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Composting-Vermicomposting of Different Types of Leaves using Earthworm Species *Eisenia fetida*

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ABSTRACT

The aim of this work was to study the variation in the nutrient quality of compost and vermicompost produced from leaf litters of different plant species namely, *Eucalyptus* hybrid, *Pinus roxburghii*, *Populus deltoides*, and *Shorea robusta* and leaves of *Parthenium hysterophorus*, mixed with municipal solid waste and to assess the potential of *Eisenia fetida* in composting different types of leaf litter. Cow dung was used as control in composting and vermicomposting experiments. In the first part of the experiment, vermicomposting resulted in a significant reduction ($P < 0.001$), in pH (0.26-7.2% in compost and 2.29-19.99% in vermicompost), C/N ratio (40.53-60.41% in compost and 47.55-69.21% in vermicompost) and an increase in the percent total nitrogen (12.66-76.17% in compost and 47.0-145.5% in vermicompost), total phosphorous (10.14-87.14% in compost and 26.45-121.84% in vermicompost), total potassium (9.90-68.40% in compost and 20.96-106.18% in vermicompost), total calcium (2.34-13.93% in compost and 11.07-24.66% in vermicompost), and total magnesium (6.63-27.02% in compost and 14.47-66.05% in vermicompost). The second part of the experiments revealed that that *E. fetida* preferred the feed in following order: cowdung (control) > PoLMSWV > ParLMSWV > EuLMSWV > PiLMSWV > SrLMSWV. The earthworms consistently gained in weight and produced offspring in all the reactors, throughout the experiment. The results show that the nutrient quality of the final product depends on the initial properties of the material used. The hypothesis that quality of the substrate material influences the worms feeding as well as growth efficiencies has also been confirmed by this study.

Keywords: leaf litter, nutrient enrichment, offspring, organic waste, vermicast, vermicompost, worm biomass

Abbreviations: ANOVA, analysis of variance; **DM**, dry matter; **EuLMSWV**, *Eucalyptus* leaf litter + municipal solid waste vermicompost; **FRI**, forest research institute; **GLM**, general linear model; **MSW**, municipal solid waste; **ParLMSWV**, *Parthenium* leaf litter + municipal solid waste; **PiLMSWV**, pine leaf litter + municipal solid waste; **PoLMSWV**, poplar leaf litter + municipal solid waste; **SrLMSWV**, *Shorea robusta* leaf litter + municipal solid waste; **SPSS**, statistical package for social sciences

INTRODUCTION

The forest is the foundation upon which the whole sustainability of hill agriculture is based. It provides raw materials in the form of forage and fodder, leaf litter for both animal bedding and composting with dung to provide manure, and fuel wood and timber resources for heating, cooking, and construction.

Tree leaves falling to the ground below should, ideally, be left as such as they play a very important role in the protection and enrichment of soil. For example, the leaf litter shields soil from the vagaries of solar heat and wind erosion. It provides food to the soil microorganisms and invertebrates who, in turn, return much of the nutrients contained in the litter to the soil (Dash 1993). The leaf litter also becomes a source of food to higher organisms such as birds feeding upon worms and insects nurtured by the litter. Furthermore, leaf litter helps capture rainwater and delay its run-off, thereby, contributing to the soil moisture and groundwater recharge (Abbasi and Ramasamy 2001).

It is established that pre-composting is very essential to avoid the mortality of worms, whereas direct vermicomposting is adequate for certain types of soft and nutritious wastes which the earthworms can easily feed upon. Other forms of municipal solid waste such as paper clippings, weeds, cotton bearing wastes is too hard for the earthworms to digest and to avoid the production of heat during initial composting. To process such wastes composting followed by vermicomposting is usually practiced, which imparts value-addition to the compost. This combination has been considered as a way of achieving stabilised substrates (Tognetti *et al*. 2007). In addition, laboratory research indicates that combining composting with vermicomposting can accelerate stabilization rates, greatly reducing the time taken to produce mature compost (Frederickson *et al.* 1997). Composting enables sanitization of waste and elimination of toxic compounds, and subsequent vermicomposting reduces particle size and increases nutrient availability; in addition, inoculation of the material resulting from the thermophilic phase of composting with earthworms reduces the expense and duration of the treatment process (Ndegwa and Thompson 2001). An integrated system including both thermophilic composting and vermicomposting processes would be necessary to provide a pathogen-free product, and with desirable characteristics, at a faster rate than either of the individual processes would produce.

This paper is a part of research work (Aalok 2009) carried out to assess the potential of *Eisenia fetida* in composting different types of leaf litters of *Eucalyptus* hybrid, *Pinus roxburghii*, *Parthenium hysterophorus*, *Populus deltoides* and *Shorea robusta* mixed with organic municipal solid waste (MSW) and compare their nutrient value. *E. fetida* was selected for the experiment because it is the best suited species in this part (Uttarakhand) of India and it thrives well and reproduces in both summer and winter conditions.

MATERIALS AND METHODS

Solid waste generation per day on an average of 0.35 kg/ person/ day in FRI campus is estimated to be 1.65 tonnes, equivalent to 602.25 tonnes/year. In view of the excellent environmental status

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of the FRI campus, such a huge amount of waste cannot be used for land filling, thus an alternate scenario was to treat waste by an ecofriendly method. Senior scientists from the Silviculture department helped the authors in plant species identification.

The organic wastes for this study i.e., leaf litter of *E.* hybrid (eucalyptus; Myrtaceae), *P. roxburghii* Sarg. (chir pine; Pinaceae), *P. deltoides* W. Bartram ex Marshall (eastern cottonwood; Salicaceae) and *S. robusta* Gaertner f. (sal; Dipterocarpaceae) and sun-dried leaves of *P. hysterophorus* L. (ragweed parthenium; Asteraceae) and MSW were collected from the Forest Research Institute (FRI) campus and cow dung from a local farm. Originally, *E. fetida* was obtained from the Vermi District Centre, Dehradun and later were cultured in the laboratory on partially decomposed (under natural environmental conditions) cow dung, approx. 2-3 months old.

Composting reactors

Composting experiments were carried out in wooden boxes of 0.5 m^3 or 500 l (90.5 cm × 85 cm × 65 cm). Four replicates of each set of experiments were laid down with cow dung as control. Composting methodology was followed as per Gajalakshmi *et al.* (2001). When a compost pile is started, materials should be added in layers to ensure proper mixing. Compost piles develop best if they are built in layers. Layering is a good way to ensure that the materials are added in the proper proportion. Once several layers are formed, however, composting will be most rapid if the layers are mixed before making new layers (Starbuck 2010). Leaf litters were chopped to approximately 2-3 cm in size and the MSW was physically segregated into biodegradable and non-biodegradable parts. The biodegradable part was used for composting. Successive layers of leaf litter and MSW (10 cm each) and 5 cm thick cow dung slurry were laid down. Each layer was topped with a 1-cm layer of garden soil (alkaline, N- 1.4-1.5 g/kg, K- 0.16-0.18 g/kg, exchangeable Ca- 3.8-4.6 g/kg, ex. Mg- 0.41-0.55 g/kg). These layers were repeated 3-4 times to fill 3/4 of the box. The entire contents were sprinkled with an adequate quantity of water to generate average moisture content of 50-60% by monitoring the moisture content at different heights of the reactor every week. The top one-third of the reactor ranged between 31-36% moisture, the middle one-third ranged between 50-60% moisture and the bottom one-third between 68-73%. The boxes were covered with black plastic sheets to prevent heat loss. After the initial setting, the compost boxes were left undisturbed as the aerobic process of composting started and gradually lifted the temperature of the reactor contents from the initial 31 to 55-60°C within 5-8 days of the start. After another 3-4 days, when the temperature usually began to fall, the plastic covers were removed and the contents thoroughly mixed. The covers were then replaced and the boxes left once again to continue the composting. The completion of composting was indicated when mixing the contents and keeping them undisturbed after covering did not lead to a rise in the temperature. The compost units were maintained at natural conditions (20-30°C).

The compost material in the boxes were initially mixed every third day and later done whenever a drop in temperature (nearly 42-45°C) was seen. Water was added whenever necessary during the composting time to keep the moisture content above 50-60%. Temperature in the wooden boxes was noted every day while volume reduction was calculated weekly by measuring the decrease in the pile size in the box with that of the initial height. Aerobic fermentation of biodegradable portion of carbonaceous organic matter by microbes causes increase in temperature which leads to rapid reduction in volume of organic matter (http://web.extension.illinois.edu/homecompost/science.html).

Vermireactors

Plastic circular containers (reactor) of size 4 l were filled from bottom up with a layer of soil of depth 5 cm and 100 g of feed [composted material (end product of the composting experiment] spread over the soil. In each reactor, twenty five, 4-week old clitellate earthworms (having individual live weight ≈300 mg) were introduced. Earthworms were collected from the stock culture maintained in the Division with cow dung as feed. Cow dung compost was kept as control.

The average moisture content of the vermireactors was maintained around 50-60% by periodic sprinkling of adequate quantity of water.

After 15 days, the vermicast was harvested and measured. The reactors were fed with the same quantity of fresh feed (100 g dry weight) and were allowed to run for a period of one month. At the end of the experiment, the earthworms were removed and juveniles if any were separated, counted and then transferred to the culture bed. The remaining 25 worms were weighed and reintroduced to the fresh reactors within a few minutes (Gajalakshmi *et al*. 2001). The experiment was carried out for 5 runs (75 days). Four replicates of each experiment were carried out and results were averaged.

Physical and chemical analysis

The composted and vermicomposted materials were air-dried, sieved and analyzed for various chemical elements. The earthworms were removed manually at the end of the experiment. Determination of pH was done by a pH meter (1: 10, compost: water solution). The concentrations of total potassium (TK), total phosphorous (TP), total calcium (TCa) and total magnesium (TMg) were estimated by the tri-acid digestion method (Jackson 1973) and atomic absorption spectrophotometer. Total nitrogen (TN) was analyzed by the Kjeldhal digestion method (Moore and Chapmann 1986). Total organic carbon (TOC) was estimated by the Walkely-Black method (Tandon 1993).

Statistical analysis

Two-way ANOVA was used to analyze the significant ($P \leq 0.05$) difference among substrates and among processes using General Linear Model (GLM) procedure of SPSS v. 11 statistical software for Windows.

RESULTS AND DISCUSSION

Physico-chemical properties of compost and vermicompost

The initial characteristics of different feed material used are presented in **Table 1**. The results of physico-chemical changes during composting and vermicomposting processes are presented in the **Table 2**. pH of all the substrates was comparatively lower after composting and vermicomposting with respect to the initial stage. Most of the other reports on vermicomposting (Gunadi and Edwards 2003; Garg and Kaushik 2005; Sangwan *et al*. 2008) have also reported similar results. The observed differences between the pH at the start and end of composting and vermicomposting were significant ($P < 0.001$) for each substrate. The lower pH recorded during the study might have been due to the production of CO_2 and organic acids by the microbial metabolism during decomposition of different substrates (Haimi and Huhta 1986; Albanell *et al*. 1988; Elvira *et al.* 1998). Ndegwa *et al*. (2000) pointed out similar results that a shift in pH might be related to the mineralization of the N and P into nitrites/nitrates and orthophosphates and bioconversion of the organic material into intermediate species of the organic acids. TOC decreased in all the substrates after composting {PoLMSWV – 42.93% of the initial amount), SrLMSWV – 39.78%, PiLMSWV – 39.59%, EuLMSWV – 37.28%, ParLMSWV – 33.09%, and control (cow dung) – 30.28%} and then increased after vermicomposting {PoLMSWV – 34.36% of the initial amount), PiLMSWV – 30.84%, SrLMSWV – 30.26%, EuLMSWV – 28.88%, control – 24.21%, and ParLMSWV – 22.95%}. Statistically the differences between the stages and substrates for final C concentration were significant ($P < 0.001$). The decrease at the end of composting resulted from the oxidation of carbon to CO_2 by microorganisms (Tiquia *et al*. 1996). Production of CO_2 reduces the percentage total carbon and generates a loss of weight during composting (Sánchez-Monedero *et al.* 2001), while percentage total N normally increases. Recal-

Table 1 Initial physico-chemical characteristics of different feed materials.

Feed material	TOC	TN%	TP%	TK%	TCa%	TMg%	C/N
Control (CD)	47.3	0.61	0.68	0.48	0.39	0.51	77.54
EuLL	50.64	1.71	0.08	1.20	1.03	0.22	29.64
PiLL	47.25	0.70	0.04	0.18	1.15	2.10	67.5
ParLL	39.15	2.88	0.28	3.40	2.10	0.61	13.57
PoLL	38.64	1.72	0.09	0.31	4.80	1.26	22.43
SrLL	42.84	0.91	0.03	0.09	2.4	0.36	47.07

All values are mean of four replicates.

CD – cow dung; EuLL – *Eucalyptus* leaf litter; PiLL – Pine leaf litter; ParLL – *Parthenium* leaf litter; PoLL - Poplar leaf litter; SrLL – *Shorea robusta* leaf litter

Table 2 Chemical characteristics of different organic wastes analyzed at three different stages.

Substrates	pH			TOC (%)			TKN (%)		
	Stages			Stages			Stages		
	Initial	Compost	Vermicompost	Initial	Compost	Vermicompost	Initial	Compost	Vermicompost
Control	8.333 ± 0.08	7.733 ± 0.21	6.667 ± 0.12	44.167 ± 0.93	30.790 ± 1.06	33.470 ± 0.93	0.600 ± 0.02	1.057 ± 0.04	1.473 ± 0.05
EuLMSW	7.513 ± 0.06	7.533 ± 0.06	7.033 ± 0.10	37.840 ± 0.94	23.730 ± 0.86	26.913 ± 1.71	0.857 ± 0.02	1.013 ± 0.04	1.333 ± 0.06
PiLMSW	7.267 ± 0.15	7.433 ± 0.18	7.100 ± 0.05	36.307 ± 1.03	21.933 ± 0.17	25.110 ± 0.84	0.527 ± 0.03	0.730 ± 0.02	1.077 ± 0.04
ParLMSW	8.267 ± 0.10	7.750 ± 0.13	7.350 ± 0.15	33.490 ± 0.88	22.407 ± 1.39	25.803 ± 0.40	1.240 ± 0.04	1.397 ± 0.07	1.823 ± 0.05
PoLMSW	7.917 ± 0.08	7.550 ± 0.13	7.167 ± 0.06	33.743 ± 0.91	19.257 ± 0.73	22.150 ± 0.68	0.837 ± 0.03	0.960 ± 0.05	1.260 ± 0.05
SrLMSW	7.617 ± 0.15	7.317 ± 0.21	6.933 ± 0.15	35.207 ± 2.40	21.200 ± 0.17	24.553 ± 0.56	0.607 ± 0.04	0.870 ± 0.07	1.167 ± 0.04
Significance		***			***			***	
CD at 5%		0.216			1.744			0.073	

Substrates	TP (%)			TK (%)			TCa (%)		
	Stages			Stages			Stages		
	Initial	Compost	Vermicompost	Initial	Compost	Vermicompost	Initial	Compost	Vermicompost
Control	0.490 ± 0.06	0.917 ± 0.05	1.087 ± 0.06	0.520 ± 0.02	0.657 ± 0.05	0.753 ± 0.04	0.390 ± 0.05	0.403 ± 0.08	0.440 ± 0.05
EuLMSW	0.473 ± 0.01	0.663 ± 0.02	1.003 ± 0.03	0.657 ± 0.02	0.870 ± 0.03	1.127 ± 0.04	0.933 ± 0.04	1.063 ± 0.01	1.163 ± 0.02
PiLMSW	0.447 ± 0.01	0.517 ± 0.02	0.757 ± 0.03	0.307 ± 0.03	0.517 ± 0.04	0.633 ± 0.05	0.973 ± 0.03	1.100 ± 0.02	1.213 ± 0.03
ParLMSW	0.537 ± 0.02	0.610 ± 0.02	0.717 ± 0.05	1.383 ± 0.04	1.520 ± 0.03	1.673 ± 0.05	1.330 ± 0.03	1.407 ± 0.02	1.483 ± 0.04
PoLMSW	0.493 ± 0.02	0.543 ± 0.02	0.660 ± 0.02	0.350 ± 0.05	0.427 ± 0.02	0.580 ± 0.05	2.257 ± 0.02	2.310 ± 0.02	2.507 ± 0.02
SrLMSW	0.480 ± 0.34	0.530 ± 0.06	0.607 ± 0.07	0.290 ± 0.09	0.363 ± 0.03	0.503 ± 0.03	1.443 ± 0.02	1.507 ± 0.02	1.640 ± 0.02
Significance		***			***			***	
CD at 5%		0.145			0.067			0.053	

Substrates	TMg (%)			C/N		
	Stages			Stages		
	Initial	Compost	Vermicompost	Initial	Compost	Vermicompost
Control	0.513 ± 0.03	0.547 ± 0.03	0.657 ± 0.03	73.843 ± 2.13	29.231 ± 0.90	22.731 ± 0.25
EuLMSW	0.333 ± 0.01	0.423 ± 0.02	0.513 ± 0.07	44.200 ± 3.81	23.427 ± 1.76	20.186 ± 0.81
PiLMSW	0.327 ± 0.02	0.367 ± 0.02	0.543 ± 0.03	69.003 ± 1.01	30.094 ± 0.29	23.320 ± 0.25
ParLMSW	0.457 ± 0.03	0.527 ± 0.01	0.633 ± 0.02	26.980 ± 2.65	16.045 ± 0.98	14.151 ± 0.62
PoLMSW	0.670 ± 0.02	0.733 ± 0.04	0.767 ± 0.05	40.410 ± 3.56	20.076 ± 0.46	17.593 ± 0.76
SrLMSW	0.370 ± 0.02	0.467 ± 0.02	0.547 ± 0.02	58.120 ± 5.84	24.384 ± 2.08	21.062 ± 0.89
Significance		***			***	
CD at 5%		0.047			3.618	

The values are mean of four replicates ± standard deviation. ***, significant at $P < 0.001$.

Eucalyptus leaf litter + Municipal solid waste vermicompost - EuLMSWV; Pine leaf litter + Municipal solid waste vermicompost- PiLMSWV; *Parthenium* leaf litter + Municipal solid waste vermicompost - ParLMSWV; Poplar leaf litter + Municipal solid waste vermicompost – PoLMSWV; *Shorea robusta* leaf litter + Municipal solid waste vermicompost – SrLMSWV

citrant organic wastes, such as cellulose and lignin may affect a degree of organic carbon loss during the decomposition process (Huang *et al.* 2004). The increase in TOC after the earthworm inoculation was probably due to the addition of earthworm casts, which are rich in organic carbon. TN in all the substrates was found higher in compost and vermicompost than the initial matter. In composted material, TN content increased in the order: Control – 76.17%, SrLMSWV – 43.32%, PiLMSWV – 38.51%, EuLMSWV – 18.20%, PoLMSWV – 14.69%, and ParLMSWV – 12.66%. In vermicomposted material the TN content increased in the order: Control – 145.5%, PiLMSWV – 104.36%, SrLMSWV – 92.25%, EuLMSWV – 55.54%, PoLMSWV – 50.54%, and ParLMSWV – 47.0%. Statistically significant differences were observed between the stages and substrates ($P < 0.001$). The increase in TN during composting process might be due to the activity of N-fixing bacteria which was expected to exist in the compost units. These bacteria have the capability to fix N_2 from the air to NO_3 contained in the compost unit (Bishop and Godfrey 1983). Earthworm accelerates microbial-mediated N transformation during the process of vermicomposting. Earthworms also enhance N levels by adding their excretory products, mucus, body fluid, enzymes etc. to the substrate. In general, N enrichment pattern and mineralization activities mainly depend upon the total amount of N in the initial waste material and on the earthworm activity in the waste decomposition sub-system (Kale 1998; Suthar 2007a).

The data indicates that, after completion of composting and vermicomposting, the amount of TP was found higher than initial values. It has been reported that the concentration of P tends to increase with composting time (Iglesias-Jiménez *et al.* 1993; Wolkowski 2003). Most literature indicates increased P concentration during vermicomposting due to loss of dry matter (DM) (Elvira *et al.* 1998; Chowdappa *et al.* 1999; Ghosh *et al.* 1999). The increased P in worm cast clearly indicates earthworm mediated P mineralization. According to Lee (1992), the organic matter that passes through the gut of earthworm results in some amount of P being converted to the more available form. The release of P in available form is partly by earthworm gut phosphatase, and further release of P may be by P-solubilizing microorganisms in casts. Le Bayon and Binet (2006) reported earthworm-mediated phosphatase enhancement in soils. They concluded that earthworms were responsible for additional alkaline phosphatases, produced in the worm gut and excreted through cast deposition. In composted material, TP content increased in the order: Control – 87.14%, EuLMSWV – 40.16%, PiLMSWV – 15.66%, ParLMSWV – 13.59%, SrLMSWV – 10.42%, and PoLMSWV – 10.14%. In vermicomposted material the TP content increased in the order: Control – 121.84%, EuLMSWV – 112.05%, PiLMSWV – 69.35%, PoLMSWV – 33.87%, ParLMSWV – 33.52%, and SrLMSWV – 26.45%. The observed differences between the TP at the start and end of composting and vermicomposting were significant ($P < 0.001$).

TK content in the composted and vermicomposted material was higher than the initial content. In composted material, TK content increased in the order: PiLMSWV – 68.40%, EuLMSWV – 32.42%, control – 26.34%, SrLMSWV – 25.17%, PoLMSWV – 22.00%, and ParLMSWV – 9.90%. In vermicomposted material the TK content increased in the order: PiLMSWV – 106.18%, EuLMSWV – 78.08%, SrLMSWV – 73.44%, PoLMSWV – 65.71%, Control – 44.80%, and ParLMSWV – 20.96%. Significant differences were seen between stages and substrates ($P < 0.001$). Increase in TK may be due to the net loss of dry mass which generally concentrated the K in composting unit (Huang *et al.* 2004). Acid production by the microorganisms seems to be prime mechanism for solubilizing the insoluble K. The enhanced number of microflora present in the gut of the earthworm in the case of vermicomposting might have played an important role in the process and increased K_2O. Satchell and Martein (1984) also found an increase of 25% in K of paper waste sludge after worm activity. Delgado *et al*. (1995) reported higher K content in vermicompost produced from sewage sludge by red worms. Studies by Suthar (2007a) revealed that vermicomposting of organic residues significantly enhanced the concentration of exchangeable K in substrates. Vermicomposting accelerates the mineralization of plant metabolites and subsequently enriches the end product with more available forms of soil nutrients. TCa and TMg contents were also higher in compost and vermicompost than in the initial substrate. In composted material, TCa content increased in the order: EuLMSWV – 13.93%, PiLMSWV – 13.05%, ParLMSWV – 5.78%, SrLMSWV – 4.43%, Control – 3.33%, and PoLMSWV – 2.34%. In vermicomposted material the TCa content increased in the order: PiLMSWV – 24.66%, EuLMSWV – 24.65%, SrLMSWV – 13.65%, Control – 12.82%, ParLMSWV – 11.50%, and PoLMSWV – 11.07%. In composted material, TMg content increased in the order: EuLMSWV – 27.02%, SrLMSWV – 26.21%, ParLMSWV – 15.31%, PiLMSWV – 12.23%, PoLMSWV – 9.40%, and Control – 6.63%. In vermicomposted material the TMg content increased in the order: PiLMSWV – 66.05%, EuLMSWV – 54.05%, SrLMSWV – 47.84%, ParLMSWV – 38.51%, Control – 28.07%, and PoLMSWV – 14.47%. The observed differences between the TCa and TMg at the start and end of composting and vermicomposting were significant ($P < 0.001$) for each substrate. However, when organic waste passes through the gut of worms the nutrients can be converted from unavailable form to available forms, which consequently enrich the worm casts with higher quality plant metabolites. Garg and Kaushik (2005) found a significant increase in Ca and Mg content in substrate material, after the completion of vermicomposting process.

The C/N ratio plays an important role in the nutrient balance in a composting heap (Goluke 1977). Composting of organic matter is accompanied by loss of carbon as CO_2 due to the action of microbes, without the loss of other nutrients. This not only improves (reduces) C/N ratio of the substrate but also enhances the concentration of nutrients in the composted material. Thus, the concentration of nutrients further increases after vermicomposting process (Abbasi *et al*. 2009). From the results it can be seen that the C/N ratios of compost and vermicompost were lesser than the initial ratios. In composted material, C/N ratio decreased in the order: Control – 60.41%, SrLMSWV – 58.04%, PiLMSWV – 56.38%, PoLMSWV – 50.31%, EuLMSWV – 46.99%, and ParLMSWV – 40.53%. In vermicomposted material the C/N ratio decreased in the order: Control – 69.21%, PiLMSWV – 66.20%, SrLMSWV – 63.76%, PoLMSWV – 56.46%, EuLMSWV – 54.33%, and ParLMSWV – 47.55%. The reduction in the C/N ratio was due to the fast degradation of organic matter mainly of cellulose and other readily available carbon and consequent volatilization of organic matter as the compost heats up. As reported by Basnayake (2001), the C/N ratio becomes a good indicator for the stability of the compost. Decrease in C/N ratio in vermicompost as compared to initial organic substrate, which might be due to relative increase in the TKN on loss of dry matter (organic carbon) as CO_2 as well as water loss by evaporation during mineralization (Viel *et al.* 1987). The decrease in C/N ratio over time might also be attributed to increase in the earthworm population (Ndegwa and Thompson 2000), which led to rapid decrease in organic carbon due to enhanced oxidation of the organic matter.

Generation of vermicasts

The results of vermicast production are summarized in **Table 3**. The data on generation of vermicast in different compost material were observed every fortnight. The analysis of data show that there was significant effect of compost material on generation of vermicast also its variation with time (fortnights) was significant. The average vermicast production was low during the first run (first fortnight) of reactor operation, indicating that the earthworms, which had been cultured with cowdung as the principal feed, took some time to acclimatize with the changeover to different feed material. From the second run onwards the worm activity became manifestly more brisk. It indicates that the vermicast output, worm biomass, and production of offspring had all registered net increasing trends over time even though the variables had fluctuated in different runs. After 5 runs, the performance of all the reactors in terms of production of castings had improved slowly, yet steadily.

E. fetida preferred the feed in following order: cowdung (control) > PoLMSWV > ParLMSWV > EuLMSWV > PiLMSWV > SrLMSWV. Statistically it was seen that gene-

Table 3 Generation of vermicast (g) per 15 days in reactors with pre-composted organic waste as feed material.

Days	Control	EuLMSWV	PiLMSWV	ParLMSWV	PoLMSWV	SrLMSWV
15	37.53 ± 0.645	19.14 ± 1.530	15.61 ± 1.001	18.32 ± 0.812	20.64 ± 2.303	13.67 ± 1.654
30	44.75 ± 0.742	21.48 ± 0.942	22.61 ± 1.181	22.62 ± 0.879	28.52 ± 0.651	19.69 ± 1.759
45	50.5 ± 1.853	25.62 ± 1.132	27.54 ± 1.690	28.52 ± 1.568	37.29 ± 0.364	22.62 ± 0.459
60	55.96 ± 0.909	30.29 ± 0.541	32.46 ± 1.660	32.75 ± 1.866	41.77 ± 0.372	28.22 ± 0.955
75	62.17 ± 1.518	34.34 ± 1.066	27.96 ± 2.959	29.9 ± 1.025	34.95 ± 0.303	30.91 ± 1.490
	CD at 5%	Significance				
Waste	0.843	***				
Days	0.766	***				
Waste*Days	1.885	***				

The values are mean of four replicates ± standard deviation. ***, significant at $P < 0.001$.
Eucalyptus leaf litter + Municipal solid waste vermicompost - EuLMSWV; Pine leaf litter + Municipal solid waste vermicompost- PiLMSWV; *Parthenium* leaf litter + Municipal solid waste vermicompost- ParLMSWV; Poplar leaf litter + Municipal solid waste vermicompost – PoLMSWV; *Shorea robusta* leaf litter + Municipal solid waste vermicompost - SrLMSWV

Table 4 Number of offspring produced by *E. foetida* each fortnight in pre-composted organic waste as feed material.

Days	Control	EuL MSWV	PiL MSWV	ParL MSWV	PoL MSWV	SaL MSWV	Mean
15	0	0	0	0	0	0	0
30	17.75 ± 2.217	4.75 ± 1.707	5.0 ± 2.581	7.75 ± 1.5	11.25 ± 1.707	3.5 ± 1.290	8.33
45	11.75 ± 1.707	6.0 ± 2.943	5.0 ± 1.825	6.25 ± 3.403	8.25 ± 2.217	3.75 ± 1.707	6.83
60	16.25 ± 2.061	5.75 ± 3.862	2.75 ± 1.707	4.5 ± 2.082	9.25 ± 2.217	2.75 ± 1.707	6.87
75	10.75 ± 2.217	4.5 ± 2.380	4.0 ± 1.825	6.5 ± 3.109	6.0 ± 1.825	3.75 ± 1.707	5.92
Mean	11.3	4.2	3.35	5.00	6.95	2.75	5.5916
	CD at 5%	Significance					
Waste	1.255	***					
Days	1.146	***					
Waste*Days	2.807	***					

Values are mean of four replicates ± standard deviation. ***, significant at $P < 0.001$.

Table 5 Worm biomass recorded each fortnight in reactors with pre-composted organic waste as feed materials.

Days	Control	EuLMSWV	PiLMSWV	ParLMSWV	PoLMSWV	SaLMSWV	Mean
15	13.56 ± 0.735	10.36 ± 0.647	11.75 ± 0.63	9.49 ± 0.824	11.09 ± 0.537	9.66 ± 0.527	10.983
30	15.32 ± 0.729	12.58 ± 0.438	14.03 ± 0.450	11.5 ± 0.627	13.18 ± 0.473	12.49 ± 0.651	13.182
45	19.39 ± 0.777	15.14 ± 0.273	16.4 ± 0.780	14.37 ± 0.443	15.16 ± 0.141	14.73 ± 0.364	15.864
60	22.82 ± 0.765	17.45 ± 0.266	18.81 ± 0.440	17.0 ± 0.741	17.15 ± 0.250	16.56 ± 0.372	18.295
75	26.27 ± 0.905	19.51 ± 0.247	21.5 ± 0.410	18.73 ± 0.537	19.49 ± 0.442	18.34 ± 0.303	20.637
Mean	19.472	15.008	14.356	15.214	16.498	14.218	15.7922
	CD at 5%	Significance					
Waste	0.352	***					
Days	0.322	***					
Waste*Days	0.788	***					

Values are mean of four replicates ± standard deviation. ***, significant at $P < 0.001$.

ration of vermicast differed significantly ($P < 0.001$) with wastes (reactors), in each fortnight, and also in the between the reactors and the fortnights.

The analysis reveal that generation of vermicast irrespective of materials increased with time up to a limit and thereafter it becomes stable. It increased up to 4th fortnight and then shows no significant increase. It may therefore be concluded that 4th fortnight is the optimum time for generation of vermicast. Substrate is released as vermicast after a few hours of ingestion. The number of hours depends on the nature of the substrate, worm species, and the length of the worm body. Generally, worms with shorter body length (epigeic worms) take lesser time in releasing the vermicast than longer bodied worms (anecics or endogeics) (Abbasi *et al.* 2009). Reinecke and Venter (1985), and Reinecke and Viljoen (1990) have also reported the increase in biomass with the feeding activity of the worms. Kale and Krishnamoorthy (1981) reported variations in the acceptability of organic wastes depending on texture as well as chemical nature of diets. Harborne (1977) reported that the chemical constituents present in foods attract and elicit feeding responses in invertebrates. Differences in litter palatability and toughness, nutrient contents and other organic compounds may be responsible for the considerable differences in residual mass between litter types (Lorenz 2004).

Number of offspring and increase in worm biomass

Tables 4 and **5** summarize the results regarding the number of offspring produced and increment in worm biomass with different precomposted organic wastes. The number of offspring produced and increase in worm biomass was higher in control than in the different types of composts. Similar results were reported by Gupta *et al*. (2007), where the maximum worm growth was recorded in cow dung alone. Aira *et al*. (2008) also reported that earthworm biomass increased significantly in pig slurry than in water hyacinth. Statistically the results show that the number of offspring produced and increment in worm biomass differed significantly ($P < 0.001$) with wastes (reactors), during each fortnight, and also between the reactors and the fortnights.

The analyses also reveal that number of offspring and worm biomass varied significantly with time. It was seen that initially, i.e., after first fortnight there was no evidence of offspring, but after the second fortnight the number of offspring was 8.33 which is the highest value since after second fortnight number of offspring recedes and becomes stable. The average numbers of offspring after 3rd, 4th and 5th fortnights. The number of offspring produced and the net increase in worm biomass in the various reactors followed the trend of net vermicast output.

Neuhauser *et al.* (1980) reported that rate of biomass gain by *E. fetida* was dependent on population density and food type. Our results confirm the general rule, also reported in literature, establishing a direct relationship between biomass growth of *E. fetida* and the quality of feed material (Butt 1993; Elvira *et al*. 1998).

The changes in biomass and number of offspring production differed depending on the substrates. Suthar (2007b), summarized that the factors relating to the growth of earthworms may also be considered in terms of physio-chemical and nutrient characteristics of waste feed stocks. Thus organic waste palatability for earthworms is directly related to the chemical nature of the organic waste that consequently affects earthworm growth parameters. The variation in growth and reproduction of *E. fetida* in different diets might be due to its preferential feeding habits (Amoji *et al.* 1998). Biomass production and reproduction are the best indicators to evaluate the vermiculturing process.

CONCLUDING REMARKS

From this study it can be concluded that vermicomposting is a better technology than compost for the conversion of different types of organic waste into manure. Chemical analysis shows that vermicompost has higher soil nutrient than compost. The results showed that TOC content decreased in compost and increased in vermicompost and TN, TP, TK, TCa and TMg contents were enhanced. The C/N ratio decreased in all the substrates indicating stabilization of the waste. The final product obtained can be used in agricultural fields as manure. The results also indicate that voracious feeding by earthworms upon a substrate and production of significant quality of vermicast does not prove that the substrate is suitable feed for the worms. The hypothesis that quality of the substrate material influences the worms feeding as well as growth efficiencies has also been confirmed by this study. This study provides a platform for the utilization of different leaf litters for the process of vermicomposting.

REFERENCES

Aalok A (2009) Studies on vermicomposting of municipal solid waste with leaf litter of different tree species. PhD thesis, Ecology and Environment Division, Forest Research Institute (FRI), Dehradun, Uttarakhand, India, 200 pp

Abbasi SA, Ramasamy EV (2001) *Solid Waste Management with Earthworms*, Discovery Publishing house, New Delhi, 178 pp

Abbasi T, Gajalakshmi S, Abbasi SA (2009) Towards modeling and design of vermicomposting systems: Mechanisms of composting/vermicomposting and their implications. *Indian Journal of Biotechnology* **8**, 177-182

Albanell E, Plaixats J, Cabrero T (1988) Chemical changes during vermicomposting with *Eisenia fetida* of sheep manure mixed with cotton industrial wastes. *Biology and Fertility of Soils* **6**, 266-269

Amoji SD, Shagoti UM, Biradar VA (1998) Selective preference for agricultural organic wastes under multiple choices by epigeic earthworms. *Journal of Environmental Biology* **19**, 375-380

Basnayake BFA (2001) *Fundamental Process and Techniques of Composting*, Short course on Integrated Solid Waste Management, held at the Institute of Fundamental Studies on the 30-31 August 2001

Bishop PL, Godfrey C (1983) Nitrogen transformation during sludge composting. *Biocycle* **24**, 34-39

Butt KR (1993) Utilization of solid paper-mill sludge and spent brewery yeast as a feed for soil-dwelling earthworms. *Bioresource Technology* **44**, 105-107

Chowdappa P, Biddappa CC, Sujatha S (1999) Effective recycling of organic waste in areca nut (*Areca catechu* L.) and cocoa (*Theobroma cacao* L.) plantation through vermicomposting. *Indian Journal of Agricultural Science* **69**, 563-566

Dash MC (1993) *Fundamentals of Ecology*, Tata McGraw-Hill, New Delhi, 210 pp

Delgado M, Bigeriego M, Walter I, Calbo R (1995) Use of California red worm in sewage sludge transformation. *Turrialba* **45**, 33-41

Elvira C, Sampedro L, Benítez E, Nogales R (1998) Vermicomposting of sludge from paper mill and dairy industries with *Eisenia andrei*: A pilot-scale study. *Bioresource Technology* **63**, 205-211

Frederickson J, Butt KR, Morris RM, Daniel C (1997) Combining vermiculture with traditional green waste composting systems. *Soil Biology and Biochemistry* **29**, 725-730

Gajalakshmi S, Ramasamy EV, Abbasi SA (2001) Assessment of sustainable vermiconversion of water hyacinth at different reactor efficiencies employing *Eudrilus eugeniae* Kingberg. *Bioresource Technology* **80**, 131-135

Garg VK, Kaushik P (2005) Vermistabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia fetida*. *Bioresource Technology* **96**, 1063-1071

Ghosh M, Chattopadhyay GN, Baral K (1999) Transformation of phosphorus during vermicomposting. *Bioresource Technology* **69**, 149-154

Goluke GC (1977) *Biological Reclamation of Solid Wastes*, Rodale Press, Emmaus, PA, USA, p 2

Gunadi B, Edwards CA (2003) The effect of multiple applications of different organic wastes on the growth, fecundity and survival of *Eisenia fetida* (Savigny) (Lumbricidae). *Pedobiologia* **47**, 321-330

Gupta R, Mutiyar PK, Rawat NK, Saini MS, Garg VK (2007) Development of a water hyacinth based vermireactor using an epigeic earthworm *Eisenia foetida*. *Bioresource Technology* **98 (13)**, 2605-2610

Haimi J, Huhta V (1986) Capacity of various organic residues to support adequate earthworm biomass for vermicomposting. *Biology and Fertility of Soils* **2**, 23-27

Harborne JB (1977) *Introduction to Ecological Biochemistry*, Academic Press, New York, pp 131-151

Huang GF, Wong JWC, Wu QT, Nagar BB (2004) Effect of C/N on composting of pig manure with sawdust. *Waste Management and Resources* **24**, 805-813

Iglesias-Jiménez E, Pérez García V, Espino M, Hernández J (1993) City refuse compost as a phosphorus source to overcome the P-fixation capacity of sesquioxide-rich soils. *Plant Soil* **148**, 115-127

Jackson ML (1973) *Soil Chemical Analysis*, Prentice Hall Private Ltd., New Delhi, India, pp 51-56

Kale RD (1998) Earthworms: Nature's gift for utilization of organic wastes. In: Edwards CA (Ed) *Earthworm Ecology*, Soil and Water Conservation Society, Ankeny, Lowa St. Lucie Press, New York, pp 355-373

Kale RD, Krishnamoorthy RV (1981) Litter preference in the earthworm *Lampito mauritii*. *Animal Science* **90**, 123-128

Lorenz K, Preston CM, Krumrei S, Feger K-H (2004) Decomposition of needle/leaf litter from Scots pine, black cherry, common oak and European beech at a conurbation forest site. *European Journal of Forest Research* **123**, 177-188

Le Bayon RD, Binet F (2006) Earthworm changes the distribution and availability of phosphorous in organic substrates. *Soil Biology and Biochemistry* **38**, 235-246

Lee KE (1992) Some trends and opportunities in earthworm research. *Soil Biology and Biochemistry* **24**, 1765-1771

Moore PD, Chapman SB (1986) *Methods in Plant Ecology* (2^{nd} Edn), Blackwell Scientific Publication, Oxford, 589 pp

Ndegwa PM, Thompson SA (2000) Effects of C-to-N ratio on vermicomposting of biosolids. *Bioresource Technology* **75**, 7-12

Ndegwa PM, Thompson SA (2001) Integrating composting and vermicomposting in the treatment and bioconversion of biosolids. *Bioresource Technology* **76**, 107-112

Ndegwa PM, Thompson SA, Das KC (2000) Effects of stocking density and feeding rate on vermicomposting of biosolids. *Bioresource Technology* **71**, 5-12

Neuhauser EF, Hartenstein R, Kaplan DL (1980) Growth of the earthworm *Eisenia foetida* in relation to population density and food rationing. *Oikos* **35**, 93-98

Reinecke AJ, Venter JM (1985) Influence of moisture on the growth and reproduction of the compost worm *Eisenia fetida* (Oligochaeta). *Review of Ecology and Biology of Soil* **22**, 473-481

Reinecke AJ, Viljoen SA (1990) The influence of feeding patterns on growth and reproduction of the vermicomposting earthworm *Eisenia fetida* (Oligochaeta). *Biology and Fertility of Soils* **10**, 184-187

Sánchez-Monedero MA, Roig A, Paredes C, Bernal MP (2001) Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. *Bioresource Technology* **78**, 301-308

Sangwan P, Kaushik CP, Garg VK (2008) Vermiconversion of industrial sludge for recycling the nutrients. *Bioresource Technology* **99**, 8699-8704

Satchell JE, Martein K (1984) Phosphate activity in earthworm faeces. *Soil Biology and Biochemistry* **16**, 191-194

Starbuck CJ (2010) University of Missouri Plant Sciences, College of Agriculture, Food and Natural Resources, Division of Plant Sciences, pp 1-6. Available online: http://extension.missouri.edu/explorepdf/agguides/hort/g06956.pdf

Suthar S (2007a) Vermicomposting potential of *Perionyx sansibaricus* (Perrier) in different waste materials. *Bioresource Technology* **98**, 1231-1237

Suthar S (2007b) Nutrient changes and biodynamics of epigeic earthworm *Perionyx excavatus* (Perrier) during recycling of some agricultural wastes. *Bioresource Technology* **98**, 1608-1614

Tandon HLS (1993) *Methods of Analysis of Soils, Plants, Water, and Fertilizers*, Fertilizer Development and Consultation Organization (FDCO) New Delhi, 143 pp

Tiquia SM, Tam NFY, Hodgkiss LJ (1996) Microbial activities during composting of spent pig-manure sawdust litter at different moisture contents. *Bioresource Technology* **55**, 201-206

Tognetti C, Mazzarino MJ, Laos F (2007) Improving the quality of municipal organic waste compost. *Bioresource Technology* **98**, 1067-1076

Viel M, Sayag D, André L (1987) Optimation of agricultural, industrial waste management through in-vessel composting. In: Bertoldi M (Ed) *Compost: Production, Quality and Use*, Elsevier Applied Science, Essex, pp 230-237

Wolkowski R (2003) Nitrogen management considerations for land spreading municipal solid waste compost. *Journal of Environmental Quality* **32**, 1844-1850