Review Article

VERMICOMPOSTING FOR EFFICIENT RECYCLING OF BIOMASS FOR ORGANIC CROP PRODUCTION IN NORTH EAST INDIA

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ABSTRACT

Vermicomposting is an efficient method of recycling available biomass in and outside the farm. In most of the cases these unutilized biomass/wastes contributes to environmental pollution. Earthworms consume biomass and excrete it in digested form called 'worm casts' or 'vermicast'. The casts are rich in nutrients, growth promoting substances, beneficial soil micro flora and having properties of inhibiting pathogenic microbes. In India a, huge amount of crop residues are available which is either burnt or removed from the field. In North Eastern region (NER) of India also, a considerable amount of crop residues, weed, forest litter and other biomass including livestock excreta are available. The climatic condition of the NER favours the luxurious growth of a number of weeds, shrubs and tree species. All these materials can be very well used for vermicomposting. Though more than twelve species are being used for vermicomposting across the globe, African night crawler (*Eudrilus eugeniae* Kinberg) and red compost worm (*Eisenia foetida* Savigny) are widely used species. Vermicompost (VC) is found to be superior to many other organic manures in terms of nutrient content. Application of VC gives better crop growth and yield compared to other manures, when applied in quantities equivalent to the nutrient requirement (N equivalent) of the test crops. The benefit of vermicomposts are better realized when it is produced within the farm itself. Vermicompost can play a great role for promoting organic farming in the country in general and NER of India in particular. Results of field experiments conducted during 2005-18 indicated that almost all the crops recorded higher yield with VC compared to farmyard manure (FYM) and integrated application of 50% FYM + 50% VC. The soil fertility and produce quality improved over the years due to application of VC. The life cycle of earthworms, process of decomposition of biomass, method of vermicomposting, effect on crop production etc. has been discussed in detail in this article.

INTRODUCTION

Vermicomposting is an efficient method to decompose all kinds of organic residues to good quality organic manures. It is almost a common scene in India that farm/market wastes/biomass are piled in the outskirt of the villages/cities and processing industries. Upon partial decomposition these materials releases bed smells and pollutes air and water. If residues can be managed properly, it can improve soil organic carbon stock and nutrient content in soil in long term (Kumar *et al.,* 2017). Vermicomosting has attracted the attention of not only scientists but also farmers worldwide, since it is a natural organic product, which is eco-friendly and leaves no adverse residues either in the soil, produce or the environment. Along with earthworms, bacteria, fungi and actinomycetes participate in the process of vermicomposting.

Modern consumeristic society generates massive quantities of wastes, which is many a time costly as well as difficult to dispose of through conventional methods. It has been computed that India as a whole generates as much as 285 million tones (mt) of rural compost, 280 mt of cattle manure, 273 mt of crop residues and 14 mt of city refuse of diverse composition per year. In north east India about 46 mt of biomass is generated per including about 9 mt of animal and livestock excreta based manure (Table 1). The favourable climatic condition of the region allows huge biomass production of weeds, shrubs, trees etc. All the above sources are very good substrate for the vermicomposting that will not only help in efficient recycling of biomass but will also improve soil health, productivity and income of the farmers.

In North Eastern region of India alone, about 8896 thousand tons of crop residue is produced annually (Table 2) which can be recycled through vermi-composting. African red worms (*E. foetida*) are more efficient for vermicompost compared to local worms. About 37 million tones of livestock and poultry dung are available in the region for recycling (Bujarbaruah, 2004). About 2000 worms are required per sq.m. of area for vermiculture. On an average, 40-70 days are required to prepare the vermicompost depending on the nature of the material to be used for recycling. About 8.2 to 9.0 Kg of crop residue can produce 1 kg of vermicompost. Hence, the crop residue alone can produce 9, 88,460 tons of vermicompost in NE region.

IMPORTANCE IN CROP PRODUCTION

The conventional agriculture is heavily dependent on fertilizer, which is expensive and seems to be unsustainable over long term. The dominance of chemical fertilizers and pesticides in intensive agriculture and diminishing use of organic manure has not only reduced the soil fertility, but also caused pollution of soil and water resources. It has been realized worldwide that chemical fertilizers while increasing crop yields may have adverse effect on soil health and its fertility in case of imbalances use. Further, indiscriminate use of chemicals, on account of environmental concern and high cost, could not sustain crop production (Singh *et al.,* 1998). Vermicompost and farmyard manure increase growth of microbial population and improved the rate of mineralization of nutrients and physical properties resulting in higher crop yield (Tiwari *et al.,* 2000). Earthworms (vermicompost) contribute 50-250 kg of nitrogen per hectare per year besides other mineralized nutrients, 30 percent control of plant parasitic nematodes and about 30 to 200 percent enhancement of plant production (Senapati et al., 1985). Application of vermicompost @ 200 g/plant with FYM @ 250g/plant could be the best option for getting higher yield of tomato and cabbage (Chaudhury *et al.,* 2003; Dey and Shil, 2016). Application of vermicompost results improvement in soil bulk density, porosity, organic matter and nutrient status of soil (Chaudhury *et al.,* 2003).

The effect of earthworms on plant growth may be due to several reasons apart from the presence of macro and micro nutrients in their secretions and in vermicasts in considerable quantities. Certain metabolites produced by earthworms may also be responsible to stimulate plant growth. It is considered that earthworms release certain vitamins and growth promoters like cytokinins and auxins that has beneficial effect of crops. The wormcast contains all the nutrients in available form and in addition, a great deal of organic matter is provided to the soil. Earthworms enhance the decomposition of organic matter and contribute 20-200 kg nitrogen per hectare per year besides other nutrients and plant growth factors (Azad Thakur, 2006).

Table 1. Nutrient potential and economic value of biological and industrial wastes in India.

Types of biomass/wastes	Total quantity available (mt)	Total NPK ('000 t/year)	Economic value (million $)
Cattle manure	280	6882	659
Crop residue	273	7153	685
Forest litter	19	237	23
Rural compost	285	3715	356
City refuge	14	294	28
Sewage sludge	1	11	1
Press mud	3	168	16
Domestic waste water	6351*	648	62
Industrial waste	66*	5	0.5
Total		19113	1830

* Million cubic metre per annum, Source: Azad Thakur (2006)

Table 2. Availability of crop residues ('000 t/annum) in NE Region of India from major crops.

State	Rice	Maize	Pulses	Oilseeds	Total
Arunachal Pradesh	214.0	116.0	8.78	30.59	369.67
Assam	5,615.6	34.10	107.07	230.09	5986.87
Manipur	583.8	30.39	8.13	2.00	624.34
Meghalaya	249.17	57.77	4.98	7.85	319.77
Mizopram	183.6	38.28	2.49	16.36	240.73
Nagaland	310.42	69.60	20.92	32.98	433.90
Tripura	889.4	4.18	8.79	11.04	913.44
Total	8,047.0	350.32	166.66	332.10	8896.10

Source: Bujarbaruah (2004)

VERMICULTURE

The mass multiplication of earthworm species under laboratory condition is called as vermiculture. In other words breeding of worm is known as vermiculture. Earthworms population in organic matter rich soils act as natural bioreactors, harness beneficial soil micro flora, destroy soil pathogens and convert organic waste into valuable products such as biofertilizers, vitamins, enzymes, antibiotics, growth hormones, proteinaceus worm biomass.

Taxonomy of earthworms

The Earthworms are invertebrates assigned to Phylum Annelida, class Chaetopoda and order Oligochaeta. The earh worms are grouped under five families i.e., Lumbricidae, Eudrilidae, Megascolecidae, Octochaftide and Monilicastridae. The species Eisenia foetida Sav., Allolophora sp., Eudrillus eugeniae and Perionyx excuvatus etc., are used for mass multiplication for preparation of vermicompost.

Life cycle of the worms

Earthworms are segmented elongated tubular apodous, hermaphrodite creature, which crawl on surface. However, there is cross fertilization i.e., two individuals copulate each other and their head remain on opposite directions. The number of segments very from 85 to 111. However, usually 90 segments are found in many species. Two pairs of male pore (Spermethical pore) are situated in 17th segment while female pore is single one opening generally in 14th segment. There is a spindle shaped structure over male and female pore called clitellum. Its size and colour vary from species to species. Usually it is 25 to 40 mm. After copulation, egg and sperm fertilize in the clitellum is shed out of body on a suitable substrate. It is called "Cocoon". Each cocoon has about 1-5 eggs. After 2-3 weeks, young worms emerge out and start living freely depending upon temperature. Maturity takes about 1.5- 2 months. Thus, worms complete life –cycle in about 3 to 3.5 months. In Eisenia foetida Sav., cocoon has 1- 3 fertilized eggs while in Eudrillus eugeniae it is 3-4 eggs. The development is little faster in Eudrillus when compared with Eisenia but it requires more attention. Freshly laid cocoon is white to dull white, soft and jelly like. Cocoons are laid on substrate when temperature and moisture remain suitable. The cocoon shedding continues up to 46 days in Eisenia foetida Sav. The cocoons are usually laid during the period of end of March to October. The characteristics of different earth worm species are given in Table 3.

Table 3. Characteristics of major species of earthworms suitable for vermicomposting

Earthworm species	Body colour	Length (mm)	Diameter (mm)	Body weight (g)	Production of cocoon/year
Eisenia foetida	Red,brown or purple or eben darker. Coloured bands on dorsal side, ventral side is pale	35-130	3-5	1.50	198
Eudrilus eugeniae	Brown and red to dark violet	32-140	5-8	0.43	188
Perionyx excavatus	Dorsally deep purple to redish brown. Lower side pale	23-120	2-5	0.60	1014
Dendrobaena veneta	Brownish red	25-40	1-2	0.70	84

Source: Azad Thakur (2007)

Activities of earthworm

Earthworms' activities are very beneficial to agriculture viz., turning of soil, burrowing and aerating of soil, feeding on agricultural and animal waste, casting etc. The burrowing activities of earthworms improve the quantity of water content of soil (Dexter, 1978). Different species of worms showed different soil activities. Some worms live about 0.6-0.9m deep below soil while some live just below the soil surface, which mainly feed, on leaf tillers, rotten or semi-rotten plant products etc. The turning of soil /mixing of soil results in redistribution of nutrient closer to roots of plants. Mixing of soil ranges from 2 to 250 tonnes/ha in a year depending upon the variety of the worms. The break-up of large mineral particles into smaller size promote better intake of food by root system of plants. The mucus associated with vermicast is hygroscopic and absorbs water and prevents water logging. It thus improves soil water holding capacity. Some of the secretions of worms and associated microbes act as plant growth promoters (Lal *et al.,* 2003).

Process of breakdown of organic matter by the earthworms

Earthworms have a unique capacity to make qualititative and quantitative changes in their enzyme system to adapt to changed situations (Bezboruah and Bhargava, 2003). They are widely spread and resistant to stresses (Veeresh, 1986). The micrioflora harbouriong in the intestines of the earthworm in conjunction with soil microflora reduce organics into simpler forms. Earthworms accelerate the process of mineralization of organic materials present in its environment. It is considered that the major part of mineralization takes place in the worm gut (within its digestive system) during its passage through it. Organic mineralization is thus found to be more in worms infested soils than in those without worms. Nitrogen gets converted to nucleic acid, ammonia, urea and nitrates during mineralization. Microbes use carbon (C) for cell synthesis as well as a source of energy. Acids get condensed to humic acid while microbes convert organic phosphorus in to its inorganic form.

The gut enzymes produced in the earthworms are supposed to play a major role in the decomposition of organic matter during its passage through the gut. Various enzymes like amylase, chitinase, cellulose protease and urease were reported to be present in the gut (Dash and Senapati, 1986). The passage soil or waste through the gut of the worm greatly enhance bacterial growth creating a favourable environment. Actinomycetes growth creates a favourable environment. The content of actinomycetes in earthworm casting is six to seven times more than in the original waste (Bridgens, 1981). This accelerates the decomposition of organics into stabilized humus. An increase in the total viable count and in the number of nitrifying bacteria had also been observed (Jambhekar, 1991). Sixteen types of micro fungi were isolated from earthworm infested soil and the gut of Pheretima psotuma (Srinivasulu, 1986).

Selection and identification of worms

India has about 300 species of earthworms, which are adapted to a range of environment and vermiculture need. Earthworms can be divided as surface living (epigeic) and burrowing (epianecic) worms. Epigeic or compost worms are found on surface and are reddish brown in colour. *Eisenia foetida* and *Eudrilus eugeniae* are exotic worms and *Perionyx excavatus* is a native species used for vermicomposting in India. Local species such as Lampito mauritii, Octochaetona serrata and Perionyx excavatus are also found useful for vermicomposting. Though more than twelve species are being used for vermicomposting across the globe, African night crawler (*Eudrilus eugenie* Kinberg) and red compost worm (*Eisenia foetida* Savigny) are widely used species. The characteristics feature of red earthworm are given in Table 4.

Table 4. Important characteristics of red earthworm (*Eisenia foetida*)

Characters	*values*
Body length	3 - 10 cm
Body weight	0.4 - 0.6 g
Maturity	50 - 55 days
Conversion rate	2.0 q / 1000 worms / 2 months
Cocoon production	1 in every 3 days
Incubation of cocoon	20 - 23 days

Source: Azad Thakur (2007)

Depending upon the habitat characteristics, distribution in soil or feed media and tropic functions, the earthworms can be again three types. These are Epiges, Endoges and Aneciques.

Epiges : These are small sized earthworms with uniform body colouration, live on surface litter or dung, tolerate disturbance, have active gizzard; but have limited period of activity. These are phytophagous. Most of these species are good bio-degraders. So are good nutrient releasers. They have high reproduction rate with short life cycle.

Endoges : These are small or large sized worms with weak pigmentation, found in top soil layer of organic and mineralized matter. Burrow branchings are horizontal and worms moderately tolerate to disturbance. These are geophagous. Life cycle is of intermediate duration but is potential in soil improvements due to high efficiency in energy utilization from poor soils.

Aneciques : These are large sized worms with pigmentation only at anterior and posterior ends. These are largely nocturnal, deep burrowing and pull leaves or litter matter into soil and are phyto-geophagous. Tolerance to disturbance is poor and reproduction rate as evident from cocoon production is low.

The earthworm should be efficient in conversion of organic matter into vermicompost. They should be tolerant to disease and should be easily cultured. They should have high growth rate, good consumption, digestion and assimilation of agricultural and animal waste etc. They worm should have wide adoptability i.e., tolerance. Mass multiplication should be in short duration. The growth rate and maturity should be first. Moreover, the worms should have compatibility with other worms present in the compost pits.

Factor affecting the earthworm multiplication

Three basic conditions control the size of worm population

a) Food availability
b) Space requirement
c) Fouling of their environment.

When food and waste is regularly fed to worms in a limited space, the worms and associated organisms break down this waste, absorbing the nutrients they require and excreting the rest. As the worms reproduce competition for the available food increases. The density of the worms may exceed that favourable for cocoon production, resulting in slower reproduction. To maintain worms population to increase they must be provided increasing amount of food, space and fresh bedding. Additionally all the worms excrete castings, which have been shown to be toxic to members of their own species. As more of the bedding is converted to castings, worms will migrate, if possible, to areas with a higher proportion of feedstock and a lower proportion of casts. If conditions deteriorate, worm's numbers may drop. This is an important consideration for municipal-scale composting, as very large quantities of worms will need to be maintained, depending on the quantity of organic waste arising and desired rate of throughput. In order to maintain worms numbers it may be necessary to harvest a slightly lower grade of vermicompost before the proportion of castings reaches toxic levels. Worms separated from the casts are then used to expand the system. Some authorities believe that under ideal conditions, worms may live as long as ten year. The optimal condition for breeding E. foetida was given by Edwards (1988) whose values do not differ much from those suitable for other species (Table 5).

Table 5. Optimal conditions for breeding *E.foetida* in animal and vegetable wastes

Condition	Requirements
Temperature	15-20^{0}C (Limits 4-30^{0}C)
Moisture content	80-90 % (Limits 60-90 %)
Oxygen requirements	Aerobicity
Ammonia content of wastes	Low: <0.5 mg/g
Salt content of wastes	Low: <0.5 %
pH	> 5 and < 9

Source: Azad Thakur (2007)

Earthworms act as artificial fertilizer factories

Palaniappan and Annaduari (1999) described earthworms as mini fertilizer factories due to following reasons-

- Earthworms gut is an effective tubular bioreactor with raw materials (feed) entering from one end and the product (Castings) coming out through the other end.
- They maintain a stable temperature through novel temperature regulation mechanisms, thus accelerating the rates of bioprocesses and preventing enzyme inactivation caused by high temperature.
- Gizzard is a novel colloidal mill in which the feed is ground into particles smaller than 2 microns, giving thereby an enhanced surface area for microbial processing.
- They have an in-house supply of enzymes such as protease, lipase, amylase, cellulase and chitinase, which biodegrade complex biomolecules into simple compounds utilizable by the symbiotic gut microflora.
- Earthworms have a built-in oxygen plant, which can separate aerial oxygen by chemical absorption into blood hemoglobin.
- They promote growth of microorganisms in their gut by providing favourable conditions.
- Castings contain nutrients in a balanced proportion and are rich in vitamins, enzymes, antibiotics and growth hormones.

VERMICOMPOSTING

Vermicomposting is a method of preparing enriched compost with the use of earthworms. It is one of the easiest methods to recycle agricultural wastes to produce quality compost. The term vermicomposting is derived from the Latin term ‘vermis’, meaning worms. Vermicomposting is essentially the consumption of organic material by earthworms. This speed-up the process of decomposition and provides nutrient rich end product, called vermicompost, in the form of ‘worm castings’.

Earthworms consume biomass and excrete it in digested form called ‘wormcasts’ or ‘vermicast’. The casts are rich in nutrients, growth promoting substances, beneficial soil micro flora and having properties of inhibiting pathogenic microbes. Worm casts are popularly called as Black Gold. During feeding earthworms use only 5-10% of the food intake for their growth and the rest is excreted out as casting. Burrowing activities of earthworms improve air and water penetration into soil and improves soil physical properties beneficial for plant growth. Vermicasts being granular with enhanced porosity and water absorption capacity and absorb moisture particularly during night and hold it effectively for releasing it to micro-roots of the vegetation. Earthworms are able to process sewage sludges and solids from waste water (Neuhauser *et al.*, 1988), brewery wastes (Butt, 1993) processes potato waste (Edwards, 1983), waste from the paper industries (Butt, 1993), wastes from the supermarkets and restaurants (Edwards, 1995), animal waste from poultry, pigs, cattle, sheep, goats, horses and rabbits (Edwards et al., 1985 and Edwards, 1988) as well as the agricultural and horticultural residues from dead plants and farm wastes (Edwards, 1995) and wastes from the mushroom industry (Edwards, 1988). Earthworms are nocturnal in habit and remain active in night. One earthworms eats equal to its body weight i.e., approximately 1 g a day and same amount of faeces is released. Thus 1000 worms will produce 1 kg/day vermicompost and within 2-3 months 1m2 bed will be converted into vermicompost. During this period the earthworm numbers will be increased to 20-30 times (Lal et al., 2003). To produce one kg of vermicompost about 8 kg of raw materials are needed. If one million worms exist in one acre, the cast they produce in that area is about 500 kg/day/acre, i.e., about 200 tonnes per year. Wormcasts consist of organic matter that has undergone physical and chemical breakdown through the activity of muscular gizzard, which grinds the materials to a particle size of 1-2 micron. Wormcast is a rich source of macro and micronutrients, vitamins, enzymes, antibiotics, growth hormones and immobilized microflora. The nutrients present in wormcasts are mostly in available form.

A. Preliminary treatment or pre-composting

Proper collection and sorting of compostable, non-compostable and non-biodegradable materials like plastic, stone, glass, ceramics and metals should be done. Composting of heavily contaminated wastes particularly with heavy metals and toxic chemicals or infested with insect pests should be avoided. Materials like bagasse should be cut into small pieces for enhancing decomposition. The cleaned matter should be heaped and large lumps should be broken (Chandra and Agrawal, 2002).

Before using the materials in the vermicomposting pits, they should be subjected to partial decomposition for about 20 days in heaps. Pre-composting the feedstock decreases the amount of energy contained within the materials, so that heating does not take occur within the worm system. Feedstock which are pre-composted for 10-14 days retain sufficient nutrition for the worms, but not so much energy that they are able to generate heat.

B. Methods of vermicomposting

Vermicomposting is done by two methods:

1. Bed method

Composting is done on the pucca / kachcha floor by making bed (6 x 2 x 1 feet size) of organic mixture. This method is easy to maintain and practice.

2. Pit method

Composting is done in the cemented pits of size 5 x 3 x 3 feet. The unit is covered with thatch grass or any other locally available materials. For commercial purpose, polythene or GIS sheet is used for covering the unit. For large scale production pit method of vermicompost is preferred.

C. Steps for vermicomposting

- Vermicompost unit should be established in a cool, moist and shady site.
- Dried leafy materials are chopped into small pieces of 5 cm size.
- Cow dung and leafy materials are mixed in the proportion of 3:1and are kept for partial decomposition (15-20 days).
- A layer of 15-20 cm of chopped dried leaves/ grasses is kept as bedding material at the bottom of the bed.
- Beds of partially decomposed materials of size 6x2x1 feet are made.
- Bed can also be prepared by putting alternate layers (5-6) of partially decomposed cow dung and chopped materials.
- Each bed contains 1.5-2.0 q of organic waste and number of such beds can be prepared to meet the requirement.
- Red earthworm (1000 no) is released in the upper layer of mixture (1000 worms /m^2 area).
- Water is sprinkled with water cane immediately after the release of worms.
- Beds are kept wet by light sprinkling of water (twice daily) and covered with gunny bags/polythene to maintain optimum moisture level. The moisture should be 40 to 60%. Frequency of watering depend according to season. During winter once a day, while in summer 2 or 3 times a day watering is needed.
- Two turning of bed material (at 15-20 days interval) should be done for maintaining aeration and proper decomposition.
- Decomposition is completed in 45-50 days. When vermicasting are ready for collection, top layers appear somewhat dark brown, granular as if used tea leaves have been spread over the layer.
- Watering should be stopped 2-3 days before harvesting and gently compost should be scrapped from the top layers.
- Harvested vermicompost is sieved before application to separate un-decomposed materials and worms.
- To separate earthworms from compost, it is kept over a thin layer of un-decomposed material for 6- 24 hours before sieving. If there are any adult worms present, they would move down or away from the heaped materials.
- The collected materials are sieved to avoid any adult /cocoon being removed with the compost.
- After collection of vermicompost from the top layer, feed materials are again replenished and composting process is rescheduled as earlier.
- Collected vermicompost is air dried in shade before packaging in convenient place.

D. Bedding materials

The bedding materials are needed to hold the air spaces so that noxious odours dot not accumulates inside the pits. Good bedding materials can be any combination of decomposed manures, shredded coconut husk, coir (coconut fibre), shredded paper products, sugarcane trash, decomposed leaves, straw, peat moss etc. The bedding materials will also be consumed by the earthworms and should be discarded after six months and afresh bedding materials should be added for efficient vermicomposting.

E. Preventive measures

- The floor of the unit should be compact to prevent worms migration into the soil.
- The organic wastes should be free from plastics, chemicals, pesticides and metals etc.
- Optimum moisture level (40-60 %) should be maintained in the beds.
- Aeration should be maintained for proper growth and multiplication of earthworms.
- 20-25 days old cow dung should be used to avoid excess heat in the compost heap.
- 18-25°C temperature should be maintained for better result.
- For protection from ants and termites etc, a small peripheral channel filled with water may be provided around the vermicompost pits.
- Crop residues for vermicomposting may be subjected to pre-treatment with 4% aqueous solution of neem insecticides to prevent infestation.

CONVERSION EFFICIENCIES

Vermicomposting efficiency of different earthworm species

In general, a bed of 1x1x3.0 m requires 30-40 kg of bedding and feed materials. This can support 1000-1500 worms, which would multiply and compost the matter from upper layers. From the top layer accumulated casts should be removed periodically as it reduces the activity of earthworms. Earthworms activity like burrowing, feeding and defecating (casting) exhilarate the process of decomposition. So larger the number of earthworms present in an appropriate medium and conditions, faster would be vermicomposting. Thus initially i.e., immediately after introduction of worms, first lot of vermicompost is ready within 60-70 days. Gradually with bacterial decomposition leading to breaking of larger masses and increase in number of worms, vermicompost is ready in 30-45 days only. It has been observed that by the use of cattle dung mixed with half decomposed grasses choppings in equal proportions takes 50-75 days, while cattle dung alone takes 40-45 days for the production of vermicompost. The efficiency of earthworms for conversion to vermicompopst varies from species to species. It is clear from the data presented in Table 6 that E. foetida is most efficient in converting raw materials to vermicomposts followed by E. eugeniae.

Table 6. Production potential of vermicompost by different earthworm species.

Earthworm species	No. of earthworms added/m^2	Quantity of feed materials added (kg/m^2)	Days taken to complete feeding	Quantity of vermicompost obtained (kg/m^2)
E. foetida	2000	200	59	38.4
E.eugeniae	2000	200	50	36.1
Local species	2000	200	75	25.2

Source: Rao and Jha (2005)

Conversion efficiency of different biomass/substrate

Efficiency of substrates for vermicomposting dpends on the type of biomass used. An experiment was conducted in 1x1x 0.6 m sized pits in which fresh cow dung was used @ 65 kg/pit having 48% dry matter content. Different substrates were used for vermicomposting and the efficiencies of different substrates were evaluated (Vishwakarma *et al.*, 2007). The conversion efficiency of different substrates to vermicompost was observed to be different (Table 7).

Table 7. Conversion effeciciencies of different substrates for production of vermicompost

Substrate	Quantity of biomass used including cow dung (kg on dry weight basis)	No. of worms released	No. of worms obtained after vermicomposting	Days required for vermicomposting	Quantity of vermicompost produced (kg)
Common weeds	250.0	2000	4000	65	100.0
Foliage of *Erythrina indica*	61.5	2000	3527	80	18.0
Ambrossia artimissifolia	97.3	2000	3000	52	27.0
Maize stover	130.0	2000	2950	80	27.7
Spent spawn of mushroom	90.0	2000	4450	60	45.0

Source: Vishwakarma *et al.* (2007)

Factor affecting vermicomposting

The quality and type of raw materials, temperature, moisture and aeration, number and quality of earthworms affect the vermicomposting process (Jambhekar, 1991). Other physico-chemical parameters affecting a composting process also affect the vermicomposting process. The basic parameters important for Vermicomposting are the moisture content and temperature (Sahu and Senapati, 1986). A temperature of around 250C is most favourable for the tropical earthworms. The pH best suited for vermicomposting is between 6.5 to 7.5 (Jambhekar, 1991). Most of the earthworms cannot tolerate saline conditions (Jaluka and Paliwal, 1986).

CHARACTERISTICS AND NUTRIENT ANALYSIS OF VERMICOMPOST

The final physical structure of the plant growth media or vermicompost produced from organic wastes depends very much on the parent waste from which they were produced. Final product from the most organic waste is usually a finely divided peat-like material with excellent structure, porosity, aeration, drainage and moisture holding capacity. Structurally, it has the appearance and many of the characteristics of peat and additionally contains plant nutrients. The nutritional values of vermicompost vary according to the composition of organic wastes and the type of worms used (Table. 8). The vermicompost is thus not a single standard materials and product. On an average, vermicompost contain more carbons and phosphorus than FYM, it has less potassium and micronutrients than FYM and both has comparable content of nitrogen. An important feature of the vermicompost is that, during the processing of the various organic wastes by earthworms, many of the nutrients that they contain are changed to forms that are readily taken up by plants, such as nitrate or ammonium nitrogen, exchangeable phosphorus and soluble potassium, calcium and magnesium.Vermicompost generally has wide C: N ratio has compared to FYM (Chandra and Agrawal, 2002).

Table 8. Nutrient status of vermicompost prepared by using different species of earthworms.

Parameter	*Vermicompost*		FYM
	E. foetida	*P. excavatus*	
pH	7.4	7.0	7.2
Electrical conductivity (dSm^{-1})	0.90	1.20	0.18
Organic carbon (%)	27.43	30.31	12.20
Free $CaCO_3$	10.50	7.0	-
C:N ratio	45.70	45.90	24.4
Major nutrients			
Total N (%)	060	0.66	0.50
Available N (ppm)	450.0	496.0	375.0
Total P_20_5 (%)	1.34	1.93	0.75
Total K_20 (%)	0.40	0.42	2.30
Micronutrients			
Fe (ppm)	17.80	19.80	24.70
Zn (ppm)	19.20	0.90	40.0
Mn (ppm)	24.60	16.50	120.0
Cu (ppm)	7.60	2.30	2.8

Source: Chandra and Agrawal (2002).

The general range of nutrients in vermicompost was given by kale (1998) (Table 9). Vishwakarma et al. (2007) reported that vermicompost is much superior to other organic manures in terms of nutrient content except poultry manure that has higher N, P and K content but lower Ca and Mg contents than vermicompost (Table 10).

Table 9. Range of nutrients in vermicompost

Properties	Range
1. Organic carbon (%)	9.15-17.98
2. Total nitrogen (%)	0.50-1.50
3. Available phosphorus (%)	0.10-0.30
4. Available potassium (%)	0.15-0.56
5. Available sodium (%)	0.06-0.30
6. Clcium and magnesium (meq/100g)	22.67-47.60
7. Copper (ppm)	2.00-9.50
8. Iron (ppm)	2.00-9.30
9. Zinc (ppm)	5.70-11.50
10.Available sulphur (ppm)	128.0-548.0

Bio-chemical properties of vermicompost

1. *C: N Ratio*

The C: N ratio is one of the most important parameters that determine the extent of composting and the degree of compost maturity. Pre-treatment of the substrate reduced the C: N ratio of legume residue, leaf litter and wheat straw to 17.04, 19.85 and 44.46, respectively. Irrespective of the materials used for composting, all the vermicomposts attained an optimum C: N ratio (‹12) which ensured an acceptable degree of maturity within 60 days. The C: N ratios of legume residues, leaf litter and wheat straw vermicompost after 60 days were 8.72, 9.95 and 12.83, respectively but for the same material it was 10.26, 9.98 and 19.02, respectively when composted by the conventional method (Zachariah and Chhonkar, 2004). Both earthworm activity and initial C: N ratios of substrate had significant influence on the C: N ratios of the compost. The C: N ratio of the composted materials narrowed down with the advancement of the period of decomposition. It was reported that the C: N ratio narrows down as nitrogen remains in the system, while some of the C is released as CO2 (Gaur and Sadasivam, 1993). Earthworm activity stimulates rate of organic matter decomposition by increasing the surface area and aeration of the substrate (Edwards, 1983). The intestinal mucus which consists of easily metabolizable compounds is considered to result in a priming effect of earthworms to microbial decomposition (Albanell *et al.,* 1988; Elvira *et al.,* 1996; Vinceslas-Akpa and Loquet, 1997). Further, nitrogen fixing bacteria indirectly help in decreasing C: N ratio by making more nitrogen available from added organic matter (Rasal *et al.,* 1988; Shinde *et al.,* 1992).

Table 10. Nutrient content (%) of vermicompost vis-à-vis other organic manures (± S.D)

Type of manure	N	P	K	Ca	Mg
Poultry manure	2.12±0.05	1.40±0.02	1.16±0.05	2.32±0.16	2.45±0.25
Farmyard manure	0.65±0.05	0.18±0.02	0.50±0.08	3.82±0.33	3.96±0.02
Goar manure	1.16±0.22	0.40±0.04	1.09±0.09	3.20±0.25	3.65±0.25
Vermi-compost	2.15±0.50	0.55±0.06	0.95±0.07	4.15±0.24	3.60±0.33
Pig manure	0.50±0.27	0.35±0.05	0.28±0.02	2.15±0.33	2.85±0.24
Liquid manure	0.56±0.03	0.45±0.01	0.18±0.04	0.10±0.002	0.07±0.01
Duck manure	1.85±0.10	1.46±0.11	0.98±0.07	1.99±0.22	2.22±0.23

Source: Vishwakarma *et al.* (2007)

2. *Biomass carbon*

Biomass C content of composts was not influenced due to earthworm activity but was significantly influenced by the kind of substrate (Zachariah and Chhonkar, 2004). Wheat straw compost recorded the highest biomass C (16.74 mg g-1) and was followed by leaf litter compost (11.93 mg g-1) and legume residues compost (9.31 mg g-1) (Table.11). The substrate effect on biomass C may be due to the difference in degree of degradation. Modini et al. (1997) reported a decrease in microbial biomass C on composting, due to decrease in easily available biodegradable organic matter in the compost which stimulated the biomass synthesis. wheat straw having wide C:N ratio, took more time for degradation and hence the higher biomass C. Though there was no significant increase in biomass C due to earthworm activity, the slight increase may be due to increased number of microorganisms present in the earthworm casts. Daniel and Anderson (1992) observed no change in microbial biomass after a gut passage lasting 6-8 hour and were of the opinion that change in microbial biomass is small and was masked by experimental and sampling error.

Table 11. Effect of earthworm on the biomass C units of the compost prepared from different materials

Substrate	-EW	+EW	Mean
Legume residue	6.8	11.8	9.3
Leaf litter	10.6	13.2	11.9
Wheat straw	14.8	18.7	16.7
Mean	10.8	14.6	

CD (P=0.05), substrate(S) 4.6; Earthworm (E) NS; SxE NS; Source: Zachariah and Chhonkar, (2004)

3. *Enzyme activity*

3.1. Cellulase activity

Zachariah and Chhonkar (2004) reported that average value of cellulase activity of vermicomposted materials was 1226.9 µg glucose g-1 dry compost hr-1 that was markedly higher than composts prepared without earthworms. Vinceslas-Akpa and Loquet (1997) showed more cellulolysis in the vermicompost based on NMR spectroscopy and also observed that cellulolysis was more in the first month of vermicomposting compared to ordinary composting. Whiston and Seal (1998) demonstrated that E. foetida can produce endogenous carboxyl methyl cellulose.

3.2. Urease activity

Urease activity of legume residue compost was less compared to leaf litter and wheat straw compost (Table 12). It may be due to the production of NH_4^+ in legume compost due to its narrow C: N ratio. Since NH_4^+ inhibits urease activity and synthesis, a release of NH_4^+ by urealysis may have been responsible for lower urease activity (Burgos *et al.*, 1993). The increase in urease activity due to earthworm inoculation may be due to the increased biomass of earthworm and microbes which increases the enzyme activity. Also the presence of N-fixers in vermicompost might have stimulated conversion of NH_4^+ to NO_3^-.

3.3. Phosphatase activity

The average value of alkaline (2540.2 µg PNP g-1 dry compost hr-1) and acid phosphatase (1946.6 µg PNP g-1 dry compost hr-1) activity of the vermicomposts were significantly higher compared to composts prepared by conventional method (160.9 and 1064.1 µg PNP g-1 dry compost hr-1) from the same materials (Table 12). Materials used for composting and interaction between earthworm and substrate also had significant influence on the phosphatase activity of the compost (Zachariah and Chhonnkar, 2004). Tiwari *et al.* (1989) also found higher phosphatase activity in earthworm casts. Van Gansen (1962) histo-chemically demonstrated alkaline phosphatase activity in E. foetida and showed crop epithelium as the area of high concentration of phosphatase activity in worm feces. Also earthworms increase phoshatase activity indirectly by stimulating microflora (Sharpley and Syres, 1976). The variation in alkaline and acid phosphatase activity shown by composts prepared from different materials may be due to a combination of variation in earthworm and microbial activity, increased biomass and the differences in various organic phosphate compounds present in different materials and the stage of composting (Benitez *et al.*, 1999).

Table 12. Enzyme activities of compost prepared from different materials

Treatment	Cellulase (µg glucose g^{-1} dry compost hr^{-1})	Urease (µg urea g^{-1} dry compost hr^{-1})	Alkaline phosphatase (µg PNP g^{-1} dry compost hr^{-1})	Acid phosphatase (µg PNP g^{-1} dry compost hr^{-1})
Without earthworm				
Legume residue	1064.4	437.7	2043	1006.3
Leaf litter	598.1	553.2	1327.2	1288.5
Wheat straw	1134.1	619.2	1456.8	897.5
With earthworm				
Legume residue	1249.7	528.9	3231.8	1705.0
Leaf litter	1156.5	592.8	2084.5	2740.3
Wheat litter	1274.6	843.3	2304.3	1394.3
CD (P=0.05)				
Substrate (S)	NS	73.9	449.1	323.1
Earthworm (E)	NS	56.7	344.7	247.9
S x E	NS	104.5	NS	456.9

Source: Zachariah and Chhonkar, (2004)

4. *Humic and fulvic acid content*

Both humic and fulvic acid content were significantly changed due to earthworm activity. Fulvic acid content of normal and vermicompost was 6.17 and 18.03 % while that of humic acids was 11.82 and 12.15%, respectively (Zachariah and Chhonkar, 2004). Compost quality increase with increasing humic acid percentage (Jimenez and Garcia, 1989). Forester *et al.* (1993) was of the opinion that low fulvic acid and high humic acid percentage were the indications that the compost has reached an advanced stage of maturity.

RATE OF VERMICOMPOST APPLICATION

The rate of application of vermicompost depends up on the nutrient composition of vermicompost, nature and requirement of crops, the soil fertility etc. The blanket recommended dose are –

Crops	Rate
Field crops	5 - 6 t/ha
Vegetables	5-10 t/ha
Fruit crops	3 - 5 kg/plant
Pots	100-200 g/pots

ECONOMIC BENEFIT

Azad Thakur (2006) reported that cost of the production of vermicompost in farmers field ranges between $ 7.5-12.8 per tonne depending upon the location and the availability of the farm waste. For Commercial units located in the cities, the production cost is found to be $21.3-42.5 per tonne. Rao and Jha (2005) reported a gross and net return of Rs. 46,500 and Rs.15, 200 per year, respectively from a small unit with bamboo thatched shed size 5m x 3m unit.

Vermicomposting may be a highly profitable venture for those who are having dairy units. It is possible to earn up to $1064 annually by maintaining a unit of 10 tonnes capacity.

- Market price of worms: $ 8.5-10/ kg
- Market price of compost: $0.11-0.22/ kg

The benefit of vermicomposts use is better realized when prepared in farm itself by the farmers.

VERMIWASH – A POTENTIAL LIQUID MANURE

Vermiwash is liquid manure obtained from vermicompost unit, which is used for foliar spray @10%. It contains plant growth hormones like auxins and cytokinins apart from nitrogen, phosphorus, potassium and micronutrients. This can be sprayed to the crops at vegetative and flowering stages after dilution with water. Vermiwash can be mixed with cow's urine and other liquid manure.

Method of vermiwash preparation

- Vermiwash can be prepared in any large container made of concrete or plastic materials.
- A hole is made at the base of the container to fix a tap like in a common water filter.
- At the base of the container, a layer of gravel or small broken pieces of bricks are placed up to the height of 10-15 cm.
- Above this layer, another layer of coarse sand is placed (10-15 cm thickness).
- Introduce sufficient number of earthworms into the container (about 2000).
- To get vermiwash continuously suspend a mud pot or a small bucket with some holes at the bottom. Place cotton or cloth in the holes so that water can trickle down.

- Everyday evening fill the container with 4 -5 liters water.
- In next morning vermiwash can be collected from the tap.
- Vermiwash can be diluted with water and may be used as a foliar spray @10 % as a liquid manure as well as biopesticide.

Table 13. Effect of vermicompost vis-a-vis other organic manures on productivity (t/ha) of field crops (Two years mean)

Type of manure	Rice	Maize	Soybean
Farmyard manure	3.10	3.89	1.56
Vermicompost (VC)	3.65	3.43	1.53
50% FYM + 50% VC	3.15	3.80	1.47
Control	2.13	2.35	1.12
CD (P=0.05)	0.18	0.21	0.23

Source: Das *et al.* (2014)

ADVANTAGES OF VERMICOMPOSTS

- It provides efficient conversion of organic wastes/crop/animal residues.
- Worms provide a good natural fertilizer viz., vermicompost, which is very eco-friendly, cheap and effective to plant growth and development.
- It is a stable enriched soil conditioner.
- It also helps in reducing population of pathogenic microorganisms.
- It also helps in reducing the toxicity of heavy metals.
- It is environmentally safe nutrient supplement for organic food production.
- It is an easily adoptable low cost technology.
- It is highly profitable venture if properly taken up.

EFFECT OF VERMICOMPOST ON CROPS AND VEGETABLES VIS-À-VIS OTHER ORGANIC AMENDMENTS

Field experiments were conducted in the Division of Agronomy, ICAR Research Complex for NEH Region, Umiam, Meghalaya, India to evaluate the efficacy of different organic manures for organic crop production during 2005-18. All the organic manures were supplied in quantities to meet the recommended N dose for the respective crops. Nutrient requirement was computed based on the concentration of nutrients in respective manures. Phosphorus requirement were supplemented with rock-phosphate. The crops tested were field crops (rice, maize and soybean) and vegetables (French bean, tomato, potato, carrot and radish). Field crops were grown during kharif (rainy) season and vegetables like potato, frenchbean and tomato were grown during pre-kharif season and radish, and carrot was grown during rabi season. All most all the crops recorded higher productivity with integrated application of 50% N through FYM + 50% N through vermicompost compared to sole application of farm yard manure and other manures (Table 13 and 14). The root crops were more responsive to vermicompost compared to other crops. Only frenchbean and tomato gave higher yield with farmyard manure followed by vermicompost (Hazarika *et al.*, 2006). The role of organic manures in improving soil fertility and productivity is well documented. In addition to their richness in essential plant nutrients, organic manures also supply plant growth promoting substances and humus forming microbes in the soil. Thus, the application of VC improved the overall physico-chemical properties of the soil, which caused improvement in growth and yield attributes, yield, produce quality, N and P content and uptake in dry matter (Das *et al.*, 2014; Patel *et al.*, 2015).

Table 14. Effect of vermicompost vis-a-vis other organic manure on productivity (t/ha) of vegetables (Two years mean)

Type of manure	Frenchbean	Tomato	Potato	Carrot	Radish
Farmyard manure	16.4	29.8	15.4	17.32	43.13
Vermicompost (VC)	15.1	27.5	16.2	21.96	45.74
50% FYM + 50% VC	16.2	27.5	14.1	10.44	42.93
Control	9.2	10.2	7.85	4.49	42.40
CD (P=0.05)	0.71	0.65	0.75	2.18	0.37

Source: Patel *et al.* (2015)

CONSTRAINTS IN VERMICOMPOSTING

The main constraints associated with the vermicomposting is the non-availability of efficient earthworm strains at farmers level, lack of technical know how with the farmers and poor extension linkage with the farmers. Residues are either burnt or used as cattle feed leaving less biomass for vermicomposting. Transportation of huge biomass to vermicomposting site is also a tedious job. Non-availability of animal excreta like cow dung etc also restricts the popularization of vermicomposting especially in hills of NER.

CONCLUSION

From the present paper it may be concluded that vermicomposting is an efficient method to recycle the crop, farm and domestic and rural industrial organic wastes into good quality manure for the crop production. The content of heavy metals and pathogenic microorganisms population should be checked before the urban wastes is used for vermicomposting. The suitability of the vermicomposting should be based on availability, content of nutrients and heavy metals in the organic residues. Vermicomposting is by far the best way of eco-friendly nutrient recycling in agriculture. It pays dividends when produced within the farm itself by the farmers.

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