

# An experimental study of vermi-biowaste composting for agricultural soil improvement

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## Abstract

Vermitechnology was investigated as a means of reducing organic waste materials. Vermicomposting conditions were optimized to convert the biowastes to nutritious composts for amending agricultural soil. Studies were undertaken to select the most suitable earthworm species for vermicomposting, to enrich vermicompost by inoculation with beneficial microbes, to standardize an economically feasible method of vermicomposting, to achieve nutrient economy through vermicompost application in acid soils (pH 4.5), and to assess the performance of vermicompost as a bioinoculant in cow-pea, banana, and cassava. Earthworm species *Eudrillus eugineae*, *Eisenia foetida*, *Perionyx sansibaricus*, *Pontoscolex corethrurus* and *Megascolex chinensis* were compared for their efficiencies in biodegrading organic wastes. *E. eugineae* was found to be a superb agent. As a bioinoculant, vermicompost increased nitrogen and phosphorous availability by enhancing biological nitrogen fixation and phosphorous solubilisation. Vermicompost-amended acid-agriculture-soil significantly improved the yield, biometric character and quality of banana, cassava and cow-pea. Vermicompost application stimulated root growth, facilitating nutrient absorption and thereby favouring higher yield.

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**Keywords:** Vermicomposting; *Eudrillus eugineae*; Humification indices; Bioinoculant; Nutrient enrichment

## 1. Introduction

Organic matter plays a key role to achieve sustainability in agricultural production because it possesses many desirable properties such as high water holding capacity, cation exchange capacity (CEC), ability to sequester contaminants (both organic and inorganic) and beneficial effects on the physical, chemical and biological characteristics of soil. The organic degradable refuse of plant and animal origin provides a good source of nutrients to improve soil productivity. However, in most developing countries the degradable organic matter from wastes dumped in the open undergoes aerobic or anaerobic degradation. These un-

engineered dumpsites permit fine organic matter to become mixed with percolating water to form leachate which may pollute adjoining water and soil (Sharma et al., 2005). With the increasing need to conserve natural resources and energy, recycling of organic wastes assumes major importance. Earthworms have been long recognized by farmers as beneficial to soil (Singh and Pillai, 1973; Edward and Lofty, 1977) and, as one of the major soil macro fauna, constitute an important group of secondary decomposers. Earthworms are key biological agents in the degradation of organic wastes (Syres et al., 1979; Albanell et al., 1988; Jambakar, 1992).

Vermicomposting technology using earthworms as versatile natural bioreactors for effective recycling of organic wastes to the soil is an environmentally acceptable means of converting waste into nutritious composts for crop production (Graff, 1981; Edward et al., 1985; Bano et al.,

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1987). Vermicompost is homogenous, with desirable aesthetics, plant growth hormones and high levels of soil enzymes, while enhancing microbial populations and tending to hold more nutrients over longer periods without adverse impacts on the environment (Ndegwa and Thompson, 2001). It can also be used as a bioremediation measure to reclaim problem soils, especially acid soils, because of the near-neutral to alkaline pH of vermicompost and the suppression of labile aluminium (Mitchell and Alter, 1993).

Considerable work has been carried out on vermicomposting of various organic materials such as animal dung, agricultural waste, forestry wastes, city leaf litter and food wastes (Hand et al., 1988a; Logsdon, 1994; Madan et al., 1988; Singh and Sharma, 2002). Similarly, industrial wastes such as guar gum industrial waste, paper pulp, and distillery wastes have been vermicomposted and turned into nutrient rich manure (Sundaravadivel and Ismail, 1995; Suthar, 2006; Suthar, 2007). Vermicomposting is defined as a low cost technology system for processing or treatment of organic waste (Hand et al., 1988b). Epigeic forms of earth worms can hasten the composting process to a significant extent (Senapathi, 1988; Kale et al., 1982; Tomati et al., 1983), with production of better quality of composts, compared with those prepared through traditional methods (Tripathi and Bhardwaj, 2004).

Certain epigeic earthworm species such as *Eisenia foetida*, *Perionyx excavatus* and *Eudrillus eugineae* are voracious feeders of organic wastes (Senapathi, 1994; Kale and Bano, 1985). All aspects of the worm biology such as feeding habits, reproduction and biomass production potential must be known (Senapathi et al., 1980; Bouche and Ferriere, 1986) in order to utilize the earthworms successfully in vermiculture. Since the diversity of earthworm species varies with different soil types and different agro climatic conditions, the species suited to a particular region must be identified. Limited study has examined the extent of reduction of inorganic fertilizers by applying vermicompost as an organic source and the effect of vermicompost on the yield and quality of crops such as cow-pea, banana and cassava which are the main diet for people in Kerala, India. To the authors' knowledge, no previous studies have been conducted on the enrichment of vermicompost by beneficial microbes to increase the fertilizer value and reduce the dose of application. In this paper, the results of a systematic and comprehensive study to select the optimum earthworm species for vermicomposting, enrichment of vermicompost and nutrient economy through vermicompost application in acid soils of Kerala, India with humid tropical climatic conditions are presented. Simple procedures and tools were used in this study to suit local conditions, where the farmers could adopt vermiculture with ease. The final outcome aids in converting the burden of waste disposal into an opportunity to produce high-potential organic fertilizers, capable of enhancing soil fertility, bioremediation and improving crop quality, thereby assisting economical growth and protecting the environment.

## 2. Methods

### 2.1. Selection of suitable earthworm species

Efficient epigeic species such as *E. eugineae* and *E. foetida* were compared with local earthworm species such as *Perionyx sansibaricus*, *Pontoscolex corethrurus* and *Megascolex chinensis* for their composting efficiency. The efficiency was assessed in terms of the time taken for vermicomposting, quality of the compost and biomass potential of the earthworms at compost maturity.

To prepare a uniform feed material, fresh banana leaves were mixed with cow-dung in the ratio of 1:1 on a weight basis and moistened to 45–50%. One ton of this biowaste was heaped on outdoor unpaved ground and exposed to the temperature between 29 and 32 °C for two weeks. The heat generated during the initial stages of decomposition, by the breakdown of complex biomolecules raised the temperature to >60 °C, i.e. to the thermophilic range. The worms were introduced after this stage since the heat could otherwise have harmed them.

Vermicomposting with different types of worms and conventional composting were conducted using a Completely Randomized Design with five conditions and four replications. Treatment details are summarized in Table 1. All tests were carried out at the ambient temperature of 29–32 °C with the moisture maintained at 40% by sprinkling 250 ml water/tank on alternate days.

Composting was carried out in cement tanks of volume 45 cm<sup>3</sup> in thatched sheds. 250 adult clitellate worms were introduced into 20 kg of pre-treated biowaste. When the compost was ready by its physical appearance, as judged by development of a dark brown to black colour with uniformly disintegrated structure, watering was stopped. One or two days later, the compost was removed from the tank together with the worms, heaped on a plastic sheet and kept in the shade. The compost was removed from the top leaving the earthworms in a bundle at the bottom. The total biomass of earthworms was estimated by counting the number of adults, juveniles and cocoons from each replication. Conventional compost, i.e. without earthworms, was also prepared both by sealed and open methods for comparison. The times taken for composting and compost recovery were noted. The ratio of decomposed (<2 mm) to undecomposed (>2 mm) of the biowaste by weight in the compost was determined by sieving. Samples of air dried compost were used for fractionation and chemical analysis. Compost samples were analyzed for pH, CEC, total organic carbon (C), total nitrogen (N), phosphorous (P), potassium (K), C/N ratio, calcium (Ca), magnesium (Mg), manganese (Mn), zinc (Zn), and copper (Cu). The samples were analysed based on standard analytical procedures (Stevenson, 1994) for alkali extractable carbon, humic acid, fulvic acid, oxidisable carbon, humic carbon and fulvic carbon. To assess the degree of maturity of the compost, different humification indices were calculated: i.e. Humification ratio (HR) – alkali extractable carbon/

Table 1  
Details of treatments

Type of study	Treatment #	Testing details	Parameters obtained
Selection of earth worm	T1	Vermicomposting by native worms which included a mixture of <i>Perionyx sansibaricus</i> , <i>Pontoscolex corethrurus</i> and <i>Megascolex chinensis</i>	<ul style="list-style-type: none"> <li>• Micronutrient content – Mn, Zn, Cu</li> <li>• Efficiency of earthworm</li> <li>• Humification indices (i.e. C/N ratio, Humic C/fulvic C, Pha%)</li> <li>• Physio-chemical properties of compost</li> </ul>
	T2	Vermicomposting by <i>Eudrillus eugineae</i>	
	T3	Vermicomposting by <i>Eisenia foetida</i>	
	T4	Conventional Composting (open)	
	T5	Conventional Composting (sealed)	
Nutrient enrichment of compost by inoculation with beneficial micro-organisms	CT1	Conventional compost alone	<ul style="list-style-type: none"> <li>• Nutrient composition N, P and K</li> <li>• Metal conc. in compost</li> <li>• Tested on chilli</li> </ul>
	CT2	Conventional compost + P-solubilisers	
	CT3	Conventional compost + <i>Azospirillum</i>	
	CT4	Conventional compost + P-solubilisers + <i>Azospirillum</i>	
	ET1	<i>Eudrillus</i> compost alone	
	ET2	<i>Eudrillus</i> compost + P-solubilisers	
	ET3	<i>Eudrillus</i> compost + <i>Azospirillum</i>	
	ET4	<i>Eudrillus</i> compost + P-solubilisers + <i>Azospirillum</i>	
Comparison of various nutrient economy	PT1	Full N P K + cow-dung as organic source	Agriculture economic: <ul style="list-style-type: none"> <li>• Cow-pea growth</li> <li>• Banana</li> <li>• Cassava</li> </ul>
	PT2	Full N P K + <i>Azotobacter/Rhizobium</i> as bioinoculant	
	PT3	Full N P K + vermicompost as bioinoculant	
	PT4	Full N P K + <i>Azotobacter/Rhizobium</i> and vermicompost as bioinoculant	
	PT5	1/2 N & P and full K + <i>Azotobacter/Rhizobium</i> as bioinoculant	
	PT6	1/2 N & P and full K + vermicompost as bioinoculant	
	PT7	1/2 N & P and full K + <i>Azotobacter/Rhizobium</i> and vermicompost as bioinoculant	
	PT8	Full NPK + vermicompost as organic source	
	PT9	Full NPK + 1/2 vermicompost as organic source	

Experimental conditions – surrounding temperature ranged from 29 to 32 °C in a thatched shed, not covered. Moisture content was maintained at 40% by sprinkling 250 ml water/treatment on alternate days and by turning over the waste mixture.

Note: For cow-pea, *Rhizobium* was applied, whereas for banana and cassava, *Azotobacter* was applied.

Dosage of full NPK for cow-pea – N: 20 kg/ha; P<sub>2</sub>O<sub>5</sub>: 30 kg/ha and K<sub>2</sub>O: 10 kg/ha.

Dosage of full NPK for banana – N: 190 g/plant; P<sub>2</sub>O<sub>5</sub>: 115 g/plant and K<sub>2</sub>O: 300 g/plant.

Dosage of full NPK for cassava – N: 50 kg/ha; P<sub>2</sub>O<sub>5</sub>: 50 kg/ha and K<sub>2</sub>O: 50 kg/ha.

oxidisable carbon, Humification Index (HI) – humic carbon/oxidisable carbon, Percentage humic acid (Pha) – humic carbon/alkali extractable carbon multiplied by 100.

## 2.2. Nutrient enrichment of vermicompost by inoculation with beneficial micro-organisms

The manurial value of a compost is determined by its plant nutrient content, while the quality of a compost is determined by the composition of the base material. An attempt was made to improve the quality of compost by inoculating with beneficial micro-organisms such as N-fixing and P-solubilising organisms to increase the fertilizer value and reduce the dose of application. Each compost sample was inoculated with beneficial micro-organisms 1 g/kg of compost and incubated for two weeks. Details of the experimental program for the study on nutrient enrichment of various composts are given in Table 1. The enriched compost was then analyzed for N, P, K, Ca, Mg, Mn, Zn and Cu (Jackson, 1973).

Using the enriched compost, a test crop, chili (*Capsicum annum*) was raised in a Randomized Block Design with

nine treatments and three replications. In addition to the eight treatments listed in Table 1, an additional treatment, ET5 – application of cow-dung – was also conducted. The soil at the experimental site comes under the USDA taxonomic classification – loamy kaolinitic isohyperthermic rhodic haplustoxs. Biometric observations were recorded at five stages of crop growth, i.e. 35, 50, 60, 80 and 90 days after planting. The experimental area has a humid tropical climate, with a mean annual rainfall of 120–150 cm and a temperature from 23 to 34 °C. Uprooted plants were chopped, dried to constant weight in an electric oven at 70 °C, ground and passed through a 0.5 mm sieve. N, P, K, Ca, Mg, Mn, Zn and Cu concentrations in the plant samples were estimated as recommended by Jackson (1973). Total uptake by the plants was calculated as the product of the fraction of these nutrients in the plant samples and the dry weight.

## 2.3. Nutrient economy through vermicompost application

The performance of vermicompost (by *E. eugineae*) as a bioinoculant, cow-dung as organic source and biofertilizers

were compared in cow-pea, banana, and cassava (Table 1). The efficiencies of biofertilizers such as *Rhizobium* and *Azotobacter* were compared with vermicompost in coating seeds or dipping seedlings, either alone or in combination. The possibility of reducing inorganic fertilizers was also investigated. In the case of cow-pea, seeds were uniformly mixed with *Rhizobium*/vermicompost, with starch solution added to ensure better stickiness. For banana, the rhizome was smeared with *Azotobacter* culture/vermicompost suspension, whereas in tapioca the setts (stem cuttings) were dipped in *Azotobacter* culture/vermicompost suspension (1:1 suspension) before planting. All routine biometric observations were recorded. The quality of fruits was assessed by estimating reducing sugars, non-reducing sugars, sugar/acid ratio, percentage acidity and shelf life. The soil samples from each plot were analysed for available macro and micronutrients. Plant samples were oven dried, powdered and analysed for important nutrients following the methods described by Jackson (1973).

#### 2.4. Statistical analysis

Data for various treatments from the experiments were subjected to statistical analysis by applying the analysis of variance technique and the *F*-test of significance (Snedecor and Cochran, 1975). The means for each treatment were compared for statistical significance by the CD (critical difference) value at the 0.05 level. The differences between all possible pairs of treatment means were compared to the CD value. If a difference was equal to or greater than the CD value, the difference is significant. The results of the replicates of each treatment for the parameters examined are consistent, with 2–6% difference between values obtained under identical conditions.

### 3. Results and discussion

#### 3.1. Selection of the most suitable earthworm species for vermicomposting

The epigeic earthworm species *E. eugineae* was composted for 40 days, with the end-point determined from the physical appearance, such as the development of a dark brown to black colour with uniformly disintegrated structure, whereas 50 days were needed for local worms and 80 days for conventional composting. The passage of organic material through the earthworm gut results in physical decomposition due to the muscular grinding

action of the gizzard (Senapathi, 1988). This comminution provides enhanced surface area for subsequent microbial decomposition. The earthworm gizzard is a colloidal mill in which the feed is ground into particles <2 µm, giving enhanced surface area for microbial processing (Bhat et al., 1960; Singh and Sharma, 2002). This may account for the reduced time with earthworms present. Further reduction in time with *Eudrillus* may be due to the higher feeding rate, since worms of this species are voracious feeders and prolific breeders (Tomati et al., 1983; Haimi and Huhta, 1987). Humified and non-humified fractions were 39.2% and 60.8% for *Eudrillus* compost, compared with 30.0% and 69.1% for conventional compost. Thus the humic fraction of vermicompost was slightly higher than for conventional compost. Humic materials are formed by microbial, enzymatic and chemical transformations of plant and animal residues (Gaur et al., 1978; Rasal et al., 1988). Actinomycetes and bacteria (both cellulolytic and lignolytic), which are important in waste degradation, increase exponentially along the entire length of the tubular bioreactor (Bhawalkar and Bhawalkar, 1993). Also peroxidase of invertebrates induces the polymerization of aromatic compounds and, in turn, the humification of organic matter (Hajra, 1988).

According to the CD criterion, there was significant difference in the production of cocoons and juveniles between *E. eugineae* and local worms (Table 2). *E. eugineae* had a production of about 17 cocoons per 100 g of compost by 250 worms, whereas local worms produced only 7 cocoons per 100 g of compost by 250 worms. There was a 40-fold increase at the end of the year in the case of *Eudrillus*, whereas it only increased 5–10 fold for local earthworm species. The number of juveniles at compost maturity also differed significantly. Whereas 540 young ones were found in 100 g of *Eudrillus* compost, 460 appeared in 100 g of local earthworm compost. Thus it is evident that *Eudrillus* had a higher growth rate than the other earthworm species investigated.

To determine the degree of compost maturity, different humification indices were calculated. To arrive at the indices, various parameters such as oxidisable carbon, humic acid, fulvic acid, alkali soluble carbon, humic carbon, and fulvic carbon were estimated. The oxidisable carbon of *Eudrillus* compost was less (19% lower) than that of conventional compost. The oxidation degree depends on the chemical nature of organic compounds, especially the quantity of aromatic molecules, nitrogen, heterocyclic groups and polymerization (Gaur and Sadasivam, 1993).

Table 2  
Biomass potential of worms at compost maturity

Treatments	Cocoons/100 g	Juveniles/100 g	No. of adult worms in the compost (9 kg)
Compost by local worms	7	460	220
Compost by <i>Eudrillus eugineae</i>	17	540	218
Compost by <i>Eisenia foetida</i>	11	227	219
Critical Difference (CD)	6.2	70	10

Table 3

Humification indices to assess degree of maturity of different composts and physico-chemical properties of different composts from biodegradation of organic wastes (banana wastes mixed with cow-dung in ratio 1:1 on weight basis)

Treatments	Treatment details	C/N ratio	Humic C/fulvic C	Pha (%)	pH	E.C.	CEC (C mol/kg)	N (%)	P (%)	K (%)
T1	L.W.C	18	1.6	71.1	6.8	2.0	82.1	1.0	0.22	1.02
T2	Eu.C	11	1.7	74.1	7.3	1.6	81.5	1.3	0.24	1.40
T3	Ei.C	15	1.6	73.0	7.5	1.8	81.3	1.0	0.21	1.05
T4	C.Co	44	1.4	62.8	6.2	2.3	79.5	0.7	0.18	1.00
T5	C.Cs	30	1.4	66.9	6.3	2.1	80.6	0.8	0.20	1.01
CD	–	4.1	0.01	2.80	0.2	0.1	9.45	0.12	0.04	0.22

Composition of the wastes: N – 1.69%, P – 0.47%, K – 1.59%.

Note: L.W.C (Local worm compost), Eu.C (*Eudrillus* compost), Ei.C (*Eisenia* compost), C.Co (Conventional compost open), C.Cs (Conventional compost, sealed), CD (Critical difference).

The humic acid in vermicompost was 28% higher than that of conventional compost, since earthworms decompose materials rapidly and there may be finer particles which can react and retain humic acid in considerably larger proportion (Ferreire and Cruz, 1992). The Ha/FA (humic acid/ fulvic acid) ratio reflects the same trend, which may be due to the neutral to alkaline nature and high microbial activity of vermicompost. The higher humifying degree of vermicompost is due to the accelerated humification process by the gut microflora. Data on humification indices are presented in Table 3. The C/N ratio of *Eudrillus* compost was 11, whereas it was 15 for *Eisenia* compost, 18 for local worm compost and 44 for conventional compost. Based on the CD value, the C/N ratio of *Eudrillus* and *Eisenia* composts were on a par, whereas a significant difference was observed in the C/N ratio of local and conventional composts. A C/N ratio <20 indicates acceptable maturity in the finished product (Jimenez and Garcia, 1992), but a ratio  $\leq 15$  is preferred (Gaur and Sadasivam, 1993). From the point of view of application of the compost in cropping situations, a higher C/N ratio indicates possible temporary immobilization of N in the soil and suggests the need for small quantities of nitrogenous fertilizers to overcome this temporary immobilization. Therefore, compost produced by *Eudrillus* had the preferable C/N ratio than both by local worms and conventional method.

The ratios of humic carbon to fulvic carbon were 1.7 and 1.6 and 1.4 for *Eudrillus*, local and conventional compost. For mature compost it should be >1.6 (Jimenez and Garcia, 1992). The greater ratio for Cha (carbon in humic acid) to Cfa (carbon in fulvic acid) in vermicompost (21% higher than that of conventional compost) was related to the mineralization of more easily hydrolysable humic acids (Farid, 1994). The fraction of humic acid (Pha) was 74.2%, 71.2% and 62.9% for *Eudrillus*, local worm and conventional compost, respectively. According to Jimenez and Garcia (1992), Pha should exceed 62 for well matured compost. Humification indices of different composts differed significantly, but all values indicate that the composts were well humified. No significant difference was found in CEC among the different composts, with values of 82.1, 81.5 and 80.6 C mol/kg for local, *Eudrillus* and conventional com-

posts, respectively. This index also assesses compost maturity, which should be >67 C mol/kg for acceptable compost maturity (Jimenez and Garcia, 1992). The large available surfaces of humus particles have many cation exchange sites which adsorb nutrients for eventual plant use (Gaur and Singh, 1995).

The pH of vermicompost ranged from neutral to alkaline, whereas it was acidic for conventional compost as shown in Table 3. Possible contributions to the near-neutral pH of vermicompost may be the secretion of  $\text{NH}_4^+$  ions and the activity of calciferous glands in earthworms.  $\text{NH}_4^+$  ions temporarily reduce the pool of  $\text{H}^+$  ions in soil (Haimi and Huhta, 1987). The calciferous glands contain carbonic anhydrase which catalyse the fixation of  $\text{CO}_2$  as  $\text{CaCO}_3$ , thereby preventing the fall in pH (Kale et al., 1982).

The nutrient composition of different composts is presented in Table 3. Significant differences in N-content were observed; it was 1.3% for *Eudrillus* compost, 1.0% for local worm compost and 0.8% for conventional compost. The higher degree of decomposition and mineralization in vermicompost may partially account for the higher N-content (Syres and Springett, 1984; Bano et al., 1987; Shuxin et al., 1991). The increased N-content in vermicompost (62% higher than that of conventional compost) may also be due to the release of nitrogenous products of earthworm metabolism through the cast (excreta), urine as well as mucoproteins. Also because *E. eugineae* belongs to the merenephridial species, the casts would be more enriched with N since the urine produced by septal nephridia is voided into the gut and discharged along with the casts (Lee, 1985). Micro-organisms in the gut of earthworms, using mucus secreted from the gut epithelium as an energy source, may fix atmospheric N in quantities that are significant for the earthworm metabolism and as a source of N for plant growth (Lee, 1985). The contents of P and K were substantially higher in vermicompost than the conventional compost by 20% and 38%, respectively. The enhancement of phosphatase activity and the physical breakdown of material results in greater mineralization (Sharpley and Syres, 1977; and Mathur et al., 1980). Selective feeding of earthworms on organically rich substances which break down during passage through the gut, biological grinding, together with enzymatic influence on finer soil particles,

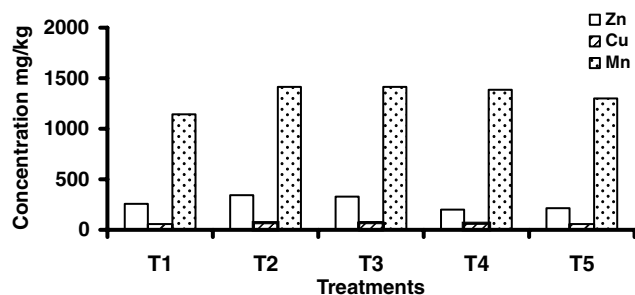


Fig. 1. Micronutrient content of different composts in the comparative study to assess the efficiencies of earthworm species for biodegradation of organic wastes.

were likely responsible for increasing the different forms of K (Rao et al., 1996).

The earthworms absorb excess Ca from their diet and transfer it to calciferous glands, from which it is excreted through the digestive tract. The calciferous glands have carbonic anhydrase which catalyse the fixation of CO<sub>2</sub> as CaCO<sub>3</sub>. In the case of trace metals, Mn, Zn and Cu concentrations in *Eudrillus* compost were 1400, 382 and 71 ppm, whereas in conventional compost, the concentrations were 1300, 231 and 52 ppm, respectively. Thus *Eudrillus* compost had 8% more Mn, 65% more Zn and 36% more Cu than the conventional compost (Fig. 1). Even if earthworms do not absorb all micronutrients from the feed material, those that are absorbed tend to accumulate in the body (Sharma et al., 2005). Lead, cadmium, zinc and copper accumulate and, under some environmental conditions, bioconcentrate in earthworms (Cortet et al., 1999). This may be because of a lack of adequate biochemical or physiological mechanisms to eliminate them from their bodies. Zn has been found to accumulate in the peritoneal epithelium in nerve cells of the ventral nerve chord in the chlorogen cells that form the outer layer of the intestine (Lee, 1985). However, these nutrients are incorporated into the compost upon the death of the worms. Earthworms may serve as bioindicators of soil contaminated with pesticides, i.e. polychlorinated biphenyls, polycyclic hydrocarbons (Saint-Denis et al., 1999) and heavy metals

(Spurgeon and Hopkin, 1999). In many cases, zinc is a critical toxic metal for these organisms (Spurgeon and Hopkin, 2000). Mortality and fecundity of earthworms as bioindicating organisms may serve as reliable, albeit time-consuming, indices of environmental pollution (Morgan et al., 1999).

### 3.2. Nutrient enrichment of vermicompost by inoculation with beneficial micro-organisms

Enrichment generally had a significant effect on the nutrient content, especially for N, P, K (Fig. 2), Mg and Mn (Table 4). *Eudrillus* compost, when treated with *Azospirillum* and P-solubilising organisms, gave a N-content of 2.08% which was significantly higher than the N-content of uninoculated *Eudrillus* compost (1.8%), (See Fig. 2). N was enriched appreciably by *Azospirillum*. The enrichment increased progressively when *Azospirillum* inoculation was supplemented with phosphate solubilising culture, a beneficial additive to obtain good quality compost, rich in N (Tiwari et al., 1989). An increase in N-content due to microbial inoculation was reported by Rasal et al., 1988. The P-contents were significantly higher when inoculated with *Azospirillum* and P-solubilising organisms (1.76%) than in uninoculated compost (0.72%). The mechanism of conversion of insoluble P by P-solubilising organisms to available forms include altering the solubility of inorganic

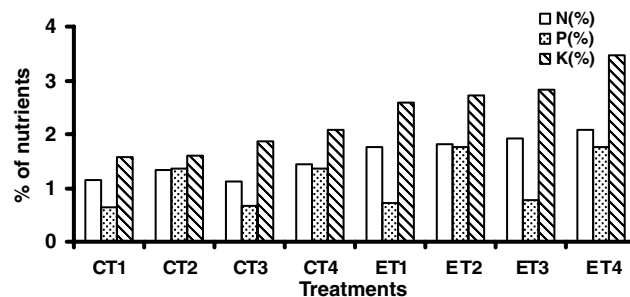


Fig. 2. Nutrient composition of compost (N, P and K) after nutrient enrichment by inoculation with beneficial micro-organisms.

Table 4

Metal concentrations in compost after nutrient enrichment by inoculation with beneficial micro-organisms

Treatments	Treatment details	Mg (%)	Mn (%)	Zn (ppm)	Cu (ppm)
CT1	C.C	1.04	0.13	233	54
CT2	C.C&P.S	1.10	0.15	232	55
CT3	C.C&A	1.03	0.14	219	55
CT4	C.C&P.S&A	1.09	0.15	231	57
ET1	Eu.C	1.30	0.15	316	58
ET2	Eu.C&P.S	1.34	0.16	336	56
ET3	Eu.C&A	1.30	0.15	315	56
ET4	Eu.C&P.S&A	1.33	0.16	382	61
CD	–	0.05	0.01	27.46	11.3

C.C (Conventional compost), C.C&P.S (Conventional compost and P-solubilising organisms), C.C&A (Conventional compost and *Azotobacter*), C.C&P.S&A (Conventional compost and P-solubilising organisms and *Azotobacter*), Eu.C (*Eudrillus* compost), Eu.C&P.S. (*Eudrillus* compost and P-solubilising organisms), Eu.C&A (*Eudrillus* compost and *Azotobacter*), Eu.C&P.S&A (*Eudrillus* compost and P-solubilising organisms and *Azotobacter*).

Table 5  
Biometric indicators of chili (*Capsicum annuum*) (95 days after planting) as influenced by application of enriched compost

Treatments	Treatment details	Height of plant	No. of leaves per plant	Shoot/root ratio
CT1	C.C	52	307	1.8
CT2	C.C&P.S	59.5	385	2.9
CT3	C.C&A	53.5	341	1.7
CT4	C.C&P.S&A	61.5	493	2.4
ET1	Eu.C	54	392	1.9
ET2	Eu.C&P.S	66	539	3.0
ET3	Eu.C&A	56	502	1.7
ET4	Eu.C&P.S&A	75	743	2.7
ET5	Cow-dung	46	251	1.5
CD	–	10.4	14.4	0.18

C.C (Conventional compost), C.C&P.S (Conventional compost and P-solubilising organisms), C.C&A (Conventional compost and *Azotobacter*), C.C&P.S&A (Conventional compost and P-solubilising organisms and *Azotobacter*), Eu.C (*Eudrillus* compost), Eu.C&P.S. (*Eudrillus* compost and P-solubilising organisms), Eu.C&A (*Eudrillus* compost and *Azotobacter*), Eu.C&P.S&A (*Eudrillus* compost and P-solubilising organisms and *Azotobacter*).

compounds to the ultimate soluble form by production of acids and H<sub>2</sub>S under aerobic and anaerobic conditions and by mineralizing organic compounds, with the release of inorganic phosphate (Rasal et al., 1988). Slight increases were observed for other nutrients such as Mg, Mn, Zn and Cu (Table 4), although these differences were insignificant according to the CD criterion.

Addition of vermicompost to soil improves the soil environment, encouraging the proliferation of roots, which in turn draw more water and nutrients from larger areas. Treatment had a significant effect on plant height, with a maximum height of 75 cm recorded after application of *Eudrillus* compost enriched with *Azospirillum* and P-solubilising organisms at 95 days after planting. The significant increase in plant height after applying N-enriched compost agrees with results reported by Singh and Yadav (1990) and Rao and Gushanlal (1986). Other biometric indicators like number of leaves/plant and shoot/root ratio also benefited from the application of enriched compost (Table 5).

The N-uptake by the plants which had received *Eudrillus* compost inoculated with *Azospirillum* and P-solubilising organisms was 66 kg/ha, whereas the N-uptake was only 41 kg/ha by plants that had received conventional compost inoculated with *Azospirillum* and P-solubilising organisms (Fig. 3a). Thus the N-uptake by plants that received enriched *Eudrillus* compost was 61% higher than the N-uptake by plants that received enriched conventional compost. The increase in N-uptake may be attributed to a small increase in N input from biological nitrogen fixation by *Azospirillum* and increased nitrate reductase activity with the enhancement in uptake of NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup>. A high portion of non-available N in organic matter could be made available to plants through vermicomposting and microbial activity.

Earthworms stimulate P uptake from the re-distribution of organic matter and by increasing the enzymatic activation of phosphatase (Mackey et al., 1982). The solubilisation of P by these micro-organisms is attributed to excretion of organic acids like citric, glutamic, tartaric, succinic, lactic, oxalic, glyoxalic, maleic, fumaric and butyric acids (Subba Rao, 1982; Gaur, 1990). These reactions take

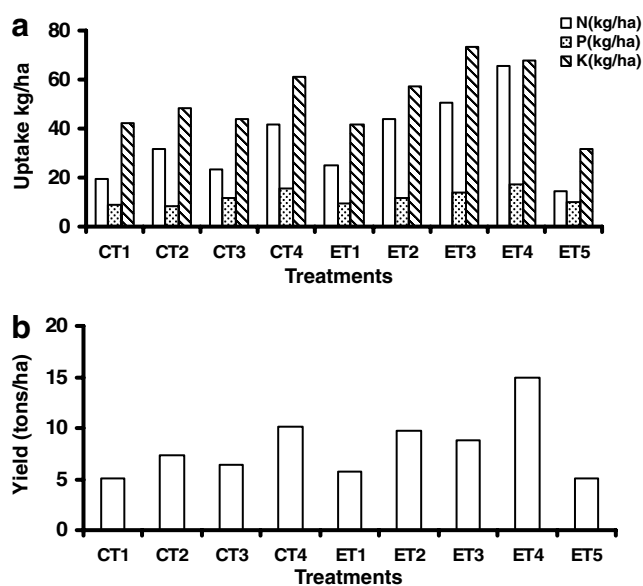


Fig. 3. Effect of application of enriched compost on (a) nutrient uptake by chili (*Capsicum annuum*); (b) yield of chili (tons/ha).

place in the rhizosphere, and because the organisms transfer more P into solution than required for their own growth and metabolism, the surplus is available for plants, thereby increasing the P uptake. The increased P availability due to the increase in solubility of P by higher phosphatase activity by vermicompost application was reported by Syres and Springett (1984).

No significant variation in K uptake by plants was observed for different treatments. The slight increase in K uptake may be due to the increase in K availability by shifting the equilibrium among the forms of K from relatively unavailable to more available forms in the soil (Bhaskar et al., 1992). *Azospirillum* inoculation and higher level of P would have enhanced root proliferation, assisting uptake of K. Similarly the increased uptake of Ca and Mg may be due to better root proliferation due to the improved soil environment after vermicompost application. As shown in Fig. 3b, the highest yield was recorded by plants which had received *Eudrillus* compost enriched with *Azospirillum*

and P-solubilisers. More than N-fixation activity, the ability of producing growth-promoting substances may explain the increased yields due to *Azotobacter* inoculation (Subba Rao, 1982). In experiments with tomatoes and cabbages in Poland, it was found that vermicompost could be used as a biopesticide and that it protected the plants from a number of microbes (Szczeczek and Brzeski, 1994).

### 3.3. Nutrient economy through vermicompost application

The effect of vermicompost application on rooting pattern in cow-pea is shown in Fig. 4. The root length and root spread were 23 cm and 14 cm in plants where vermicompost was applied as a bioinoculant, whereas the corresponding values were 16 cm and 10 cm in plants where vermicompost was applied as an organic source. The number of nodules per plant was 53% higher in plants that received vermicompost as a bioinoculant than in plants which received vermicompost as an organic source. Application of vermicompost as a bioinoculant helps to introduce the beneficial micro-organisms into the rhizosphere of plant which stimulates the nitrogenase enzyme responsible for N-fixation of atmospheric N in legumes. This in turn enriches the N status of soil, thereby increasing the availability of N. Earthworms increase extractable N by feeding on microbial biomass and increasing the turnover and mineralization of microbial tissues (Bhole, 1992).

The available nutrient status of soil was greatly enhanced by the application of vermicompost as an organic source, or as seed inoculants. Earthworm casts are rich in nutrients essential for plant growth (Edward and Lofty, 1977; Lee, 1985). They have been found to contain elevated amounts of  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ , Mg, K and P relative to surrounding soil (Tiwari et al., 1989; Parkin and Berry, 1994). As microbial activity is increased due to addition of vermicompost, it indirectly enhances endocellular enzymes. Hence, coating seeds with vermicompost assists in introducing the micro-organisms into the rhizosphere of plants, helping to increase the N and P availability by making available biologically fixed N and biologically solubilised P. The increased availability of P was attributed to the intimate mixing of ingested particles with soil in earthworm casts

and to the downward movement of particles into earthworm burrows with infiltrating rain water (Mackey et al., 1982). Most of the P present in casts must be physically sorbed, rather than held in chemically stabilized forms, and would consequently be readily available to plants (Sharpley and Syres, 1977). Thus the greater release of P from casts was likely due to a shift in the P sorption isotherm relative to that of undisturbed soil. The increased nutrient availability in acid soil may be due to the favourable pH caused by vermicompost application. Suppression of labile aluminium in acidic soils by vermicompost extract (VCE) was observed by chelation, combined with pH-induced precipitation (Mitchell and Alter, 1993). The same authors (Alter and Mitchell, 1992) reported that in solutions of  $\text{pH} > 6$ , a 98% reduction of total Al was obtained due to pH effects, whereas at pH 4, a reduction of 90% was obtained due to chelation.

In banana, the effect of treatments was studied at six different stages of plant growth: early vegetative stage, late vegetative stage, shooting stage, post-shooting stage, bunch maturation stage and harvest stage. More functional leaves were produced in plants receiving vermicompost as an organic source than in those grown on ordinary soil. This may account for the increased girth of the pseudostem (Refer to Table 6). The satisfactory rate of photosynthesis and meristematic activity may be the main factors causing increased girth. Yield indicators such as bunch height, number of hands per bunch, number of fingers per bunch, girth of fingers and weight of fingers were all significantly influenced by applying vermicompost as an organic source. The quality of produce, as judged by total, reducing, non-reducing sugars and shelf life, was high in vermicompost-treated plots, as indicated in Table 6. The balanced application of nutrients helps to retard oxidation processes responsible for enzymatic browning on banana peels.

For cassava, a significant difference in biometric indicators could be observed in plants after different treatments. From the numbers of functional leaves (Fig. 5a and b) at various growth stages, i.e. 2, 4, 6, 8 MAP (months after planting) and harvest, the positive role of vermicompost in the rate of leaf production and its role in extending the

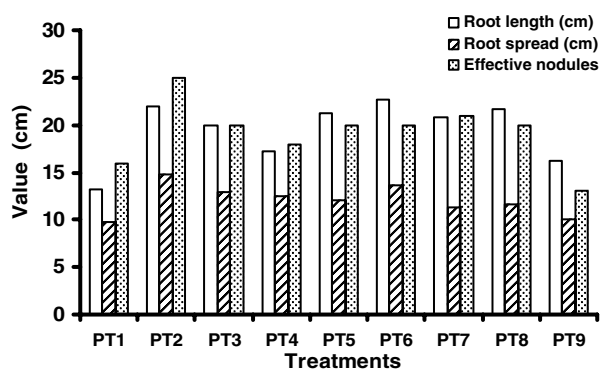


Fig. 4. Effect of vermicompost application on rooting pattern in cow-pea.

Table 6

Treatment effects on number of functional leaves and pseudo stem girth in banana at harvest stage

Treatments	Number of functional leaves	Pseudo stem girth (cm)	Reducing sugar (%)	Shelf life (days)
PT1	10	44.9	3.96	3.0
PT2	11	49.6	4.16	3.5
PT3	12	57.3	4.27	4.0
PT4	12	54.0	4.48	6.0
PT5	11	52.9	4.38	5.0
PT6	13	58.6	5.32	6.0
PT7	12	54.3	4.56	6.5
PT8	14	63.3	6.12	7.0
PT9	13	58.3	5.98	8.0
CD	N.S	6.3	1.27	0.8

Details of treatments are given in Table 1.

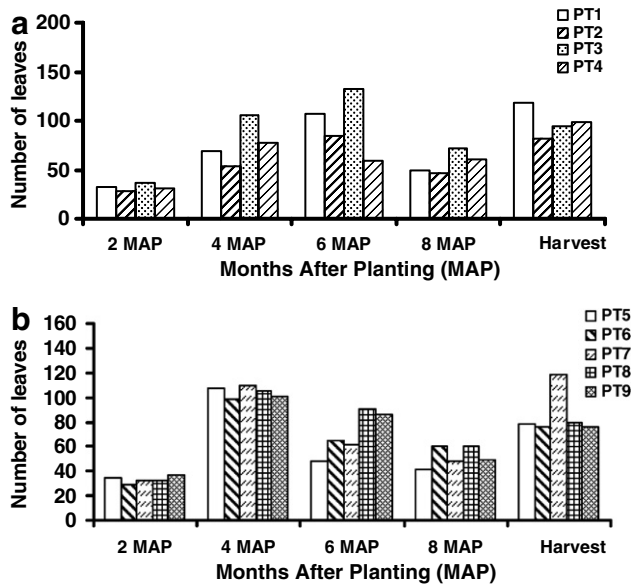


Fig. 5. Effect of vermicompost application on the number of functional leaves in cassava at various growth stages, (a) PT1-PT4 and (b) PT5-PT9.

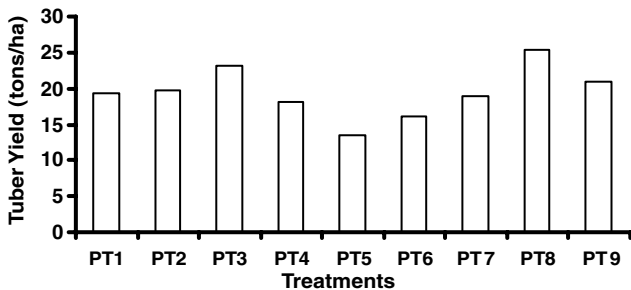


Fig. 6. Effect of vermicompost application on tuber yield in cassava.

longevity of leaves is established. A high number of functional leaves per plant are desirable because the effective area for photosynthesis is proportional to this parameter. Since Cassava exhibits a phasic growth pattern in which canopy development precedes tuber growth, a higher number of functional leaves per plant leads to higher tuber yield. In cassava, vermicompost-stimulated root growth enhances nutrient absorption, thereby favouring higher tuber formation (see Fig. 6).

#### 4. Conclusions

*E. eugineae* reduced the time required for composting significantly due to a higher feeding rate. The reproductive potential of 17 cocoons and 550 juveniles per 100 g of compost in 41 days exceeded that for local worms of 7 cocoons and 400 juveniles in 56 days. Humification indices gave a higher degree of compost maturity for *Eudrillus* compost.

The enrichment had a significant effect on the nutrient content of composts, especially N, P and K. Use of vermicompost as a bioinoculant stimulated the nitrogenase enzyme activity in cow-pea, improved the quality of pro-

duce in banana and stimulated higher tuber formation in cassava. It increased the availability of N and P and encouraged multiplication of beneficial micro-organisms.

By harnessing vermitechnology, the transition from chemical nutrition to bio-nutrition can be quick, without a significant loss in yield. This helps in the management of land without affecting ecological processes. Thus it can help achieve Sustainable Land Management, the foundation of Sustainable Agriculture.

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