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; EuL.MSWV, *Eucalyptus* leaf litter + municipal solid waste vermicompost; FRI, forest research institute; GLM, general linear model; MSW, municipal solid waste; ParL.MSWV, *Parthenium* leaf litter + municipal solid waste; PiL.MSWV, pine leaf litter + municipal solid waste; Pol.L.MSWV, *Populus* leaf litter + municipal solid waste; SrL.MSWV, *Shorea* 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 (Abbas 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 following 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 sanitation 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 (Ndewga 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...
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. hybridum* (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. roxburghii* 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 m³ 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 undisturbed. The composting process 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 composting time to keep the moisture content above 50-60% (20-30°C).

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### 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 ciliellate 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 com-

post 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 juvenile earthworms that 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 Chapman 1986). Total organic carbon (TOC) was estimated by the Walkley-Black method (Tandon 1993).

### Statistical analysis

Two-way ANOVA was used to analyze the significant (P ≤ 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

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 (Gundadi 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 CO₂ and organic acids by the microbial metabolism during decomposition of different substrates (Hampi 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 nitrates/nitrites and orthophosphates and bioconversion of the organic material into intermediate species of the organic acids. TOC decreased in all the substrates after composting (PicLMSW – 42.93% of the initial amount), SrLMSW – 39.78%, PlLMSW – 39.59%, EuLMSW – 37.28%, ParLMSW – 33.09%, and control (cow dung) – 30.28% and then increased after vermicomposting (PicLMSW – 34.36% of the initial amount), PlLMSW – 30.84%, SrLMSW – 30.26%, EuLMSW – 28.88%, control – 24.21%, and ParLMSW – 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 CO₂ by microorganisms (Tiquia et al. 1996). Production of CO₂ reduces the percentage total carbon and generates a loss of weight during composting (Sánchez-Monedero et al. 2001), while percentage total N normally increases. Recall-
Table 1 Initial physico-chemical characteristics of different feed materials.

<table>
<thead>
<tr>
<th>Feed material</th>
<th>TOC (%)</th>
<th>TN%</th>
<th>TP%</th>
<th>TK%</th>
<th>TCa%</th>
<th>TMg%</th>
<th>C/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (CD)</td>
<td>47.3</td>
<td>0.61</td>
<td>0.68</td>
<td>0.48</td>
<td>0.39</td>
<td>0.51</td>
<td>77.54</td>
</tr>
<tr>
<td>EuLMSW</td>
<td>50.64</td>
<td>1.71</td>
<td>0.08</td>
<td>1.20</td>
<td>1.03</td>
<td>0.22</td>
<td>29.64</td>
</tr>
<tr>
<td>PiLL</td>
<td>47.25</td>
<td>0.70</td>
<td>0.04</td>
<td>0.18</td>
<td>1.15</td>
<td>2.10</td>
<td>67.5</td>
</tr>
<tr>
<td>ParL</td>
<td>39.15</td>
<td>2.88</td>
<td>0.28</td>
<td>3.40</td>
<td>2.10</td>
<td>0.61</td>
<td>13.57</td>
</tr>
<tr>
<td>PoL</td>
<td>38.64</td>
<td>1.72</td>
<td>0.09</td>
<td>0.31</td>
<td>4.80</td>
<td>1.26</td>
<td>22.43</td>
</tr>
<tr>
<td>SrL</td>
<td>42.84</td>
<td>0.91</td>
<td>0.03</td>
<td>0.09</td>
<td>2.4</td>
<td>0.36</td>
<td>47.07</td>
</tr>
</tbody>
</table>

All values are mean of four replicates.

CD – cow dung; EuL – *Eucalyptus* leaf litter; PiL – *Pinus* leaf litter; ParL – *Parthenium* leaf litter; PoL – Poplar leaf litter; SrL – *Shorea robusta* leaf litter

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

<table>
<thead>
<tr>
<th>Substrates</th>
<th>pH</th>
<th>TOC (%)</th>
<th>TKN (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Compost</td>
<td>Vermicompost</td>
</tr>
<tr>
<td>Control</td>
<td>8.33 ± 0.08</td>
<td>7.73 ± 0.21</td>
<td>6.67 ± 0.12</td>
</tr>
<tr>
<td>EuLMSW</td>
<td>7.51 ± 0.06</td>
<td>7.53 ± 0.06</td>
<td>7.03 ± 0.10</td>
</tr>
<tr>
<td>PiLMSW</td>
<td>7.26 ± 0.15</td>
<td>7.43 ± 0.18</td>
<td>7.10 ± 0.05</td>
</tr>
<tr>
<td>ParLMSW</td>
<td>8.26 ± 0.10</td>
<td>7.70 ± 0.13</td>
<td>7.30 ± 0.15</td>
</tr>
<tr>
<td>PoLMSW</td>
<td>7.97 ± 0.08</td>
<td>7.50 ± 0.13</td>
<td>7.16 ± 0.06</td>
</tr>
<tr>
<td>SrLMSW</td>
<td>7.61 ± 0.15</td>
<td>7.31 ± 0.21</td>
<td>6.93 ± 0.15</td>
</tr>
</tbody>
</table>

Significance

*** 0.001 0.001 0.001

CD at 5% 0.216 1.744 0.073

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

C/N: 57.54

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 composting due to loss of dry matter (DM) (Elvira et al. 1999; Ghosh 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.

citran 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 vermocompost than the initial matter. In composted material, TN content increased in the order: Control – 76.17%, SrLMSW – 43.32%, PiLMSW – 38.51%, EuLMSW – 18.20%, PoLMSW – 14.69%, and ParLMSW – 12.66%. In vermocomposted material the TN content increased in the order: Control – 145.5%, PiLMSW – 104.36%, SrLMSW – 92.25%, EuLMSW – 55.54%, PoLMSW – 50.54%, and ParLMSW – 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). Earthworms accelerate microbial-mediated N transformation during the process of vermocomposting. 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).
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 – 69.35%, PoLMSWV – 33.87%, ParLMSWV – 33.52%, 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 is the case of vermicomposting might have played an important role in the process and increased K. O. Satchell and Martine (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. Vermicompost 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%, PoLMSWV – 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 CO₂ due to the action of microbes, without the loss of other nutrients. Loss of dry matter also 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 CO₂ 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.

<table>
<thead>
<tr>
<th>Days</th>
<th>Control</th>
<th>EuLMSWV</th>
<th>PiLMSWV</th>
<th>SrLMSWV</th>
<th>PoLMSWV</th>
<th>EuLMSWV</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>37.53 ± 0.645</td>
<td>19.14 ± 1.530</td>
<td>15.61 ± 1.001</td>
<td>18.32 ± 0.812</td>
<td>22.64 ± 2.303</td>
<td>13.67 ± 1.654</td>
</tr>
<tr>
<td>30</td>
<td>44.75 ± 0.742</td>
<td>21.48 ± 0.942</td>
<td>22.61 ± 1.181</td>
<td>22.62 ± 0.879</td>
<td>28.52 ± 0.651</td>
<td>19.69 ± 1.759</td>
</tr>
<tr>
<td>45</td>
<td>50.5 ± 1.853</td>
<td>25.62 ± 1.132</td>
<td>27.54 ± 1.690</td>
<td>28.52 ± 1.568</td>
<td>37.29 ± 0.364</td>
<td>26.62 ± 0.459</td>
</tr>
<tr>
<td>60</td>
<td>55.96 ± 0.909</td>
<td>30.29 ± 0.541</td>
<td>32.46 ± 1.160</td>
<td>32.75 ± 1.866</td>
<td>41.77 ± 0.372</td>
<td>28.22 ± 0.955</td>
</tr>
<tr>
<td>75</td>
<td>62.17 ± 1.518</td>
<td>34.34 ± 1.066</td>
<td>27.96 ± 2.959</td>
<td>29.9 ± 1.025</td>
<td>34.95 ± 0.303</td>
<td>30.91 ± 1.490</td>
</tr>
</tbody>
</table>

*CD at 5% Significance*
Statistically the results show that the number of offspring increased significantly in pig slurry than in water hyacinth. Aira (maximum worm growth was recorded in cow dung alone. The number of offspring produced and increment in worm biomass varied significantly with time. It was seen thereafter it 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.

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 (2000) 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 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).

<p>| Table 4 Number of offspring produced by E. fetida each fortnight in pre-composted organic waste as feed material. |</p>
<table>
<thead>
<tr>
<th>Days</th>
<th>Control</th>
<th>Eu.L MSWV</th>
<th>Pil. MSWV</th>
<th>Par.L MSWV</th>
<th>PoL MSWV</th>
<th>Sa.L MSWV</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0</td>
<td>10.00 ± 0.735</td>
<td>11.75 ± 0.63</td>
<td>11.75 ± 0.63</td>
<td>11.75 ± 0.63</td>
<td>11.75 ± 0.63</td>
<td>11.75 ± 0.63</td>
</tr>
<tr>
<td>30</td>
<td>17.75 ± 2.217</td>
<td>4.75 ± 1.707</td>
<td>5.0 ± 2.581</td>
<td>7.75 ± 1.5</td>
<td>11.25 ± 1.707</td>
<td>3.5 ± 1.290</td>
<td>8.33</td>
</tr>
<tr>
<td>45</td>
<td>11.75 ± 1.707</td>
<td>6.0 ± 2.943</td>
<td>5.0 ± 1.825</td>
<td>6.25 ± 3.403</td>
<td>8.25 ± 2.217</td>
<td>3.75 ± 1.707</td>
<td>6.83</td>
</tr>
<tr>
<td>60</td>
<td>16.25 ± 2.061</td>
<td>7.5 ± 3.862</td>
<td>2.75 ± 1.707</td>
<td>4.5 ± 2.082</td>
<td>9.25 ± 2.217</td>
<td>2.75 ± 1.707</td>
<td>6.87</td>
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<tr>
<td>75</td>
<td>10.75 ± 2.217</td>
<td>4.5 ± 2.380</td>
<td>4.0 ± 1.825</td>
<td>6.5 ± 3.109</td>
<td>6.0 ± 1.825</td>
<td>3.75 ± 1.707</td>
<td>5.92</td>
</tr>
<tr>
<td>Mean</td>
<td>11.33</td>
<td>4.13</td>
<td>3.35</td>
<td>5.00</td>
<td>6.95</td>
<td>2.75</td>
<td>5.5916</td>
</tr>
</tbody>
</table>

CD at % Significance
Waste 1.255 ***
Days 1.146 ***
Waste*Days 2.807 ***

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

<p>| Table 5 Worm biomass recorded each fortnight in reactors with pre-composted organic waste as feed materials. |</p>
<table>
<thead>
<tr>
<th>Days</th>
<th>Control</th>
<th>Eu.L MSWV</th>
<th>Pil. MSWV</th>
<th>Par.L MSWV</th>
<th>PoL MSWV</th>
<th>Sa.L MSWV</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>13.36 ± 0.735</td>
<td>10.6 ± 0.647</td>
<td>11.75 ± 0.63</td>
<td>9.49 ± 0.824</td>
<td>11.09 ± 0.537</td>
<td>9.66 ± 0.527</td>
<td>10.983</td>
</tr>
<tr>
<td>30</td>
<td>15.52 ± 0.729</td>
<td>12.58 ± 0.438</td>
<td>14.03 ± 0.450</td>
<td>11.5 ± 0.627</td>
<td>13.18 ± 0.473</td>
<td>12.49 ± 0.651</td>
<td>13.182</td>
</tr>
<tr>
<td>45</td>
<td>19.39 ± 0.777</td>
<td>15.14 ± 0.273</td>
<td>16.4 ± 0.780</td>
<td>14.37 ± 0.443</td>
<td>15.16 ± 0.141</td>
<td>14.73 ± 0.364</td>
<td>15.864</td>
</tr>
<tr>
<td>60</td>
<td>22.82 ± 0.765</td>
<td>17.45 ± 0.266</td>
<td>18.81 ± 0.440</td>
<td>17.0 ± 0.741</td>
<td>17.15 ± 0.250</td>
<td>16.56 ± 0.372</td>
<td>18.295</td>
</tr>
<tr>
<td>75</td>
<td>26.27 ± 0.905</td>
<td>19.51 ± 0.247</td>
<td>21.5 ± 0.410</td>
<td>18.73 ± 0.537</td>
<td>19.49 ± 0.442</td>
<td>18.34 ± 0.303</td>
<td>20.637</td>
</tr>
</tbody>
</table>

CD at % Significance
Waste 0.352 ***
Days 0.322 ***
Waste*Days 0.788 ***

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

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 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 physicochemical 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 (Amoju 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 T Mg 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.

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