Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with cow dung and agricultural residues

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Abstract

In India, thousands of tons of textile mill sludge are produced every year. We studied the ability of epigeic earthworm Eisenia foetida to transform textile mill sludge mixed with cow dung and/or agricultural residues into value added product, i.e., vermicompost. The growth, maturation, mortality, cocoon production, hatching success and the number of hatchlings were monitored in a range of different feed mixtures for 11 weeks in the laboratory under controlled environmental conditions. The maximum growth and reproduction was obtained in 100% cow dung, but worms grew and reproduced favorably in 80% cow dung + 20% solid textile mill sludge and 70% cow dung + 30% solid textile mill sludge also. Addition of agricultural residues had adverse effects on growth and reproduction of worms. Vermicomposting resulted in significant reduction in C:N ratio and increase in TKN, TP, TK and TCa after 77 days of worm activity in all the feeds. Vermicomposting can be an alternate technology for the management of textile mill sludge if mixed with cow dung in appropriate quantities.

Keywords: Solid textile mill sludge; Cow dung; Agricultural residues; Eisenia foetida; Growth; Fecundity; Hatchlings; Physico-chemical characteristics; Vermicompost

1. Introduction

Disposal of industrial sludge by environmentally acceptable means poses a very great challenge worldwide. Use of earthworms in management of sludge has been suggested (Elvira et al., 1998). The use of earthworms in sludge management has been termed as vermistabilization (Neuhauser et al., 1988). The transformation of industrial sludge into vermicompost is of double interest: on the one hand, a waste is converted into value added product, and, on the other, it controls a pollutant that is a consequence of increasing industrialization.

Considerable work has been carried out on the use of earthworms in composting various organic materials and it has been established that epigeic forms of earthworms can hasten the composting process to a significant extent with production of a better quality of compost as compared with those prepared through traditional composting methods (Ghosh et al., 1999). The growth patterns of earthworms have been investigated in animal manure (Edwards et al., 1985; Hartenstein et al., 1979; Kaplan et al., 1980; Gunadi et al., 2002); plant litter (Fredericksen et al., 1997; Shanthi et al., 1993; Gunadi et al., 1998; Bansal and Kapoor, 2000) and municipal sludge (Baker et al., 2002; Dominguez et al., 2000; Neuhauser et al., 1988). But there have been only a few studies on the influence of industrial sludge on the growth and fecundity of earthworms, and chemical quality of the vermicompost. Butt (1990) showed that solid paper mill sludge was a suitable feed for Lumbricus terrestris under laboratory conditions. This sludge had no deleterious effects on the earthworms, although growth rate was poor. The low level of nitrogen (0.5%) was considered a limiting factor. By the addition of spent yeast from the brewing industry, the C:N ratio of this sludge could be adjusted according to the requirements (Butt, 1993). Elvira et al. (1996) studied the efficiency of Eisenia andrei (Bouche) in bioconverting paper-pulp mill sludge mixed with primary
sewage sludge. The mixture at a 3:1 ratio was a suitable medium for optimum growth and reproduction of the earthworms. The presence of earthworms accelerated the mineralization of organic matter, favored the breakdown of structural polysaccharides and increased the humification rate. Solid paper-mill sludge mixed with sewage sludge in the 3:2 ratio resulted in the highest growth rate and the lowest mortality of *E. andrei*, whereas paper mill sludge mixed with pig slurry exhibited a high mortality (Elvira et al., 1996). High mortality was attributed to changes in the environmental characteristics.

Elvira et al. (1998) studying the growth and reproduction of *E. andrei* in mixed paper mill sludge and cattle manure found that, the number of earthworms increased between 22- and 36-fold and total biomass increased between 2.2- and 3.9-fold in different feed mixtures. The vermicompost was rich in nitrogen and phosphorus and had good structure, low level of heavy metals, low conductivity, high humic acid contents and good stability and maturity. The authors reported a significant difference in the growth rates and cocoon production by *E. andrei* between the laboratory and the pilot experiments. Similarly, sludge from dairy industries also needs to be mixed with other organic residues to improve their structure and balance the nutrient content in the mixture (Gratelly et al., 1996). Hartenstein and Hartenstein (1981) in their lab-scale experiments on vermicomposting of activated sludge observed that approximately 1 g worm could convert 4 g of activated sludge in 5 days.

The authors have observed that most of the textile mills in India dispose the raw and unstabilized sludge in open dumps, along the road side, railway tracks or agricultural fields which have polluted the underground and surface water at several locations. Over the last few years, regulations for textile mill sludge disposal have become more rigorous and such unscientific disposals are not permitted. The unavailability of land and public consciousness has made such dumps and landfills expensive and impractical. Until now no information is available about the utilization of solid textile mill sludge (STMS) for vermicomposting. The aim present work was to assess the growth and fecundity of *Eisenia foetida* in STMS mixed with cow dung (CD) and/or agricultural residues (AR); as well as to assess the physical and chemical changes in different substrates.

2. Methods

2.1. Cow dung (CD)

Fresh CD was procured from the Devi Bhawan cowshed, Hisar, India. The main characteristics of CD were: total solids, 454 g/kg; pH (1:10 ratio) 7.64; total organic carbon (TOC), 421 g/kg; total Kjeldhal nitrogen (TKN), 6.1 g/kg; total phosphorus (TP), 6.8 g/kg and C:N ratio, 69.0.

2.2. Agricultural residues (AR)

Wheat crop residues consisting of dry straw and leaves were collected, after the harvesting of crop, from the agricultural fields of Guru Jambheshwar University, Hisar, India. The agricultural residue was air-dried and shredded to 2–5 mm sizes before use.

2.3. Solid textile mill sludge (STMS)

Fresh STMS was obtained from the wastewater treatment plant of a textile factory (H.P. Cotton Mill Ltd.) located near Hisar, India. The main characteristics of STMS were: total solids, 192 g/kg; pH (1:10 ratio) 8.4; TOC, 138 g/kg; TKN, 0.66 g/kg and C:N ratio: 230.

2.4. Eisenia foetida

Young non-clitellated specimens of *E. foetida*, weighing 200–250 mg live weight, were randomly picked from a stock culture maintained in the laboratory by the authors with CD as culturing material.

2.5. Experimental design

Nine circular 1 l plastic containers (diameter 14 cm, depth 12 cm) were filled with 150 g feed mixture (on dry weight basis) containing different percentage of STMS, CD and/or AR (Table 1). These mixtures were turned over manually every 24 h for 15 days in order to eliminate volatile toxic substances. After 15 days, 5 non-clitellated earthworms were introduced in each container. All containers were kept in darkness at room temperature (22–26 °C). The moisture content of the feed in each container was maintained at 60–80%, throughout the study period by periodic sprinkling of adequate quanti-

<table>
<thead>
<tr>
<th>Feed mixture no.</th>
<th>Cow dung (CD) (g)</th>
<th>Agricultural residue (AR) (g)</th>
<th>STMS (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150 (100)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>120 (80)</td>
<td>0</td>
<td>30 (20)</td>
</tr>
<tr>
<td>3</td>
<td>105 (70)</td>
<td>0</td>
<td>45 (30)</td>
</tr>
<tr>
<td>4</td>
<td>90 (60)</td>
<td>0</td>
<td>60 (40)</td>
</tr>
<tr>
<td>5</td>
<td>75 (50)</td>
<td>0</td>
<td>75 (50)</td>
</tr>
<tr>
<td>6</td>
<td>37.5 (25)</td>
<td>37.5 (25)</td>
<td>75 (50)</td>
</tr>
<tr>
<td>7</td>
<td>45 (30)</td>
<td>45.0 (30)</td>
<td>60 (40)</td>
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<td>8</td>
<td>52.5 (35)</td>
<td>52.5 (35)</td>
<td>45 (30)</td>
</tr>
<tr>
<td>9</td>
<td>60 (40)</td>
<td>60.0 (40)</td>
<td>30 (20)</td>
</tr>
</tbody>
</table>

The figures in parentheses indicate the percentage content in the initial feed mixture.
ties of water. There were three replicates for each feed mixture.

Growth, clitellum development and cocoon production were measured weekly for 11 weeks. The feed in the container was turned out, and earthworms and cocoons were separated from the feed by hand sorting, after which they were counted, examined for clitellum development and weighed. The worms were weighed without first voiding them, since it has been reported that the gut content would lie around 10% of live weight, whereas larger differences are expected in relation to feed (Neuhäuser et al., 1980). Corrections for gut content were not applied to any of the data in this study. Then all measured earthworms and the feed (but not cocoons) were returned to the container. The hatching of cocoons and the number of hatchlings were studied by incubating the cocoons at 25 °C in glass-dishes in distilled water as described by Venter and Reinecke (1988). The cocoons were inspected daily at a fixed hour of the day and hatchlings were removed. The hatchlings were allowed to develop in other containers contained the same feed in which their parents were reared.

At the end of vermicomposting period the earthworms and cocoons were separated and the final compost from each reactor was air-dried at room temperature. Homogenized samples of final compost were ground in a stainless steel blender, stored in airtight plastic vials for further chemical analysis.

2.6. Chemical analysis

All the samples were used on dry weight basis for chemical analysis that was obtained by oven drying the known quantities of material at 110 °C.

All the chemicals used were analytically reagent (AR) grade supplied by SD Fine Chemicals, Mumbai, India. Alkali resistant borosilicate glass apparatus and double glass distilled water was used throughout the study for analytical work. All the samples were analyzed in triplicate and results were averaged.

The pH was determined using a double distilled water suspension of each mixture in the ratio of 1:10 (w/v) that had been agitated mechanically for 30 min and filtered through Whatman no. 1 filter paper. Total organic carbon (TOC) was measured using the method of Nelson and Sommers (1982). Total Kjeldhal nitrogen (TKN) was determined after digesting the sample with concentrated H2SO4 and concentrated HClO4 (9:1, v/v) Bremner and Mulvaney (1982) procedure. Total P (TP) was analyzed using the colorimetric method with molybdenum in sulphuric acid. Total K (TK) and total Ca (TCa) were determined, after digesting the sample in diacid mixture (concentrated HNO3;concentrated HClO4, 4:1, v/v), by flame photometer [Elico, CL 22 D, Hyderabad, India] (Bansal and Kapoor, 2000).

3. Results and discussion

3.1. Growth and fecundity of earthworms

The changes in worm biomass for all the studies feed mixtures over the observation period is illustrated in Fig. 1(a) and (b). No mortality was observed in any treatment during initial 11 weeks. Increasing proportion of STMS in the feed mixture promoted a decrease in biomass of E. foetida. The fastest growth was observed in 100% CD (32.5 mg earthworm⁻¹ day⁻¹) after 30 days which was reduced to 16.04 mg earthworm⁻¹ day⁻¹ in 50%CD + 50%STMS feed mixture. Replacement of CD by AR in feed mixtures further reduced the worm biomass (Table 2). The maximum individual biomass of E. foetida in 100%CD was 1.75–2.0-fold higher than other tested feed mixtures. The feed mixture with 40%CD + 40%AR + 20%STMS had 3.35-fold lower individual biomass than 100%CD. The maximum mean biomass was reached on day 56 (1260 ± 92.9 mg earthworm⁻¹) in 100%CD. In contrast to 100%CD, the maximum mean biomass was reached on day 28 in all other feed mixtures except 50%CD + 50%STMS (day 36). Initial increase in biomass was followed by a stabilization, and, later weight loss was observed in mixtures including 100%CD. The difference in worm biomass was no longer evident after 11 weeks, when all the worms had a very similar biomass in all the feed mixtures other than 100%CD. The overall impression was that CD + STMS mixtures were better feed than CD + AR + STMS feed mixtures in terms of earthworm biomass increase over the whole observation period.

In all the feeds, E. foetida specimens were fully ciliated by 3rd week except 50%CD + 50%STMS feed mixture (4 weeks). Cocoon production was monitored from 3rd week onwards. Cocoon production was started in 3rd week in 100%CD, 80%CD + 20%STMS, 30%CD + 30%AR + 40%STMS and 35%CD + 35%AR + 30%STMS feed mixtures and in fourth week in the rest of the feeds except 50%CD + 50%STMS (5th week). Table 2 shows the mean number of cocoons produced per earthworm in each feed mixture for the period from 3rd to 11th week. Cocoon production was between 12.4 (100%CD) and 6.8 cocoons earthworm⁻¹ for different feed mixtures tested. Cocoon production fluctuated considerably with time. Initially cocoon production rate was high. This rate decreased after 8th week and then approximately constant. Since cocoon production is highly dependent on food availability, which explain much fluctuation. Total number of cocoons produced was maximum (62) in 100%CD and minimum (43) in 25%CD + 25%AR + 50%STMS feed mixture. The results showed that CD amended with 20% and 30%STMS can be a suitable growth medium for E. foetida (Tables 2 and 3). These mixtures probably provides earthworms with sufficient amount of easily metabolizable organic matter and non-assimilated carbohydrates, that favor growth
and reproduction of this animal (Edwards and Fletcher, 1988; Flack and Hartenstein, 1984).

The greatest mean number of hatchlings per cocoon was in the 80%CD + 20%STMS feed followed by 70%CD + 30%STMS and 100%CD. The minimum number of hatchlings per cocoon was in 50%CD + 50%STMS feed (Tables 2 and 3). It can be seen from the data (Table 3) that there was no clitellum development in hatchlings in feeds having 30% or more STMS content. This indicated that greater percentage of STMS in the feed mixture significantly affected the cocoon production, number of hatchlings per cocoon and clitellum development in hatchlings. Elvira et al. (1997) showed that *E. andrei* were unable to survive in paper-pulp mill sludge. However, feed mixtures of paper-pulp mill sludge with pig and poultry slurry were suitable materials for vermicomposting. They attributed this mortality to degradation processes that result in changes in environmental characteristics. After 20 weeks of observations, mortality occurred in different feed mixtures including control. Maximum mortality (100%) was reported in 25%CD + 25%AR + 50%STMS feed.
mum morality (40%) was observed in 100%CD and 80%CD + 20%STMS. These results suggested that feed nos. 5–9 (Table 1) cannot be used as substrate for *E. foetida* but must be supplement with more organic materials. Similar observations have been reported by Elvira et al. (1998) for paper-pulp mill sludge vermicomposting by *E. andrei*.

### 3.2. Changes in physico-chemical quality of the feed mixtures

The vermicomposting significantly modified the physical and chemical properties of different feed mixtures tested (Table 4). The vermicompost was much darker in color than originally and had been processed more or less into a homogeneous mixture after 77 days of earthworm activity. The lower pH recorded in the final products might have been due to the production of CO₂ and organic acids by microbial activity during the process of bioconversion of different substrates in the feed mixtures (Haimi and Hutha, 1986; Elvira et al., 1998). Lower pH of the final product suggested that the vermicompost obtained in this study should be corrected for pH before use for plants (Verdonck et al., 1987). A large fraction of TOC was lost as CO₂ (between 27% and 52%) by the end of vermicomposting period. Elvira et al. (1996) have attributed this loss to the presence of earthworms in the feed mixtures. TKN had increased by the end of vermicomposting period between 6.4 and 5.0 g/kg in different feed mixtures, probably because of mineralization of organic matter (Table 4). Similar results have been reported by Hand et al. (1988) who found that *E. foetida* in cow dung slurry increased the nitrate–nitrogen content. A decrease in pH may also be an important factor in nitrogen retention as this element is lost as volatile ammonia at higher pH values (Hartenstein and Hartenstein, 1981). Earthworms also have a great impact on nitrogen transformations in manure, by enhancing nitrogen mineralization, so that mineral nitrogen was retained in the nitrate form (Atiyeh et al., 2000). Initial C:N ratios were exceptionally high in CD+AR+STMS (120–140) feed mixtures than CD+STMS feed mixtures (68–80). The final C:N ratios of CD+STMS mixtures were about 15±2 and of CD+AR+STMS feed mixtures were about 25±5. This overall decrease in C:N ratio was associated with an increase in TKN of final worm-worked product. According to Senesi (1989), a decline of C:N ratio to less than 20 indicate an advanced degree of organic matter stabilization and reflects a satisfactory degree of maturity of organic wastes. Microflora in the intestine of worms and gut enzymes, as well as microflora present in the feed, are involved in the decomposition (Whiston and Seal, 1988; Kavian and Ghatneker, 1991). Enhanced organic matter decomposition in the presence of earthworms has been reported, which results in lowering

### Table 2

<table>
<thead>
<tr>
<th>Feed no.</th>
<th>Maximum individual biomass (mg)</th>
<th>Mean growth in first 30 days (mg/day)</th>
<th>Clitellum development started after</th>
<th>Started producing cocoons after</th>
<th>Mean cocoons earthworm⁻¹ (after 11 weeks)</th>
<th>Mortality after 20 weeks (%)</th>
<th>Mean no. of hatchlings per cocoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Control)</td>
<td>1260 ± 92.9</td>
<td>32.5</td>
<td>3 weeks</td>
<td>3 weeks</td>
<td>12.4</td>
<td>40</td>
<td>0.98</td>
</tr>
<tr>
<td>2</td>
<td>718 ± 51.6</td>
<td>25.7</td>
<td>3 weeks</td>
<td>3 weeks</td>
<td>11.4</td>
<td>40</td>
<td>1.14</td>
</tr>
<tr>
<td>3</td>
<td>691 ± 54.2</td>
<td>24.6</td>
<td>3 weeks</td>
<td>4 weeks</td>
<td>9.2</td>
<td>60</td>
<td>1.12</td>
</tr>
<tr>
<td>4</td>
<td>668 ± 53.5</td>
<td>23.9</td>
<td>3 weeks</td>
<td>4 weeks</td>
<td>8.8</td>
<td>60</td>
<td>0.77</td>
</tr>
<tr>
<td>5</td>
<td>599 ± 50.4</td>
<td>16.4</td>
<td>4 weeks</td>
<td>5 weeks</td>
<td>8.6</td>
<td>80</td>
<td>0.35</td>
</tr>
<tr>
<td>6</td>
<td>402 ± 38.9</td>
<td>13.7</td>
<td>3 weeks</td>
<td>4 weeks</td>
<td>6.8</td>
<td>100</td>
<td>0.69</td>
</tr>
<tr>
<td>7</td>
<td>473 ± 42.6</td>
<td>16.9</td>
<td>2 weeks</td>
<td>3 weeks</td>
<td>8.6</td>
<td>80</td>
<td>0.58</td>
</tr>
<tr>
<td>8</td>
<td>412 ± 48.2</td>
<td>14.7</td>
<td>2 weeks</td>
<td>3 weeks</td>
<td>8.8</td>
<td>80</td>
<td>0.54</td>
</tr>
<tr>
<td>9</td>
<td>377 ± 36.3</td>
<td>13.4</td>
<td>3 weeks</td>
<td>4 weeks</td>
<td>9.8</td>
<td>40</td>
<td>0.48</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Feed no.</th>
<th>Residual no. of cocoons</th>
<th>Total no. of hatchlings</th>
<th>Total biomass of hatchlings (mg)</th>
<th>Total no. of clitellated hatchlings</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>49</td>
<td>6560</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
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<td>4020</td>
<td>2</td>
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<td>3</td>
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<td>36</td>
<td>2040</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>21</td>
<td>1410</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>5</td>
<td>180</td>
<td>0</td>
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<td>0</td>
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<td>7</td>
<td>4</td>
<td>17</td>
<td>832</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>19</td>
<td>988</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>25</td>
<td>1580</td>
<td>0</td>
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</table>
of C:N ratio (Kale et al., 1982; Edwards, 1988; Talashilkar et al., 1999).

The amount of TP in the feed mixtures increased gradually with incubation period. The feed mixtures containing AR had more TP after 77 days sampling. Mansell et al. (1981) showed that plant litter contained more available P after ingestion by earthworms and they attributed this increase to physical breakdown of the plant material by worms. Satchell and Martin (1984) found that an increase of 25% in TP of paper waste sludge, after worm activity. They attributed this increase in TP to direct action of worm gut enzymes and indirectly by stimulation of the microflora.

TK and TCa concentrations were also higher in the final product than in the initial feed mixture. In contrast, a decrease in TK (Elvira et al., 1998) and no significant increase in TCa (Elvira et al., 1996) have been reported for the vermicomposting of paper-pulp mill sludge. They have attributed this decrease to leaching of the soluble elements by excess water that drained through mass. Benitez et al. (1999) have found that the leachates collected during vermicomposting process had higher K concentrations. This study support our results, as water was sprinkled in such quantities in this study that there was no excess water which avoided the leaching of minerals with run off water.

4. Conclusion

Our trials demonstrated vermicomposting as an alternate technology for the management of solid textile mill sludge mixed with cow dung and agricultural residues. Addition of agricultural residues in feed significantly reduced the worm biomass and reproduction. In the feeds consisting of 80%CD + 20%STMS and 70%CD + 30%STMS, the growth dynamics of *E. foetida* was similar to that observed in 100%CD, although after 77 days the mean biomass of worms in these feed mixtures was lower than 100%CD. This lower growth of worms was more pronounced when they were fed with feed nos. 6–9 (Table 1). Our results conform the general rule, also reported in literature, establishing a direct relationship between the biomass growth of *E. foetida* and the quality of feed material (Elvira et al., 1998; Butt, 1993). Moreover, the final product obtained in this study had lower C:N ratio, rich in TKN, TP, TK and TCa than initial feed mixtures. The pH of final product was lower that initial feeds, which may be attributed to evolution of CO2, accumulation of organic acids. These laboratory-scale experiments on value addition and management of STMS provide a valuable insight about the pattern of growth and development of earthworm and physico-chemical changes in the feeds brought about by earthworm activity. The compost obtained from the feed mixtures containing higher percentage of solid textile mill sludge needs further research before their use as manure for plants.

References


