Geotechnical Properties of Vermicomposts of Press Mud using
Eisenia fetida, Eudrilus eugeniae and Megascolex megascolex

Prakash Mallappa Munnoli1* · Jaime A. Teixeira da Silva2 · Saroj Bhosle3

ABSTRACT

Studies were carried out to evaluate the geotechnical properties of vemicomposts (VCs) such as porosity, void ratio, density, air content, water holding capacity and particle size distribution (PSD) prepared from sugar industrial waste press mud (PM) using surface feeders Eisenia fetida, Eudrilus eugeniae and the deep burrower Megascolex megascolex. A comparison of the geotechnical properties of 40-day samples of VCs from field trials by a core cutter showed that the VC using M. megascolex was superior to E. eugeniae and E. fetida VCs in terms of water and air content and percentage void. The PSD of PM was higher than industrial soil, while M. megascolex VC > E. eugeniae VC > E. fetida VC > E. fetida > M. megascolex. This study clearly indicates that the indigenous deep burrower M. megascolex can be used in the vermicomposting of PM while also enhancing the geotechnical properties, soil aggregation and water holding capacity of a VC.

Keywords: air content, particle size, percentage air voids, porosity, soil aggregation

INTRODUCTION

There are about 566 sugar industries in India generating a huge quantity of solid wastes: 43.13 mt y−1 bagasse and 5.5 mt y−1 press mud (PM) (NWMC, 1992). Selviraj et al. (2005) reported that 9 mt y−1 is organic in nature. These wastes, although rich in organic matter, are presently being disposed on land creating environmental problems (Munnnoli 2007). PM of the Sanjeevani Sugar Factory, Dayanand Nagar, Goa, India, was selected for field experimentation to assess the amenability of PM to vermiprocessing, and to ascertain the geotechnical properties of the vermicompost (VC) derived from it.

Vermitechnology (VT) efficiently utilizes the synergistic work of earthworms and microorganisms in the bioconversion of organic wastes generated by agro-based and food processing industries (Singh 1997; Munnoli 2007; Munnoli and Bhosle 2008; Suhart and Singh 2008; Sangawan et al. 2008). Earthworms consume organic wastes (OWs) and grind them in their gizzard, which results in an increase of specific surface area of OW, which helps to increase micro-bial enzyme activity allowing biowastes to be completely bioconverted (Edwards and Bater 1992). VT is being successfully utilized in the environmental management of stud-

Table 1 Significance of geotechnical properties in vermitechnology.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Indicator</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (G)</td>
<td>Comparison with other materials</td>
<td>Munnoli 2007</td>
</tr>
<tr>
<td>Water content (w)</td>
<td>Vermicast as a micro dam</td>
<td>Munnoli and Bhosle 2008a, 2008b</td>
</tr>
<tr>
<td>Voids ratio (e)</td>
<td>Vermicomposting process; removal of odor of substrates</td>
<td>Munnoli 2007</td>
</tr>
<tr>
<td>Porosity (n)</td>
<td>Earthworm burrowing activity and microbial activity free capillary water flow through soils</td>
<td>Munnoli 1998; Singh and Dwivedi 2004; Munnoli 2007; Bottinelli et al. 2010</td>
</tr>
<tr>
<td>Bulk density (b)</td>
<td>Amorphous nature, light weight, volume to be handled; Important parameter for other GT properties</td>
<td>Munnoli 2007</td>
</tr>
<tr>
<td>Dry density (d)</td>
<td>Amorphous nature and water holding capacity</td>
<td>Munnoli 2007</td>
</tr>
<tr>
<td>Saturated density (Vw)</td>
<td>&gt;1 meaning moisture capacity above 100%</td>
<td>Punnia 2001</td>
</tr>
<tr>
<td>Degree of saturation (S)</td>
<td>Extent of moisture</td>
<td>Punnia 2001</td>
</tr>
<tr>
<td>Air content (a)</td>
<td>Air circulation and survival of earthworms and aerobic microorganisms</td>
<td>Munnoli 2007</td>
</tr>
<tr>
<td>% Air voids (na)</td>
<td>Microbes and plants require an adequate level of oxygen in soil for their growth and activity; ensures sufficient availability of air surrounding the earthworm; prevents CO2 toxicity</td>
<td>Munnoli 2007</td>
</tr>
<tr>
<td>Particle size distribution</td>
<td>Gives comparison of changes in particle sizes and extent of aggregation, grinding/bioconversion capabilities of earthworms and also role of microbes</td>
<td>Munnoli1998; Munnoli et al. 2002; Munnoli 2007; Munnoli and Bhosle 2009; Abbasi et al. 2009; Paradelo et al. 2009; Bottinelli et al. 2010; Munnoli et al. 2010</td>
</tr>
</tbody>
</table>

Received: 1 May, 2010. Accepted: 29 September, 2010.
ges from paper mill and dairy industries using *Eisenia an-
drei* (Elvira 2006), agro-based industrial OW from tomato skin seed using *Pheritima elongata* (Singh 1997), potato peel OW using *P. elongata*, *Eisenia fetida* and *Eudrilus eugeniae* (Munnoli 2000), or treatment of a wide range of OWs (kitchen waste, agro residues, institutional and industrial wastes, including textile industry sludge and fibers) using *E. fetida* (Garg 2006). The species *E. fetida*, *E. eugeniae*, *Lampito mauritii*, *Ampyttes diffingius* and the deep burrowers *P. elongata* and *Lumbricus terrestris*, *Lum-
bricus rubellus*, *Megascolex megascolex* and *Perionyx ex-
cavatus* play an important role in OW management (Mun-
noli and Bhosle 2008; Sutar and Singh 2008; Sangawan et al. 2008). Soil aggregation and geotechnical (GT) properties play an important role in VT (Table 1) (Munnoli 2002, 2007) in the retention and movement of water within a VC, and, together with its air content, provide drier conditions for plant growth (Butt et al. 2005). Bhawalkar and Bhawal-
kar (1992) reported the use of VT for treatment of sugar-
cane PM using the deep burrower *P. elongata*. Jambhekar (1992) recycled PM derived from the sugar industry in Maharashtra, India and assessed the ability of *E. fetida*, *E. eugeniae* and *Prionyx arboricola* to biodegrade it. These earthworms could be efficiently used for producing humus with the help of some industrial solid and agricultural wastes. Hedge (1995) investigated the suitability of dif-
derent crop residues together with sugar industry wastes like PM and bagasse for treatment with *E. eugeniae*. Giraddi and Tippannavar (2000) reported the complete bioconver-
sion of PM within 85 days with *E. eugeniae* whereas in earlier studies, Singh (1997) reported bioconversion within 35-40 days using *P. elongata*.

Therefore, in the present study an attempt has been made to recycle PM in field trials using three different spe-
cies, the deep burrower *M. megascolex*, and two surface feeders *E. fetida* and *E. eugeniae*. The GT properties of the resulting VCs were evaluated. The study will be of impor-
tance in choosing a VC based on its GT and particle size
distribution (PSD) for application on various types of deg-
raded soils to improve soil fertility from the perspective of water holding capacity and soil aggregation and in re-
claiming mining waste lands.

**MATERIALS AND METHODS**

**Soil samples**

Soil and fresh PM samples were collected from a vermicomposting plant site of the Sanjeevani Sugar Factory, Dayananad Nagar, Goa, India. The PM was very good organic substrate available as a waste and was characterized at the source for GT properties (Table 2) and PSD of PM and soil (Table 5).

**Earthworm species**

*E. fetida* and *E. eugeniae* were obtained from the Institute of Natu-
ral Organic Agriculture (INORA), Pune. *M. megascolex* was col-
lected from a local cashew plantation farm at Verna, Goa, India.

**Vermi-beds**

For *M. megascolex*, vermi-beds were prepared in a 1 m × 1 m × 0.6 m (w × l × h) tank. A 2.5 cm thick layer of soil + cow dung (CD) (1: 3) about 7-days old (i.e. an easily biodegradable sub-
strate) and having a nearly neutral pH was spread evenly in the tank. 100 earthworms per tank were introduced at the cen-
tre and corners. A 5-cm thick layer of CD was then applied. The earthworms developed within 3-4 weeks and the beds were used for experiments.

For *E. fetida* and *E. eugeniae* a 5-cm thick layer of bedding material (partially dried grass) was laid at the bottom of beds (same dimension as the *M. megascolex* tank) above which a 5-cm thick layer of CD (7-days old) was spread evenly. 100 worms each of *E. fetida* and *E. eugeniae* were introduced onto separate beds. The earthworms developed within 2-3 weeks and the beds were used for further experiments.

The beds were covered with paddy, a wire mesh and a jute bag above each tank to minimize evaporation. Relative humidity (RH) was maintained at 60-70%.

Vermi-beds were further uniformly covered with a 5-cm thick layer of PM. 70% RH was maintained by sprinkling water regu-
larly.

**Vermicompost samples**

The VC samples were obtained from vermi-beds after 40 days as
the bioconversion time required for *E. fetida*, *E. eugeniae* and *M. megascolex* was 40-45, 40 and 35-40 days, respectively based on juvenile predominance and the number of hand-sorted earthworms.

**Analysis of samples**

1. **Water content**

Water content was determined by oven drying. A known weight (W1) of the VC was kept in an oven for 24 hrs at 100°C and re-
weighed (W2) (Punmia 2002):

\[ \text{Water content } w = (W_1 - W_2)/W_1. \]

2. **pH**

About 5 g of sample was placed in 100 ml distilled water and sha-
ken vigorously. The sample was allowed to settle for 1 hr. These
solutions were used to determine pH using a digital pH meter.

**Geotechnical properties**

GT properties were calculated using the procedures and deriv-

1. **Specific gravity by density bottle**

The empty weight of a density bottle (M1) was noted, a known quantity of VC was added and its weight (M2) was noted. The bottle was filled with distilled water and weighed once more (M3). The control was weighed (M4) by filling only with distilled water:

\[ \text{Specific gravity } G = (M_2-M_1)/\{(M_2-M_1) - (M_3-M_4)\} \]

2. **Bulk density (BD) of VC**

A core cutter of known volume was immersed in a vermi-bed slowly until it was completely filled with the VC:

\[ \text{BD} = \gamma = V/W \]

where \( V \) = volume of core cutter; \( W_1 \) = empty weight of core cutter; \( W_2 \) = empty weight of core cutter + VC; \( W \) = weight of VC in the core cutter = \( W_1 - W_2 \).

3. **Dry density (\( \gamma_d \))**

The dry density \( \gamma_d \) was ascertained by the relation:

\[ \gamma_d = \gamma/(1+w) \]

where \( \gamma = \text{BD} ; w = \text{water content.} \)

4. **Voids ratio ‘e’**

Voids ratio ‘e’ was calculated from the following relation using specific gravity \( G \); dry density (\( \gamma_d \)) found above and the density of water (\( \gamma_w \)) was taken as unity:

\[ e = (G \times \gamma_w)/\gamma_d - 1 \]

5. **Porosity \( n \) was obtained by the relation:**

\[ n = 1 - \gamma_d/(G \times \gamma_w) \]
6. Saturated density was obtained by the relation:

\[ \gamma_{sat} = \left(1 + \frac{\gamma_s}{\gamma_w}\right) \times \gamma_w \]

7. Degree of saturation \( S_r \) was obtained from the relation:

\[ S_r = \frac{\gamma_s}{\gamma_w} \]

8. Air content was determined as:

\[ a_c = 1 - \text{ac} \]

9. Percentage air voids \( n_a \) was determined as:

\[ n_a = 1 - \left(\frac{\gamma_s}{\gamma_w}\right) \times (1 + w) \times G \]

**Particle size distribution (PSD)**

PSD was determined in accordance with IS: 2720 (part IV). The oven-dried samples were machine sieved with a set of sieve sizes ranging from 4.75 mm to 90 μm. The percent finer (cumulative weight of oven-dried VC passing through a particular sieve taken as percentage) was calculated for soil, PM and VCs (Table 5).

The identification of soil type was carried out in accordance with IS: 1498–1970 by visual observation and based on the results of the sieve analysis.

**Statistical analysis**

Data was analyzed statistically using analysis of variance (ANOVA) to detect significant differences between the means of GT properties (Table 4) and PSD (Table 6) using Fisher’s LSD test. All statistical computations were performed with Microsoft Excel 2007 (Mahajan, 2004).

**RESULTS AND DISCUSSION**

The PM OW openly stored on the ground was found to be soft and spongy with loose BD of 450 Kg/m³, moisture content of 60-70%, pH 8.6, specific gravity 0.5. These properties, together with the GT properties (Table 2) indicate its suitability as a substrate for vermicomposting.

**Geotechnical properties**

The results of the geotechnical properties of PM and VCs are presented in Tables 2 and 3, respectively. The weight of the samples drawn in the core cutter shows the least weight is of PM VC from \( M. \text{megascolex} \) (< soil + CD (1:3) suggesting the VC had the least bulk and dry density than other VCs: \( M. \text{megascolex} \) > \( E. \text{eugeniae} \) > \( E. \text{fetida} \) > soil + CD (1:3) suggesting the amorphous nature of VCs. \( M. \text{megascolex} \) has an increase in density, confirming previous reports of increased BD of VC of CD (Edwards and Lolly 1977; Edwards and Bollen 1996; Munnoli 2007). BD is required to estimate, evaluate and calculate many physical properties and processes, is essential to convert data from weight-based to volume- and area-related data; one of the dominant factors changing BD is the soil OM (Munnoli 2007; Ruehlmann and Korschens 2009).

There was a decrease in the BD of soils treated with VC and VC + NPK compared to those treated with NPK alone, possibly due to increased porosity (Vasanthi and Kumara-samy 1999; Parthasarathi 2008). Azarmi et al. (2008) conducted in-situ experiments by incorporating sheep manure VC using \( E. \text{fetida} \) (0, 5, 10, 15 t ha⁻¹) into the top 15 cm of the soil surface. The soil samples collected from 15 cm depth after 3 months showed \( \gamma = 1.6933, 1.6300, 1.6133, 1.5633 \), respectively (Azarmi et al. 2008), clearly demonstrating that the soil becomes softer, looser and more porous in nature as the quantity of VC increased. The addition of VC can cause a significant decrease in BD, up to as much as 30% (Kolher 1995) due to the increased porosity of the soil (Bazzoffi et al. 1998). Ravikumar (2008) reported the BD of vermiash compost to vary from 0.65 to 0.90 Mg m⁻³ due to incorporation of organic residues and fly ash. The BD of soil after harvest of the crop onion (\( Allium \text{ cepa L.} \)) was 1.53 Mg m⁻³ due to application of 100% recommended dose of nitrogen (RDN) through urea. BD decreased significantly due to a VC supplement (Mamatha 2006), consistent with a report by Nandi and for the same crop. Lower

**Table 2** Geotechnical properties of press mud.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (G)</td>
<td>0.5 ± 0.05</td>
</tr>
<tr>
<td>Water content (w)</td>
<td>24.3 ± 0.6</td>
</tr>
<tr>
<td>Voids ratio (c)</td>
<td>1.0</td>
</tr>
<tr>
<td>Porosity (n)</td>
<td>0.5</td>
</tr>
<tr>
<td>Bulk density (γ)</td>
<td>0.32</td>
</tr>
<tr>
<td>Dry density (γ_d)</td>
<td>0.25</td>
</tr>
<tr>
<td>Saturated density (γ_s)</td>
<td>0.75</td>
</tr>
<tr>
<td>Degree of saturation (S_r)</td>
<td>0.14</td>
</tr>
<tr>
<td>Air content (a_c)</td>
<td>0.86</td>
</tr>
<tr>
<td>% Air voids (n_a)</td>
<td>93.9</td>
</tr>
</tbody>
</table>

**Table 3** Geotechnical parameters of vermicomposts of press mud (n = 3).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Soil + CD (1:3)</th>
<th>Eisenia fetida</th>
<th>Eudrilus eugeniae</th>
<th>Megascolex megascolex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of sample in core cutter (g)</td>
<td>59.7</td>
<td>44</td>
<td>39</td>
<td>36.9</td>
</tr>
<tr>
<td>Specific gravity (G)</td>
<td>1.18</td>
<td>1.34</td>
<td>1.25</td>
<td>1.16</td>
</tr>
<tr>
<td>Water content (w)</td>
<td>1</td>
<td>2.25</td>
<td>3.01</td>
<td>3.23</td>
</tr>
<tr>
<td>Voids ratio (c)</td>
<td>1.43</td>
<td>3.09</td>
<td>6.81</td>
<td>7.16</td>
</tr>
<tr>
<td>Porosity (n)</td>
<td>0.589</td>
<td>0.84</td>
<td>0.87</td>
<td>0.88</td>
</tr>
<tr>
<td>Bulk density (γ)</td>
<td>0.97</td>
<td>0.72</td>
<td>0.64</td>
<td>0.60</td>
</tr>
<tr>
<td>Dry density (γ_d)</td>
<td>0.485</td>
<td>0.22</td>
<td>0.16</td>
<td>0.142</td>
</tr>
<tr>
<td>Saturated density (γ_s)</td>
<td>1.07</td>
<td>1.05</td>
<td>1.05</td>
<td>1.019</td>
</tr>
<tr>
<td>Degree of saturation (S_r)</td>
<td>0.825</td>
<td>0.59</td>
<td>0.55</td>
<td>0.523</td>
</tr>
<tr>
<td>Air content (a_c)</td>
<td>0.125</td>
<td>0.41</td>
<td>0.45</td>
<td>0.48</td>
</tr>
<tr>
<td>Percentage air voids (n_a)</td>
<td>10%</td>
<td>34%</td>
<td>40%</td>
<td>42%</td>
</tr>
</tbody>
</table>

*Water content, Voids ratio, Porosity, air content is expressed as fraction.*
BD was reported for alfisol after harvesting maize and wheat using organic manure (Suresh and Mathur 1989). BD decreased from 1.68 to 1.39 by incorporating coir pith at 10 t ha⁻¹ in sandy and clay loams (Durai 1982). Use of organic manures increased BD of acid soil (Prasad, 1994), East Indian Galangal soil (Maheshwarappa et al. 1999) and alfisol (Prakash 2002). Ghosh et al. (2010) reported improved physical properties of sodic Australian vertisols with organic amendments (cotton gin trash (60 Mg ha⁻¹), cattle manure (60 Mg ha⁻¹) and composted chicken manure (18 Mg ha⁻¹) and a significant increase in nutrients (N, P, K, Ca, Mg). A decrease in BD was reported in soils with high OM content (Arvidsson 1998) and application of an undecomposed organic resource, wheat straw (Sarkar 2003). A higher BD was noticed in chemical fertilizer-treated plots than in organic input treatment (Sesbania aculeata shoot and wheat straw) plots caused by a loss of soil organic carbon (Singh et al. 2009) and an increase of 12-19% after 20 years without worms (Clements et al. 1991).

The degree of saturation (Sr) was highest in the control soil + CD (1 : 3), and there was no measurable difference in the saturation density (γₛₐ) with VCs (Table 3). The voids ratio (e) of VCs was 3.84, 3.68 and 3.28 times more than CD + soil (1:3) for M. megascoleox VC > E. eugeniae VC > E. fetida VC > soil + CD (1:3), respectively. M. megascoleox is a deep burrower, is longer than E. eugeniae and E. fetida, has more movement in the soil at a greater depth and leaves large holes following burrowing, and these factors would surely contribute to the higher air content (Nobel et al. 1970), which in turn would increase the space for air circulation and survival of earthworms and aerobic microorganisms (Loquet et al. 1977; Kale 1994; Munnoli 2007).

The voids ratio (e) of VCs was 5.476 and 3.55 times higher than that of soil + CD for M. megascoleox, E. eugeniae and E. fetida, respectively in the order M. megascoleox VC > E. eugeniae VC > E. fetida VC > soil + CD (1:3). A VC with a higher ratio has a bad odor indicates that the system is overloaded with the possibility of anaerobic conditions due to a reduction in voids. Earthworms’ activities improve soil aeration (Edwards and Lofty 1977; Munnoli 2007).

The porosity (n) of VCs was 1.5, 1.47 and 1.42 times higher than that of soil + CD for M. megascoleox, E. eugeniae and E. fetida, respectively in the order M. megascoleox VC > E. eugeniae VC > E. fetida VC > soil + CD (1:3). This indicates the porous nature of the VC, an important property pin pointing earthworm activity, which in turn shows the substrate preference of the earthworms: the greater the porosity, the greater the liking of a food substrate. In the present case, M. megascoleox VC has a higher porosity, implying that PM is a very good substrate for M. megascoleox. An increase of porosity from 35.33 to 40.33% was recorded in VC-treated plots (Azrami 2008). Increased OM in soil influences aggregation and associated pore space distribution (Hudson 1994).

Water entry into soil is essentially a surface process in which porosity distribution of the soil material is the determining factor (Biswas and Mukherjee 1994; Stewart et al. 1988). Therefore activities of both surface feeders and deep burrower species are responsible for improved porosity (Aina 1995; Bottinelli et al. 2010) of soil with rounded pores (Marrari et al. 2000). When pore size increases from 30-50 to 50-500 μm and there is a decrease in the number of pores >500 μm (Pagliai et al. 1980), this enables free capillary water to flow through soils (Singh and Dwivedi 2004, Nahamani et al. 2005a, 2005b; Prabhakar et al. 2006; Munnoli 2007). Aina (1984) noted a 2.5-fold increase in infiltration due to earthworms (Eudrilids) in forest soils. 17% greater moisture capacity, doubled infiltration rates with Lumbricids (Stockdill 1966; Stockdill and Cossens 1966), and adding deep burrower species to earthworm-occupied soils resulted in about 4% additional soil moisture (Springett et al. 1985; Lal 1988) in New Zealand. The role of earthworms in increasing the mean weight diameter and macro porosity of water-stable aggregates has been reported for tropical alfisol (Lal and Akinremi 1983; Hulugalle and Ezumah 1991) for well graded soil using M. megascoleox (Munnoli 2007), for loamy soil with E. fetida (Azrami et al. 2008) and with Metaphire posthuma (Bottinelli et al. 2010).

Porosity depends upon the texture and aggregation of the soil (Lee 1991). Application of sewage sludge compost at rates equivalent to 50 and 150 t ha⁻¹ manure, based on organic carbon content, increased the porosity of a sandy loam soil at all times over two years (Guidi et al. 1983). The increased porosity in VCs and VC-treated plots is probably due to aggregation of the soil particles by the action of microorganisms in the VC, which produces polysaccharides providing a cementing action between soil particles (Six et al. 1995; Thakur et al. 1995; Sengar and Salini Gupta 2006; Munnoli 2007; Singh 2009) and possibly also by fungal mycelia (Edwards and Bohlen 1996; Tewatia 2007). The addition of organic manure affects soil aggregation and will have long-term implications on soil OM dynamics (Fonte et al. 2009).

The percentage air voids (nₐ) of VCs was 4.2, 4.0 and 3.4 times higher than that of soil + CD (1:3) for M. megascoleox, E. eugeniae and E. fetida, respectively in the order M. megascoleox VC > E. eugeniae VC > E. fetida VC > soil + CD (1:3), which demonstrates the that deep burrower species are superior in terms of air voids (P < 0.05). Low porosity and hydraulic conductivity of soil can cause inadequate aeration which may lead to accumulation of salts and toxic substances (Biswas and Mukherjee 1994). Earthworm activity is also dependent on oxygen level in soil as earthworms breathe from the skin (Munnoli 2007). ANOVA shows that the sum of squares within GT parameters is significant but not between VCs (P < 0.05; within GT parameters F = 24.1884057**; between VCs F = 0.3290498) (Table 4). The two properties weight of sample in core cutter and percentage air voids differ significantly i.e., difference in means > LSD (CD) 8.85 (Fisher’s LSD). This suggests that the GT properties do not differ significantly between species although M. megascoleox VC GT properties are better than those of E. fetida and E. eugeniae.

### Table 4 Analysis of variance of vermicomposts’ geo-technical properties (P < 0.05).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom (Df)</th>
<th>Sum of squares</th>
<th>Mean sum squares</th>
<th>Variance ratio (F)</th>
<th>F (Table)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT parameters</td>
<td>11-1=10</td>
<td>911.089915</td>
<td>911.089915</td>
<td>24.1884057**</td>
<td>2.18</td>
</tr>
<tr>
<td>Verrincomposts</td>
<td>4-1=3</td>
<td>37.199457</td>
<td>12.399819</td>
<td>0.3290498 NS</td>
<td>2.92</td>
</tr>
<tr>
<td>Error</td>
<td>10*3=30</td>
<td>1130.511456</td>
<td>37.6837152</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44-1=43</td>
<td>10282.8003</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Means of weight in core cutter. Percentage air voids differ significantly > LSD(CD) 8.85
All four groups do not differ significantly

GT = geotechnical

**Highly significant. NS: Not significant
Geotechnical properties of press mud vermicompost. Munnoli et al.

making the particle size of PM finer. The grinding capability of *E. eugeniae* was higher than that of *E. fetida* and *M. megascolex*. *M. megascolex* has a higher aggregation than the other two earthworms and industrial soil. During vermi-processing at an intermediate stage of soil processes the PSD for *M. megascolex* increased beyond that of PM. This demonstrates that during initial periods of vermi-processing grinding predominates and as vermi-beds stabilize, aggregation predominates.

Both grinding and aggregation are natural soil processes in a soil ecosystem. The role of earthworms in building soil and aggregating it was possible by using *P. elongata* (Singh, 1997; Munnoli, 2002). In the case of soil obtained from an ongoing vermi-processing plant of Hindustan Lever Ltd., Zahura, Punjab, India (which treats tomato skin seed OW using *P. elongata*) after two years of commissioning there was significant aggregation compared to the soil from outside vermi-beds (Munnoli 1998). Aggregation has been reported by the pigmented species *L. terrestris*, *L. rubelius*, *L. costensis*, *Dendrobaena octaedra* and *Bimastos eiseni*, but no aggregation in unpigmented species *Octolasion cyanenum*, *Octolasion lacteum*, *Aporrectodea caliginosa*, and *Aporrectodea longa* (Svendsen 1957). Similarly, higher aggregation was reported for *M. megascolex* than for *E. eugeniae* and *E. fetida* in VC of CD (Munnoli 2009). *E. eugeniae*, with bacterial inoculum isolated from VC of PM, also demonstrated aggregation in a Petri dish experiment (Munnoli 2008b). This also fully confirms that the PM VC of *M. megascolex* was higher than that of *E. fetida* and *E. eugeniae*. This clearly depicts the functional role of deep burrower earthworms in building soil. Aggregation is a significant property (Edwards and Lofty 1977) used to develop degraded soils, as aggregation is the basic requirement on which all other geotechnical parameters depend (Munnoli 2007; Paradelo et al. 2009).

The ANOVA (Table 6) shows a significantly greater PSD between groups while that within groups is highly significant (*P* < 0.05; *F* = 9.60; *F* = 80.03 PSD). In addition, there were no significant differences between the VC of *E. eugeniae* and that of *E. fetida*; all VCs differed significantly with PM (Table 6; Fig. 1).

The use of VC in improving soil characteristics is well documented (Stewart, 1988; Springett 1992; Munnoli 2002a 2007; Munnoli and Bhosle 2009). The VC of tomato skin seed using *P. elongata* on soil with no vegetative growth showed significant vegetation (Munnoli 1998) and a decrease in electrical conductivity of saline soils using PM VC (Munnoli 2007). Also, application of VC increased microbial growth and activity (Arancon 2006; Munnoli 2007; Munnoli et al. 2010).

### Soil type

The soil type is SW, well graded (Fig. 1), loamy (GUILD 1948); SM-SC: poorly graded sandy silt and clay mixture

<table>
<thead>
<tr>
<th>IS sieve size (mm)</th>
<th>Soil</th>
<th>Press mud</th>
<th>Eisenia fetida</th>
<th>Eudrilus eugeniae</th>
<th>Megascolex megascolex</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75</td>
<td>83.50</td>
<td>64.00</td>
<td>81.2</td>
<td>81.82</td>
<td>95.46</td>
</tr>
<tr>
<td>2.36</td>
<td>66.50</td>
<td>50.00</td>
<td>67.54</td>
<td>69.73</td>
<td>58.65</td>
</tr>
<tr>
<td>1.18</td>
<td>46.00</td>
<td>32.5</td>
<td>52.45</td>
<td>54.01</td>
<td>44.11</td>
</tr>
<tr>
<td>0.850</td>
<td>39.0</td>
<td>20.50</td>
<td>46.17</td>
<td>49.29</td>
<td>26.84</td>
</tr>
<tr>
<td>0.600</td>
<td>27.00</td>
<td>13.5</td>
<td>37.75</td>
<td>40.93</td>
<td>21.39</td>
</tr>
<tr>
<td>0.50</td>
<td>9.50</td>
<td>4.5</td>
<td>18.04</td>
<td>20.66</td>
<td>15.94</td>
</tr>
<tr>
<td>0.300</td>
<td>0.50</td>
<td>0.0</td>
<td>3.66</td>
<td>4.57</td>
<td>2.31</td>
</tr>
<tr>
<td>0.200</td>
<td>0.07</td>
<td>0.0</td>
<td>1.72</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Pan (0.00)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

ANOVA *P* < 0.05; *F* = 9.60; *F* = 80.03

Values are expressed as mean (n = 3)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degree of freedom (df)</th>
<th>Sum of squares</th>
<th>Mean sum of squares</th>
<th>Variance ratio</th>
<th>F (Table)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between vermicomposts</td>
<td>4-2-3</td>
<td>1184.283389</td>
<td>394.7611296</td>
<td>9.60618831</td>
<td>3.01</td>
</tr>
<tr>
<td>Within particle size distribution</td>
<td>9-1-8</td>
<td>26312.16465</td>
<td>3299.020581</td>
<td>80.0356182</td>
<td>2.36</td>
</tr>
<tr>
<td>Error</td>
<td>8*3=24</td>
<td>986.2670611</td>
<td>41.09446088</td>
<td>** Highly significant **</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>36-1=35</td>
<td>28482.71</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5 Cumulative percentage finer of press mud, soil, oven-dried vermicomposts of press mud.

![Fig. 1 Comparison of particle size distribution of vermicomposts with industry soil and press mud.](image-url)

![Graph](image-url)
CONCLUSIONS

E. eugia can be a suitable species for recycling PM based on its grinding capacities. GT and PSD values revealed that the PM VC using M. megascolax was far superior to those of surface feeders E. eugia can and E. fetida. Therefore, this suggests that indigenous species of M. megascolax should be used in large-scale vermireactors for recycling PM and the use of this VC for developing waste lands should be increasingly advocated.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help of Prof. Sunila Mavinkurve and Mr. Nikhil Dessai, Manager of the Sanjeevani Sugar Factory for support and guidance during field trials. We also thank Rev. Fr. P. M. Rodrigues, Director Agnel Technical Education Complex, Verna, Goa for providing all in-house institutional facilities. Funding received from the Council for Advancement of Peoples Action and Rural Technology (CAPART) is thankfully acknowledged.

REFERENCES


Ashari R, Giglou MT, Taleshmikari RD (2008) Influence of vermicompost on soil chemical and physical properties in tomato (Lycopersicum esculentum) field. Journal of Biotechnology 7 (14), 2397-2401


Munnoli PM, Arora JK, Sharma SK (2002a) Impact of vermi processing on soil characteristics. Journal of Industrial Pollution Control 18 (1), 87-92


Munnoli PM, Bhosle S (2008b) Soil aggregation by vermicompost of sport mud. Current Science 95 (11), 1533-1535


Prabhakar K, Balanunugruh K, Ranganathan LS (2008) Influence of vermi- compost on the physical chemical and biological properties in different types of soils along with yield and quality of the pulse crop black gram. Iranian


Munnoli PM, Bhosle S (2008a) Soil aggregation by vermicompost of sport mud. Current Science 95 (11), 1533-1535


Geotechnical properties of press mud vermicompost. Munnoli et al.

Journal of Environmental Health Science Engineering 5 (1), 51-58
Singh NB, Khare AK, Bhargava DS, Agrawal S (2003) Vermicomposting of tomato skin seed waste. Institution of Engineers Journal (EN) 84, 30-34
Stewart VI, Scullion J, Salih RO, Al-Bakri KH (1988) Earthworms and structure rehabilitation in sub soils and in top soils affected by opencast mining for coal. Biological Agriculture and Horticulture 5, 325-338
Tewatia RK, Kalve SP, Choudhary RS (2007) Role of bio-fertilizers in Indian agriculture. Indian Journal of Fertiliser 3 (1), 111-118