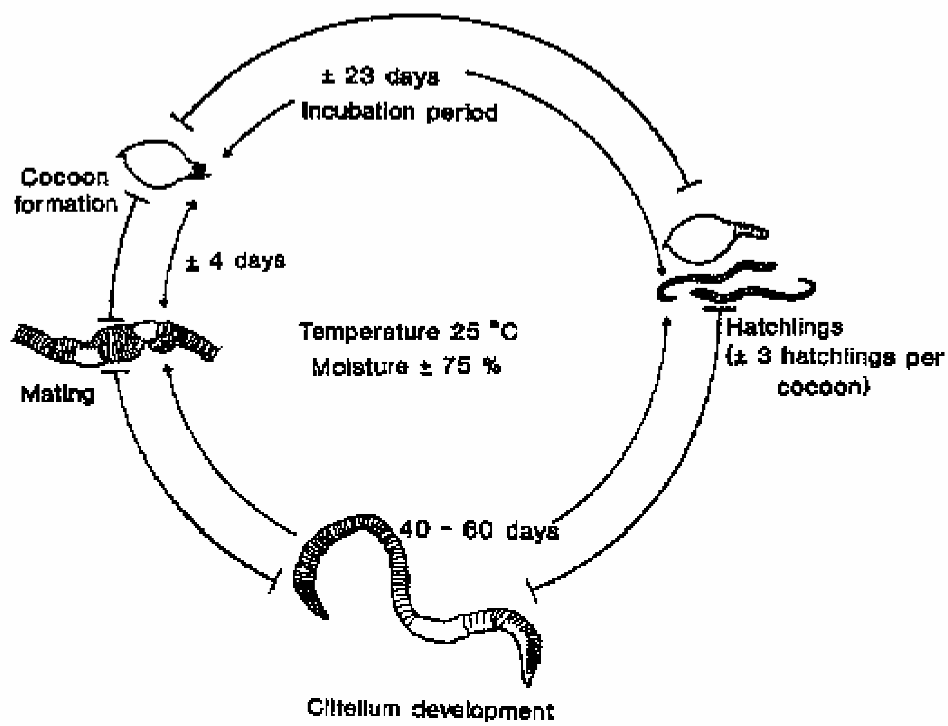

Fig 1: Life cycle of *Eisenia foetida*

(2) Eudrilus eugeniae

This species, popularly known as Night Crawler, can be said to be the second most widely used earthworm for vermicomposting. It grows faster than other species accumulating mass at the rate of 12 mg/day. Mature individuals can attain body weight up to 4.3 g/individual. Maturity is attained over a period of 40 days, and, a week later, individuals commence cocoon laying (on average 1 cocoon/day). Life span in laboratory is estimated to range from 1 to 3 years. Native of Equatorial West Africa, low temperature tolerance of *Eudrilus eugeniae* is lower than that of *Eisenia foetida*, but this species can be used as vermicomposting worm in tropical and sub-tropical regions.

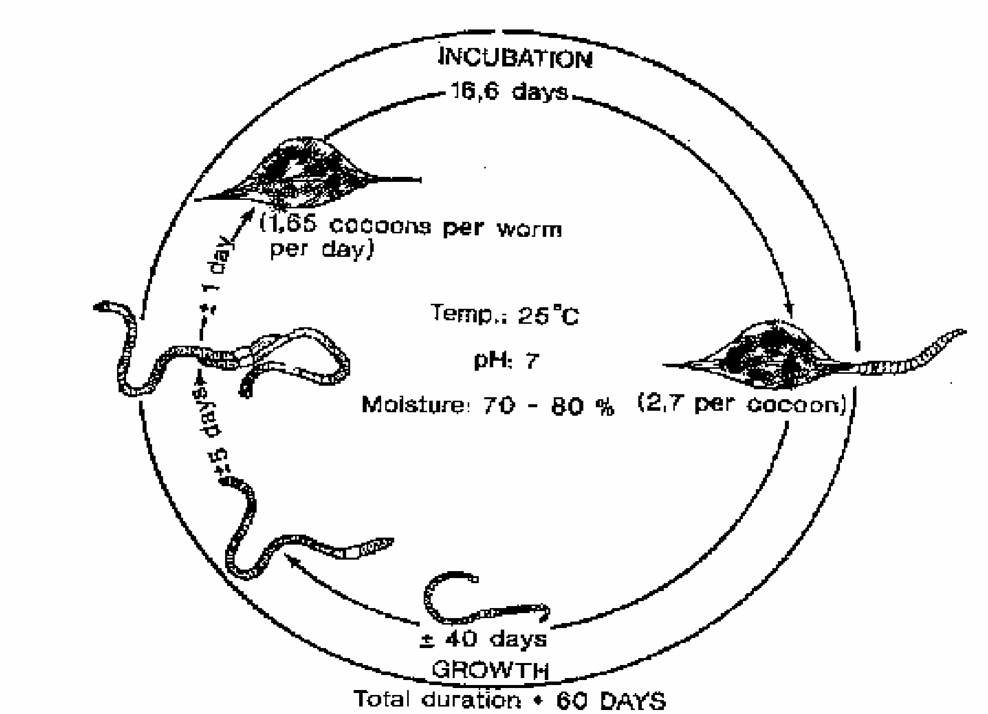

Fig 2: Life cycle of *Eudrilus eugeniae*

(3) Perionyx excavatus

In India, this species is quite common in Eastern Himalayas, Western Himalaya, Pilibhit, Bengal and Little Andaman Islands. It is highly adaptable and can tolerate a wide range of moisture and quality of organic matter. Average growth rate of Perionyx excavatus is 3.5 mg/day and body weight (maximum) 600 mg. Maturity is attained within 21-22 days and reproduction commences by 24^{th} day, with 1 to 3 hatchings per cocoon. Scientists opine that this species is amongst the best suited for vermicomposting in tropical climates.

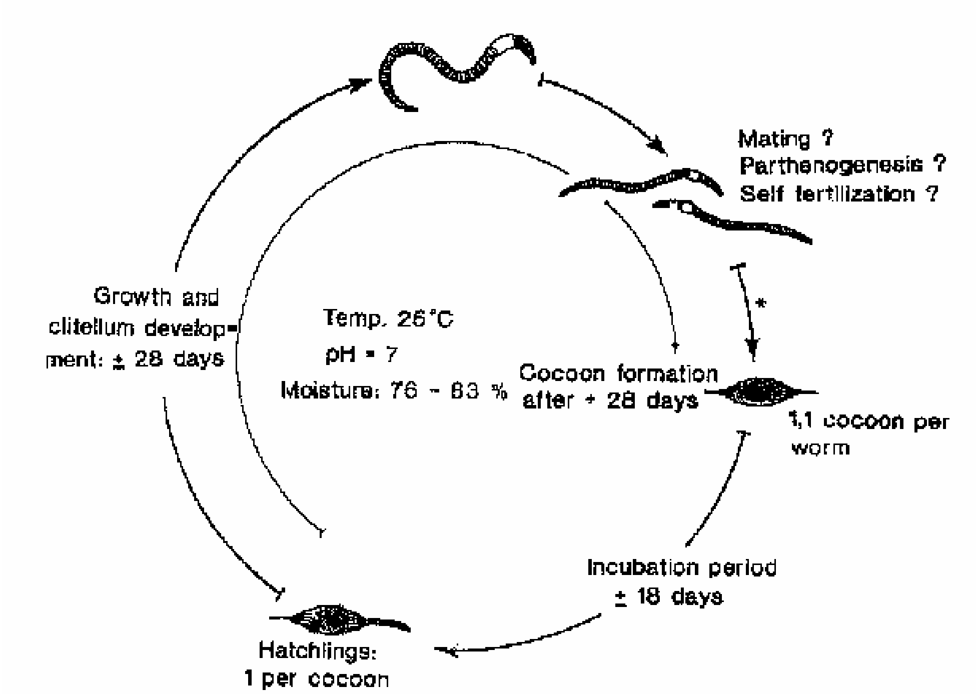

Fig 3: Life cycle of *Perionyx excavatus*

Vermicomposting process

It is an aerobic, bio-oxidation, non-thermophilic process of organic waste decomposition that depends upon earthworms to fragment, mix and promote microbial activity. The basic requirements during the process of vermicomposting are

- Suitable bedding
- Food source
- Adequate moisture
- Adequate aeration
- Suitable temperature
- Suitable pH

1. Bedding

Bedding is any material that provides a relatively stable habitat to worms. For good vermicomposting, this habitat should satisfy the following criteria:

• **High absorbency:** As worms breathe through skin, the bedding must be able to absorb and retain adequate water.

• **Good bulking potential:** The bulking potential of the material should be such that worms get oxygen properly.

• **Low nitrogen content (high Carbon: Nitrogen ratio):** Although worms consume their bedding as it breaks down, it is very important that this be a slow process. High protein/nitrogen levels can result in rapid degradation and associated heating may be fatal to worms. Table 2 provides a list of some of the most commonly used bedding materials.

Table 2: Common Bedding Materials

Bedding Material	Absorbency	Bulking Potential	C:N Ratio
Horse Manure	Medium-Good	Good	22 - 56
Peat Moss	Good	Medium	58
Corn Silage	Medium-Good	Medium	38 - 43
Straw – general	Poor	Medium-Good	48 - 150
Straw – oat	Poor	Medium	48 - 98
Straw – wheat	Poor	Medium-Good	100 - 150
Paper from municipal waste stream	Medium-Good	Medium	127 - 178
Newspaper	Good	Medium	170
Bark – hardwoods	Poor	Good	116 - 436
Bark -- softwoods	Poor	Good	131 - 1285
Corrugated cardboard	Good	Medium	563
Lumber mill waste -- chipped	Poor	Good	170
Paper fiber sludge	Medium-Good	Medium	250
Paper mill sludge	Good	Medium	54
Sawdust	Poor-Medium	Poor-Medium	142 - 750
Shrub trimmings	Poor	Good	53
Hardwood chips, shavings	Poor	Good	451 - 819
Softwood chips, shavings	Poor	Good	212 - 1313
Leaves (dry, loose)	Poor-Medium	Poor-Medium	40 - 80
Corn stalks	Poor	Good	60 - 73
Corn cobs	Poor-Medium	Good	56 - 123

If available, shredded paper or cardboard makes excellent bedding, particularly when combined with typical on-farm organic resources such as straw and hay.

2. Food Source

Regular input of feed materials for the earthworms is most essential step in the vermicomposting process. Earthworms can use a wide variety of organic materials as food but do exhibit food preferences (Table 3). In adverse conditions, earthworms can extract sufficient nourishment from soil to survive. However earthworms feed mainly on dead and decaying organic waste and on free living soil microflora and fauna. Under ideal conditions, worms can consume amount of food higher than their body weights, the general rule-of-thumb is consumption of food weighing half of their body weight per day. Livestock excreta, viz., goat manure, cattle dung or pig manure are the most commonly used worm feedstock as these materials have higher nitrogen content. When the material with higher carbon content is used with C: N ratio exceeding 40: 1, it is advisable to add nitrogen supplements to ensure effective decomposition. The food should be added only as a limited layer as an excess of the waste many generate heat. From the waste ingested by the worms, 5-10% are being assimilated in their body and the rest are being excreted in the form of vermicast.

3. Moisture

Perhaps the most important requirement of earthworms is adequate moisture. They require moisture in the range of 60-70%. The feed stock should not be too wet otherwise it may create anaerobic conditions which may be fatal to earthworms.

4. Aeration

Factors such as high levels of fatty/oily substances in the feedstock or excessive moisture combined with poor aeration may render anaerobic conditions in vermicomposting system. Worms suffer severe mortality partly because they are deprived of oxygen and partly because of toxic substances (e.g. ammonia) produced under such conditions. This is one of the main reasons for not including meat or other fatty/oily wastes in worm feedstock unless they have been pre-composted to break down the oils and fats.

5. Temperature

The activity, metabolism, growth, respiration and reproduction of earthworms are greatly influenced by temperature. Most earthworm species used in vermicomposting

Table 3: Different worm feed stocks, their advantages and disadvantages

Worm feed	Advantages	Disadvantages	Remarks
Cow dung	Good nutrition; natural food, therefore little adaptation required	Weed seeds make pre-composting necessary	All manures are partially decomposed and thus ready for consumption by worms
Poultry droppings	High N content results in good nutrition and highly N-rich product	High protein levels can be dangerous to worms, and hence it should be mixed with other organic residues or may be pre-composted	Some suggest that poultry manure is not suitable for worms because it is so "hot"; however, Georg, (2004) has shown that worms can adapt if initial proportion of poultry manure to bedding is 10% or less by volume.
Sheep/Goat excreta	Good nutrition	Requires pre-composting (weed seeds); small particle size can lead to packing, necessitating extra bulking material	With right additives to increase C:N ratio, these manures are also good beddings
Pig waste	Good nutrition; produces excellent vermicompost	Usually in liquid form, therefore must be dewatered or used with large quantities of highly absorbent bedding	Scientists at Ohio State University found that vermicompost made with hog manure outperformed all other vermicomposts, as well as commercial fertilizer.
Agricultural waste	Higher N content makes these good feed as well as reasonable bedding.	Moisture levels not as high as other feeds, requires more input and monitoring	Probably best to mix this feed with others, such as animal manures
Horse excreta	It can be a very good material for vermiculture.	Nitrogen content lesser than cow dung, C: N ratio is very high.	Must be mixed with other organic wastes like cow dung before feeding to earthworms

Aquatic weeds	Good nutrition; results in excellent product, high in micronutrients and beneficial microbes	Salt must be rinsed off, as it is detrimental to worms; availability varies by region	Beef farmer in Antigonish, Nova Scotia (Canada) producing certified organic vermicompost from cattle manure, bark, and seaweed. Water hyacinth has been tested as a feed stock for earthworms
Pre consumer vegetable waste	Higher N content, results in excellent product, worms like this material	Moisture levels are high, requires more monitoring	Vermicast Industries Inc. has developed a process to get the pre consumer vegetable waste be vermicomposted in 8-10 days. (www.csrplus.com)
Paper waste	Excellent nutrition, worms like this material.	Must be shredded and/or soaked (non-waxed) prior to feeding	Some worm growers claim that corrugated cardboard stimulates worm reproduction
Municipal solid waste	Good nutrition; results in excellent product, high in micronutrients. The waste is stabilized and free from foul odour.	Precautions are required to control the harmful microorganisms if sewage sludge is used.	The In statute of Natural Organic Agriculture (INORA) has developed techniques for vermicomposting of MSW.

require moderate temperatures from 10 – 35^{o} C. While tolerances and preferences vary from species to species. Earthworms can tolerate cold and moist conditions far better than hot and dry conditions. For *Eisenia foetida* temperatures above 10^{o}C (minimum) and preferably 15^{o}C be maintained for maximizing vermicomposting efficiency and above 15^{o}C (minimum) and preferably 20^{o}C for vermiculture. Higher temperatures (> 35^{o} C) may result in high mortality. Worms will redistribute themselves within piles, beds or windrows such that they get favorable temperatures in the bed.

6. pH

Worms can survive in a pH range of 5 to 9, but a range of 7.5 to 8.0 is considered to be the optimum. In general, the pH of worm beds tends to drop over time due to the fragmentation of organic matter under series of chemical reactions. Thus, if the food sources are alkaline, the effect is a moderating one, tending to neutral or slightly acidic, and if acidic (e.g., coffee grounds, peat moss); pH of the beds can drop well below 7. In such acidic conditions, pests like mites may become abundant. The pH can be adjusted upwards by adding calcium carbonate.

7. Other Important Parameters

There are a number of other parameters of importance to vermicomposting and vermiculture:

7.1. Pre-composting of organic waste: Scientists reported the death of *Eisenia foetida* after 2 weeks in the fresh cattle solids although all other growth parameters such as moisture content, pH, electrical conductivity, C: N ratio, NH_4 and NO_3^- contents were suitable for the growth of the earthworms. They attributed the deaths of earthworms to the anaerobic conditions which developed after 2 weeks in fresh cattle solids. It is established that pre-composting of organic waste is very essential to avoid the mortality of worms.

7.2. Salt content: Worms are very sensitive to salts, preferring salt contents less than 0.5% in feed . If seaweed is used as a feed (and worms do like all forms of seaweed), then it should be rinsed so as to reduce salt content. Some manures have high soluble salt contents (up to 8%). This is not usually a problem when the manure is used as a feed, because the material is usually applied on top and worms can avoid it until salts are leached out. If manures are to be used as bedding, they can be leached first to reduce the salt content. This is done by simply running water through the material for some time. If the manures are pre-composted outdoors, salts will not be a problem.

7.3. Urine content: Gaddie and Douglas have stated that if the manure is from animals raised or fed off in concrete lots, it will contain excessive urine because the urine cannot drain off into the ground. This manure should be leached before use to remove the urine. Excessive urine will build up toxic gases like ammonia in the bedding.

7.4. Other toxic components: Different feeds can contain a wide variety of potentially toxic components. Some of the more notable are:

• **De-worming medicine** in manures (particularly horse manure): Most modern de-worming medicines break down fairly quickly and are not a problem for vermicomposting or vermiculture. However, application of fresh manure from recently de-wormed animals could prove harmful.

• **Detergent cleansers industrial chemicals, pesticides**. These can often be found in feeds such as sewage or septic sludge, paper-mill sludge, or some food processing wastes.

• **Tannins.** Some trees, such as cedar and fir, have high levels of these naturally occurring substances. They can harm worms and even drive them away from the beds.

It has been pointed out that pre-composting of wastes can reduce or even eliminate most of these threats. However, pre-composting also reduces the nutrient value of the feed.

7.5. Pests and Diseases

Moles prey on earthworms and hence are often a problem when using windrows or other open-air vermicomposting systems. Damage due to rats and moles can be prevented by putting some form of barrier, such as wire mesh, paving, or a good layer of clay, under the windrow. Putting some type of windrow cover (e.g., old gunny bags) over the material will eliminate damage to worms by birds, apart from improving moisture retention and excessive leaching likely during high rainfall events. Centipedes eat compost worms and their cocoons. Fortunately, they do not seem to multiply to a great extent within worm beds or windrows. If they do become a problem, one method suggested for reducing their numbers is to heavily wet (but not quite flood) the worm beds. The water forces centipedes and other insect pests (but not the worms) to the surface, where they can be destroyed by means of a hand-held propane torch. Ants are more of a problem because they consume the feed meant for the worms. This problem can be checked by avoiding sweet feeds in the worm beds and maintaining a pH of 7 or slightly higher. White and brown mites compete with worms for food and can thus have some economic impact, but red mites are parasitic on earthworms. They suck blood or body fluid from worms and they can also suck fluid from cocoons. The best prevention for red mites is to make sure that the pH of the bedding is neutral or slightly alkaline. This can be done by keeping the moisture levels below 85% and through the addition of calcium carbonate, as required. Sour crop or protein poisoning happens when worms are overfed leading to protein build up in the bedding and production of toxic acids and gases due to protein decay. The better option is to maintain proper feed quality and micro-environmental conditions which rule out any possibility of sour crop.

Vermicompost

It has been estimated that earthworms add 230 kg N/ ha/ year in grasslands and 165 kg N/ha/year in woodland sites. Earthworms increase the nitrate production by stimulating bacterial activity and through their own decomposition. There are reports that concentrations of exchangeable cations such as Ca, Mg, Na, K, available P and Mo in the worm casts are higher than those in the surrounding soil. Vermicompost can not be described as being nutritionally superior to other organic manures. Instead, it is a unique way of manure production. The fertility value of vermicompost produced using different organic waste is given in Table 4.

Table 4. Chemical composition of worm cast

Characteristics	
Organic carbon%	9.15 to 17.88
Total Nitrogen %	0.5 to 0.9
Phosphorus %	0.1 to 0.26
Potassium %	0.15 to 0.256
Sodium %	0.055 to 0.3
Calcium & magnesium (Meq/100 g)	22.67 to 47.6
Copper; mg L^{-1}	2.0 to 9.5
Iron, mg L^{-1}	2.0 to 9.3
Zinc, mg L^{-1}	5.7 to 9.3
Sulphur, mg L^{-1}	128.0 to 548.0

Conclusion

As a processing system, the vermicomposting of organic waste is very simple. Worms ingest the waste material - break it up in their rudimentary gizzards - consume the digestible/putrefiable portion, and then excrete a stable, humus-like material that can be immediately marketed and has a variety of documented benefits to the consumer. Vermitechnology can be a promising technique that has shown its potential in certain challenging areas like augmentation of food production, waste recycling, management of solid wastes etc. There is no doubt that in India, where on side pollution is increasing due to accumulation of organic wastes and on the other side there is shortage of organic manure, which could increase the fertility and productivity of the land and produce nutritive and safe food. So the scope for vermicomposting is enormous.