

Dynamics of vermicomposting of solid textile mill sludge spiked with various organic wastes

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Abstract

In our laboratory the work is in progress to demonstrate the management of solid textile mill sludge (STMS) by vermicomposting. The laboratory based experiments have been conducted on vermicomposting of STMS spiked with cow dung (CD), biogas plant slurry (BPS), poultry droppings (PD) and agricultural residues.

The results showed that *Eisenia foetida* did not survive in fresh STMS. The maximum growth and reproduction was in 100% CD but worms grew and reproduced in those feed mixtures also which contained 20 -30 % STMS. Vermicomposting resulted in significant reduction in C: N ratio and increase in total nitrogen content. Total potassium content, calcium content and heavy metals' (Fe, Zn, Pb and Cd) content were lower in the final product than initial feed material. Microbial activity measured as dehydrogenase activity increased with time up to day 60 or 75 but decreased on day 90 indicating the exhaustion of feed and decrease in microbial activity. Replacement of CD by PD and BPS had no significant effect on vermicompost quality. These experiments demonstrate that vermicomposting can be an alternate technology for recycling and environmentally sustainable management of STMS using an epigeic earthworm *Eisenia foetida*.

Introduction

The problem of disposal of industrial solids has now obtained complex dimensions. India has a large network of textile industries of varying capacity. Textile industries have been placed in the category of most polluting industries by the Ministry of Environment and Forests, Government of India. Textile industries in India were initially centered around big cities like Ahmedabad, Mumbai, Chennai, Coimbatore, Bangalore and Kanpur. Now the industries are well developed and a large number of small textile processing units are scattered all over the country. There are approximately more than 2500 textile processing units in India out of which more than 700 units are integrated textile mills with gross annual production of 9000 million meters of different variety of cloth (Bal, 1999). Their effluents constitute a major part of the total industrial effluents in India. On an industrial scale the sludge resulting from the dyeing and printing operations of textile mills is managed through destructive methods: land filling practices and incineration. Due to the prohibitive cost of sludge disposal most of the textile mills in India dispose of the sludge in agricultural fields, open dumps, along the roadside or railway tracks and poorly designed sanitary land fills which can pollute surface or ground water causing public health hazards. Apart from this, such practices entail wastage of organic and inorganic nutrients present in the sludge that might be put to good use (Elvira et al., 1996). Meanwhile the unavailability of land, stringent national waste disposal standards and public consciousness has made dumps and landfills increasingly expensive and impractical (Ndegwa and Thompson, 2001). The situation of sludge

disposal and management in other developing countries is no different and may perhaps existing elsewhere too (Abbasi and Ramasamy, 2001). In such a scenario there is an obvious need to reuse and recycle the sludges.

The potential of the use of vermicompost in the agricultural fields depends upon its fertilizer properties which in turn depends on the raw material used for vermicomposting. *Eisenia foetida* is an epigeic earthworm species which lives in organic wastes. In order to utilize this species successfully in vermicomposting, its survival, growth and fecundity in different wastes should be known. In our laboratory the work is in progress to demonstrate the management of solid textile mill sludge (STMS) by vermicomposting. The laboratory based experiments have been conducted on vermicomposting of STMS spiked with cow dung (CD), biogas plant slurry (BPS), poultry droppings (PD) and agricultural residues.

Materials and Methods

Eisenia foetida

Healthy adult earthworms commonly known as red wigglers were randomly picked (Clitellated or un-clitellated) for use in the experiments from several stock cultures containing 500-2000 earthworms in each, maintained in the laboratory with CD as culturing material.

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: 197g/kg, pH (1: 10 ratio): 8.3, TOC: 142 g/kg, TKN: 0.74 g/kg and C: N ratio: 199. The sludge was dried in shade prior to use for vermicomposting.

Cow dung (CD)

Fresh CD was procured from the Devi Bhawan cowshed, Hisar, India. The main characteristics of CD were: total solids: 434 g/kg, pH (1: 10 ratio) 7.62, total organic carbon (TOC): 416 g/kg, total Kjeldhal nitrogen (TKN): 6.5 g/kg, total phosphorus (TP): 6.3 g/kg and C: N ratio: 64.0

Poultry droppings (PD)

Fresh poultry droppings were collected from a poultry Research and Breeding Farm located near Hisar, India. The main characteristics of the PD were: total solids = 464g/kg, pH (1: 10 ratio, w/v) = 8.2, total organic content (TOC) = 302g/kg, total Kjeldhal nitrogen (TKN): 6.9 g/kg, C: N ratio = 44.

Biogas plant slurry (BPS)

Anaerobically digested biogas plant slurry was procured from post-methanation storage tank of an on-farm biogas plant. The raw material used in the biogas plant was the cow dung collected from an intensively live stocked cow farm at village Agroha, Hisar, India. The main characteristics of BPS were: pH (1: 10 ratio) 8.30, total organic carbon (TOC): 416g/kg, total Kjeldhal nitrogen (TKN): 5.2g/kg, total available phosphorus (TAP): 5.3 g/kg and C: N ratio: 80.0.

Experimental design

Different wastes were mixed with STMS in different ratios (See tables 1 and 2) One kg (on dry weight basis) of each feed mixture was taken as feed in circular plastic

containers (volume 10L, diameter = 50cm and depth =15cm). The moisture content of these wastes was adjusted 70 - 80% during the study period by spraying adequate quantities of distilled water. These mixtures were turned over manually everyday for 15 days in order to eliminate volatile gases which may be potentially toxic to earthworms. After 15 days, 20 adult *Eisenia foetida* individuals of known biomass were introduced into each container. The substrate was covered with a moist jute cloth piece to avoid pests. All containers were kept in dark at 25± 1°C. The experiment was replicated thrice for each substrate.

Table 1: Percentage of different wastes in STMS+ PD feed mixture

Feed mixture No.	Cow dung (CD) (%)	Poultry droppings (PD) (%)	STMS (%)
1	0	70	30
2	0	60	40
3	0	50	50
4	0	40	60
5	0	30	70
6	70	30	0
7	30	70	0
8	25	25	50
9	100	0	0

Table 2 Initial content (percentage) of different wastes in STMS+ BPS feed mixture

Feed mixture No.	Biogas plant slurry (BPS) (%)	STMS** (%)	Cow dung (CD) (%)
10	0	0	100
11	100	0	0
12	90	10	0
13	80	20	0
14	70	30	0
15	60	40	0

Homogenized samples of the feed were drawn at 0, 30, 45, 60, 75 and 90 days from each container. The 0 day refers to the time when feed was filled in the container before pre-composting. The cocoons, earthworms and hatchlings were removed manually from each sample. The samples were air dried in shade at room temperature, ground in a stainless steel blender and stored in plastic vials for further chemical analysis. At the end of the experimental period (day 90) all earthworms including hatchlings were counted and weighed after washing with water and drying by paper towels.

Chemical analyses

All the chemicals used were analytically reagent (AR) grade. Alkali resistant borosilicate glass apparatus and double glass distilled water was used through out the study for analytical work. 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 samples were analyzed in triplicate and results were averaged.

The pH and EC were determined using a double distilled water suspension of each waste in the ratio of 1: 10 (w/v) that had been agitated mechanically for 30min 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) according to Bremner and Mulvaney (1982) procedure. Total available phosphorus (TAP) was analyzed using the colorimetric method with molybdenum in sulphuric acid. Total K (TK) was determined after digesting the sample in diacid mixture (concentrated HNO₃: concentrated HClO₄, 4: 1, v/v), by flame photometer. (Bansal and Kapoor, 2000). Heavy metals' content in the vermicomposts were determined by using diacid digest of the sample. Analysis was done using atomic absorption spectrophotometer (AAS). Standard solutions were prepared by using the nitrate salts of the estimated heavy metals.

Dehydrogenase enzyme activity was measured using the method of Casida et al. (1964). One gram of each container waste was mixed with 1.0 ml of 2,3,5-triphenyltetrazolium chloride (3%) in 2.5 ml double distilled water and incubated at 30°C for 24h. The accumulation of the end product triphenylformazan (TPF) was determined in a methanol extract (10 ml) using spectrophotometer at 485 nm.

Results and Discussion

Physico-chemical changes in feed mixtures

Eisenia foetida could not tolerate the fresh STMS. Addition of at least 30% CD or PD or BP (on dry weight basis) was essential for the survival of the earthworms in the STMS. The vermicompost was much darker in color than originally and had been processed into homogeneous manure after 90 days of earthworm's activity, whereas the material without earthworms remained in compact clumps. There was a shift in the pH values towards acidic from the initial alkaline pH in all the feed mixtures (Table 3, 7 and 9). Most of other reports on vermicomposting (Mitchell, 1997; Gunadi and Edwards, 2003) have reported similar results but with different degree of pH change. The pH shift towards acidic conditions could be attributed to mineralization of the nitrogen and phosphorus into nitrites/nitrates and orthophosphates and bioconversion of the organic material into intermediate species of organic acids (Ndegwa et al., 2000). They have also reported that different substrates could result in the production of different intermediate species and different wastes show a different behavior in pH shift. A large fraction of the TOC was lost as CO₂ (between 30 and 45%) by the end of the vermicomposting feeding. Data revealed that TOC loss was more in STMS containing feed mixtures than PD+CD and 100% CD feed mixtures. TKN had increased by the end of vermicomposting period between 40 to 100% in different feed mixtures, probably because of mineralization of the organic matter. Increase in TKN was less evident in the feed materials with 50%, 60% and 70% STMS. The final nitrogen content of the compost would be dependent on the initial nitrogen present in the feed material and the extent of decomposition (Crawford, 1983). According to Viel et al. (1987) losses in organic carbon might be responsible for nitrogen addition. 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). Addition of nitrogen in the form of mucus, nitrogenous excretory substances, growth stimulating hormones and enzymes from earthworms has also been reported (Tripathi and Bhardwaj, 2003). According to them, these nitrogen rich substances were not originally present in the feed material and hence might have contributed to the additional nitrogen content. Decrease in pH may be another important factor in nitrogen retention as this

element is lost as volatile ammonia at high pH values (Hartenstein and Hartenstein, 1981).

The C: N ratio, one of the most widely used indices for maturity of organic waste, decreased with time in all the experiments due to decomposition. Initial C: N ratio of different feed mixtures was very high [69 for CD and 131 for 30% CD+70% STMS feed mixture] (Table 4 and 8). According to Senesi (1989), a decline of C: N ratio to less than 20 indicates an advanced degree of organic matter stabilization and reflects a satisfactory degree of maturity of organic waste. In our experiments C: N ratios were between 15 and 25 for some of the fed mixtures after 90 days of worm activity. This overall decrease in C: N ratio was associated with an increase in TKN during the three months of study. Levi-Minzi et al. (1986) reported that the C:N ratio of farmyard manure decreased after storing for a period of three months. However, in our experiments, earthworms initially accelerated the decrease in C: N ratio significantly, demonstrating much more rapid decomposition and rates of mineralization of the organic matter, accompanied by increase in TKN during the first few weeks. Similar results have been reported by other workers (Bansal and Kapoor, 2000; Atiyeh et al., 2000).

Dehydrogenase activity in soils and other biological systems has been used as a measure of overall microbial activity (Garcia et al., 1997), since it is an intracellular enzyme related to oxidative phosphorylation processes. On day zero dehydrogenase activity was lower in those fed mixtures which had higher STMS content (Table 5). The dehydrogenase activity increased up to 60 or 75 days in all the experiments but had decreased by 90 days sampling. The initial increases in dehydrogenase activity indicate increased microbial activity. The dehydrogenase activity is dependent on the substrate availability (Moore and Russel, 1972), so the decrease of the dehydrogenase activity would mean that most of the easily available organic matter had been decomposed before 90 days sampling of the vermicompost process (Benitez et al., 1999). The smaller increase in dehydrogenase activity in the feed mixtures with 50%, 60% and 70% STMS content indicated that these feed mixtures were not favorable to microbial growth.

The amount of TP in the feed mixtures increased gradually with incubation period. The feed mixtures having more CD or PD or BPS content had more TP after 90 days sampling. The feed mixtures under earthworm treatment exhibited faster increase in TP content than did the feed mixtures without earthworms, which showed the efficiency of earthworms in mineralization of TP in the feed mixture. Such effects of earthworms in mineralizing wide ranges of organic materials with the help of various bacteria and enzymes in the intestine has been described in detail by Edward and Lofty (1972). 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 the worms. Satchell and Martin (1984) found an increase of 25% in total P 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 micro flora. On the other hand, TK and TCa concentrations in the final cast were slightly lower than in the initial feed mixtures. This might have been due to leaching of these cations by the excess water that drained through the feed mixtures. There are contradictory reports regarding the nutrient quality of vermicompost. Delgado et al. (1995) have reported a higher content of TK in the sewage sludge vermicompost, whereas Orozco et al. (1996) reported an increase in TCa and decrease in TK after ingestion of coffee pulp waste by earthworms. However, Elvira et al. (1998) have reported a decrease in TK and TCa in vermicompost after bioconversion of paper pulp- mill sludge by *Eisenia andrei*. The differences in the results could be attributed to the differences in the chemical nature of

the initial raw materials. In our experiments total heavy metal concentrations in the final products were slightly lower than in the initial feed mixtures (Table 6). On the other hand Elvira et al. (1998) have reported an increase in heavy metal concentrations in the final product. In our case, the decrease in heavy metal concentrations could be related to leaching of these cations by excess water drainage.

Growth and reproduction of *E. foetida*

Table 10 show the values obtained for different parameters of growth and reproduction in *Eisenia foetida* over the experimental period in different feed mixtures. Increasing proportion of STMS in the feed mixtures promoted a decrease in survival and growth of *Eisenia foetida*. Mortality was recorded in 100% STMS, 90% STMS +10% CD and 80% STMS+ 20% CD feed mixtures. Hundred percent CD had the highest number of total earthworms and clitellated earthworms but a lower number of cocoons than 60% CD+ 40% STMS, 50% CD+ 50% STMS and 40% CD+ 60% STMS after 90 days. This might have been due to the hatching out of the cocoons. It can be seen from the data that there was little increase in the total number of earthworms and clitellated earthworms in the feed mixtures having more than 50% STMS, but they had a greater number of cocoons than did 100% CD. This indicated that a greater percentage of STMS in the feed mixture significantly delays the sexual maturity and reproduction of *Eisenia foetida*. Chan and Griffiths (1988) reported that worms fed with untreated pig manure died within a few hours. Similarly Elvira et al. (1997) showed worms 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 which result in changes of the environmental characteristics.

Table 10: Total number of earthworms, clitellated earthworms and cocoons after 90 days in CD + STMS feed mixtures

CD+STMS feed (in g)	Total number of earthworms	Clitellated earthworms	Cocoons
1000+0	286± 23	77± 11	160± 34
00+100	232± 21	58± 9	136± 27
800+200	261± 28	44± 10	88± 24
700+300	240± 19	31± 8	102± 28
600+400	136±17	8± 3	187± 31
500+500	70± 13	6± 3	218± 36
400+600	36± 6	5± 3	173± 29

Conclusions

The information presented here provides a basis for the utilization of sludge from textile mills spiked with cow dung, biogas plant slurry or poultry droppings in small as well as large-scale vermicomposting. The growth and reproduction of the *Eisenia foetida* was best when allowed to feed on 100% BPS or 100%CD. The growth rate and cocoon production by the earthworms was having an inverse relationship with the percentage of STMS in the feed mixture. In the feeds containing up to 30%STMS, the growth dynamics of *E. foetida* was similar to that observed in 100%CD, although up to 10-12 weeks. The mean biomass of worms in these feed mixtures was lower than 100%CD.

The net weight gain by the earthworms was significantly lower in feed mixtures having more than 40%STMS (Table 10). These results confirm the general rule, also reported in literature, establishing a direct relationship between the worm biomass growth and the quality of the food (Elvira et al. 1998, Butt, 1993, Kaushik and Garg, 2003, 2004; Garg and Kaushik, 2005). The pH of final product was lower than initial feeds, which may be attributed to evolution of CO₂ and accumulation of organic acids. The vermicomposting process not only decreased the organic carbon content but also substantially increased the nitrogen content. The final product was more stabilized as demonstrated by a significant decrease in C: N ratio. The decrease in dehydrogenase activity at 90 days sampling indicates the exhaustion of easily metabolisable components of the feed. Finally, the use of *Eisenia foetida* can potentially help to convert this waste (STMS) into a value-added product if mixed up to 30% in CD or PD or BPS, so avoiding its disposal in open dumps, agricultural fields and along the roadsides.

References

- Abbasi, S.A., Ramasamy, E.V., 2001. Solid waste management with earthworms. Discovery Publishing House, New Delhi, India. pp. 78.
- Atiyeh, R.M., Arancon, N.Q., Edwards, C.A., Metzger, J.D., 2002. The influence of earthworm-processed pig manure on the growth and productivity of marigolds. **Biores. Tech.** 81 (2), 103-108.
- Atiyeh, R.M., Dominguez, J., Subler, S., Edwards, C.A., 2000. Changes in biochemical properties of cow manure during processing by earthworms (*Eisenia andrei* Bouche) and the effects on seedling growth. **Pedobiologia** 44, 709-724.
- Bal, A.S., 1999. Wastewater management for textile industry– An overview. **Indian J. Environ. Hlth.** 41, 264-290.
- Bansal, S., Kapoor, K.K., 2000. Vermicomposting of crop residues and cattle dung with *Eisenia foetida*. **Biores. Technol.** 73, 95-98.
- Benitez, E., Nogales, R., Elvira, C., Masciandaro, G., Ceccanti, B., 1999. Enzyme activities as indicators of the stabilization of sewage sludge composting with *Eisenia foetida*. **Biores. Technol.** 67, 297-303.
- Bremner, J.M., Mulvaney, R.G., 1982. Nitrogen total. In: Methods of soil analysis. Am. Soc. Agron. Madison, Wisconsin. A.L. Page, R.H. Miller and D.R. Keeney (eds.), pp. 575-624.
- Butt, K.R., 1993. Utilisation of solid paper-mill sludge and spend brewery yeast as feed for soil-dwelling earth worms. **Biores. Technol.** 44, 105-107.
- Casida Jr., L.E., Klevin, D.A., Santoro, T., 1964. Soil Dehydrogenase activity. **Soil Sci.** 93, 371–376.
- Chan, L.P.S., Griffiths, D.A., 1988. The vermicomposting of pre-treated pig manure. **Biol. Wastes** 24, 57-69.
- Crawford, J.H., 1983. Review of composting. **Process Biochem.** 18, 14-15.
- Delgado, M., Bigeriego, M., Walter, I., Calbo, R., 1995. Use of California red worm in sewage sludge transformation. **Turrialba** 45, 33-41.
- Edwards, C.A., Lofty, J.R., 1977. Biology of Earthworms. 2nd ed. Chapman and Hall, London, 9, 333.
- Elvira, C., Goicoechea, M., Sampedro, L., Mato, S., Nogales, R., 1996. Bioconversion of solid paper-pulp mill sludge by earthworms. **Biores. Technol.** 75, 173 –177.
- Elvira, C., Sampedro, L., Benitez, E., Nogales, R., 1998. Vermicomposting of sludges from paper mill and dairy industries with *Eisenia andrei*: a pilot scale study. **Biores. Technol.** 63, 205-211.

- Elvira, C., Sampedro, L., Dominguez, J., Mato, S., 1997. Vermicomposting of wastewater sludge from paper-pulp industry with nitrogen rich materials. **Soil Biol. Biochem.** 29, 759-762
- Garcia, C., Hernandez, T., Costa, F., 1997. Potential use of Dehydrogenase activity as an index of microbial activity in degraded soils. **Commun. Soil Sci. Plant An.** 28, 123-134.
- Garg, V.K., Kaushik, P., 2005. Vermistabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*. **Biores. Technol.** 96, 1189-1193.
- Gunadi, B., Edwards, C.A., 2003. The effect of multiple application of different organic wastes on the growth, fecundity and survival of *Eisenia fetida*. **Pedobiologia.** 47 (4), 321-330.
- Hartenstein, R., Hartenstein, F., 1981. Physicochemical changes effected in activated sludge by the earthworm *Eisenia foetida*. **J. Environmental Qual.** 10, 372-376.
- Kaushik, P., Garg, V.K. 2003. Vermicomposting of mixed solid textile mill sludge and cow dung with epigeic earthworm *Eisenia foetida*. **Biores. Technology,** 90, 311-316.
- Kaushik, P., Garg, V.K., 2004b. Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with w dung and agricultural residues. **Biores. Technol.** 94, 203 – 209.
- Levi-Minzi, R., Riffaldi, R. Saviozzi, A., 1986. Organic matter and nutrients in fresh and mature farmyard manure. **Agricul. Wastes** 16, 225-236.
- Mansell, G.P., Syers, J.K., Gregg, P.E.H., 1981. Plant availability of phosphorus in dead herbage ingested by surface-casting earthworms. **Soil Biol. Biochem.** 13, 163-167.
- Mitchell, A., 1997. Production of *Eisenia foetida* and vermicompost from feedlot cattle manure. **Soil Biol. Biochem.** 29, 763-766.
- Moore, A.W., Russel, J.S., 1972. Factors affecting dehydrogenase activity as an index of soil fertility. **Plant Soil** 37, 675- 682.
- Ndegwa, P.M., Thompson, S.A., 2001. Integrating composting and vermicomposting the treatment and bioconversion of biosolids. **Biores. Technol.** 76, 107-112.
- Ndegwa, P.M., Thompson, S.A., Das, K.C., 2000. Effects of stocking density and feeding rate on vermicomposting of biosolids. **Biores. Technol.** 71, 5-12.
- Nelson, D.W., Sommers, L.E., 1982. Total carbon and organic carbon and organic matter. In: Page, A.L., Miller, R.H., Keeney, D.R. (eds.), *Method of Soil Analysis*. American Society of agronomy, Madison, pp. 539-579.
- Orozco, F.H., Cegarra, J., Trujillo, L.M., Roig, A., 1996. Vermicomposting of coffee pulp using the earthworm *Eisenia foetida*: effects on C and N contents and the availability of nutrients. **Biol. Fertil. Soil** 22, 162-166.
- Satchell, J.E., Martin, K., 1984. Phosphate activity in earthworm faeces. **Soil Biol. Biochem.** 16, 191-194.
- Senesi, N., 1989. Composted materials as organic fertilizers. **Sci. Total Environment.** 81/82, 521-524.
- Tripathi, G., Bhardwaj, P., 2004. Comparative studies on biomass production, life cycles and composting efficiency of *Eisenia foetida* (Savigny) and *Lampito mauritii* (Kinberg). **Biores Technol.**, 92, 275-278
- Viel, M., Sayag, D., Andre, L., 1987. Optimization of agricultural, industrial waste management through in-vessel composting. In: de Bertoldi, M. (Ed.), *Compost: Production, Quality and Use*. Elsevier Appl. Sci. Essex, pp. 230-237.

Table 3: Nutrient content (g/kg) in the initial mixture (IM) and the final product (FP) after 90 days in CD+ STMS feed mixtures

CD+ STMS feed (in g)	TOC		TKN		TP		TK		TCa	
	IM	FP	IM	FP	IM	FP	IM	FP	IM	FP
1000+0	421± 26	337±21	6.1±0.8	12.4± 1.3	6.8± 1.6	10.1± 1.7	6.2± 1.5	4.8± 0.8	3.8± 0.6	3.6± 0.6
900+100	377± 33	241± 27	4.9± 0.5	11.7± 1.4	6.5± 0.9	8.3± 1.6	6.7± 1.3	4.6± 0.7	2.8±0.6	2.4± 0.5
800+200	354± 31	183± 25	4.4± 0.6	10.9± 1.6	4.9± 0.6	5.9± 1.1	5.8± 1.2	5.0± 0.8	2.4± 0.4	2.2± 0.5
700+300	319± 28	177± 18	4.2± 0.7	10.7± 1.4	4.4± 0.7	5.6± 1.5	5.5± 1.6	3.3± 0.7	2.3± 0.6	2.3± 0.6
600+400	300± 27	170± 21	3.9± 0.4	10.0± 1.4	4.4± 0.5	5.0± 1.4	4.9± 1.1	3.7± 0.7	2.4± 0.5	2.3± 0.4
500+500	297± 37	170± 24	3.5± 0.6	9.2±1.7	3.7± 0.5	4.1± 1.1	4.4±0.7	2.3± 0.6	2.3± 0.5	2.3± 0.4
400+600	296± 29	148± 18	2.8± 0.5	6.2± 1.3	3.6± 0.7	4.0± 0.9	3.3± 0.8	1.9± 0.4	2.0± 0.4	2.3± 0.5
300+700	290± 37	128± 28	2.2± 0.4	5.6± 1.6	3.3±0.6	3.8± 0.8	2.8± 0.6	1.7± 0.4	2.2± 0.5	2.2±0.4

Table 4: Changes in C:N ratio during vermicomposting in CD+ STMS feed mixtures

CD+STMS feed (in g)	Days					
	0	30	45	60	75	90
1000 + 0	69.0± 12.1	55.9± 16.4	44.0± 9.3	37.6± 5.8	35.3± 4.8	26.4± 3.2
900 + 100	76.9± 15.7	43.2± 7.8	35.3± 5.6	28.3± 7.6	23.3± 5.2	20.5± 3.1
800 + 200	76.9± 18.5	53.0± 6.3	36.0± 6.4	25.0± 5.5	20.3± 4.7	17.0± 2.6
700 + 300	75.9± 12.6	50.7± 6.2	28.2± 3.5	25.5± 5.3	20.3± 4.1	16.5± 3.1
600 + 400	80.4± 11.4	53.8± 7.5	33.1± 3.7	23.1± 4.6	21.8± 3.8	16.7± 3.7
500 + 500	84.8± 14.3	57.8± 8.6	44.2± 6.5	28.3± 4.3	25.7± 3.1	18.4± 2.3
400 + 600	105.0± 21.4	79.3± 14.2	54.1± 5.8	37.5± 5.1	29.4± 2.7	23.8± 2.5
300 + 700	131.0± 16.8	83.1± 11.4	54.6± 9.3	34.6± 6.2	29.2± 4.5	22.8± 3.4

Table 5: Dehydrogenase activity (\square g TPFg⁻¹h⁻¹) during vermicomposting in CD+ STMS feed mixtures

CD + STMS feed (in g)	Days				
	0	30	60	75	90
1000 + 0	492± 67	814± 78	1419± 167	1847± 295	1560± 186
900 + 100	372± 54	653± 65	1086± 212	1640± 173	1470± 252
800 + 200	298± 48	539± 68	899± 174	901± 105	773± 117
700 + 300	286± 63	396± 73	541± 161	686± 143	661± 125
600 + 400	279± 48	302± 53	370± 73	566± 94	550± 103
500 + 500	269± 56	344± 66	377± 69	396± 57	358± 62
400 + 300	226± 49	254± 41	305± 104	377± 88	359± 43
300 + 700	199± 41	246± 32	294± 86	338± 76	314± 49

Table 6: Heavy metal content (mg/kg) in the initial mixture (IM) and the final product (FP) after 90 days in CD+ STMS feed mixtures

CD+STMS feed (in g)	Total-Cu		Total-Cr		Total-Fe		Total-Zn	
	IM	FP	IM	FP	IM	FP	IM	FP
1000+0	19± 2.3	24± 2.7	4± 0.3	4± 0.4	58± 11.4	54± 12.2	196± 43.5	150± 25.3
900+100	19± 2.5	19± 2.3	17± 1.2	13± 1.4	60± 14.3	58± 13.1	186± 38.2	115± 21.5
800+200	18± 2.1	19± 2.4	16± 1.3	12± 1.1	62± 15.4	55± 16.5	191± 24.7	169± 15.4
700+300	22± 2.4	25± 2.6	17± 1.4	13± 1.3	65± 16.3	57± 13.6	183± 23.1	158± 17.6
600+400	23± 2.3	25± 2.1	16± 1.3	12± 1.5	65± 14.7	62± 11.7	186± 24.7	118± 12.5
500+500	19± 2.5	19± 2.6	16± 1.4	12± 1.6	64± 17.2	62± 9.8	190± 26.5	164± 12.6
400+600	26± 2.1	27± 2.5	16± 1.4	12± 1.8	66± 14.8	61± 6.3	201± 31.5	169± 18.7
300+700	30± 2.4	31± 2.3	15± 1.3	12± 1.9	65± 15.8	63± 11.5	190± 34.2	119± 21.3

Table 7: Nutrient content (g/kg) [mean \pm SE] in the initial feed mixture (IM) and the final product (FP) of different STMS+ PD feed mixtures

Feed No.	pH		TOC*		TKN*		TP*		TK*		TCa*	
	IM	FP	IM	FP	IM	FP	IM	FP	IM	FP	IM	FP
1	8.4 \pm 0.2	6.7 \pm 0.1	310 \pm 3	184 \pm 6	4.1 \pm 0.4	12.3 \pm 0.3	5.7 \pm 0.2	10.7 \pm 0.4	5.0 \pm 0.2	4.7 \pm 0.6	1.2 \pm 0.1	1.9 \pm 0.4
2	8.2 \pm 0.2	6.4 \pm 0.1	300 \pm 4	174 \pm 7	3.6 \pm 0.4	11.0 \pm 0.4	5.9 \pm 0.4	9.1 \pm 0.6	4.8 \pm 0.2	3.3 \pm 0.6	1.8 \pm 0.2	2.2 \pm 0.3
3	8.1 \pm 0.1	6.7 \pm 0.1	281 \pm 2	170 \pm 11	2.8 \pm 0.3	10.6 \pm 0.5	4.1 \pm 0.5	8.4 \pm 0.4	5.9 \pm 0.2	4.0 \pm 0.6	2.2 \pm 0.1	2.2 \pm 0.3
4	8.0 \pm 0.2	6.5 \pm 0.1	299 \pm 8	167 \pm 12	2.8 \pm 0.3	9.9 \pm 0.2	3.8 \pm 0.2	8.3 \pm 0.3	4.2 \pm 0.1	3.0 \pm 0.7	1.5 \pm 0.1	2.5 \pm 0.4
5	8.0 \pm 0.1	6.6 \pm 0.2	280 \pm 6	172 \pm 15	2.6 \pm 0.4	9.2 \pm 0.2	4.0 \pm 0.3	9.2 \pm 0.3	4.2 \pm 0.2	4.1 \pm 0.3	2.5 \pm 0.1	3.2 \pm 0.3
6	8.2 \pm 0.1	6.7 \pm 0.1	280 \pm 7	233 \pm 9	3.6 \pm 0.3	12.1 \pm 0.3	6.9 \pm 0.3	12.9 \pm 0.3	3.7 \pm 0.5	2.9 \pm 0.1	4.1 \pm 0.2	5.3 \pm 0.5
7	8.3 \pm 0.1	6.7 \pm 0.1	373 \pm 2	241 \pm 16	7.0 \pm 0.2	15.4 \pm 0.4	8.3 \pm 0.2	16.2 \pm 0.3	4.7 \pm 0.3	2.9 \pm 0.1	4.7 \pm 0.3	5.6 \pm 0.5
8	8.1 \pm 0.1	6.7 \pm 0.2	254 \pm 3	173 \pm 18	4.2 \pm 0.3	9.0 \pm 0.2	4.3 \pm 0.2	9.5 \pm 0.4	4.3 \pm 0.2	2.0 \pm 0.1	3.7 \pm 0.3	4.3 \pm 0.3
9	8.2 \pm 0.1	6.6 \pm 0.2	416 \pm 9	309 \pm 7	6.5 \pm 0.4	12.4 \pm 0.3	6.8 \pm 0.3	10.1 \pm 0.6	6.2 \pm 0.3	4.8 \pm 0.3	3.8 \pm 0.5	3.6 \pm 0.4

Table 8: Changes in C: N ratio of STMS+ PD feed mixtures with time during vermicomposting

Feed mixture No.	Time (days)					
	0	30	45	60	75	90
1	76.3 \pm 5.63	61.3 \pm 4.89	51.8 \pm 5.36	30.6 \pm 3.19	22.2 \pm 2.43	14.9 \pm 1.31
2	82.6 \pm 1.80	66.5 \pm 2.14	51.1 \pm 2.60	33.8 \pm 0.93	23.3 \pm 0.74	15.8 \pm 0.26
3	100.8 \pm 6.83	80.2 \pm 3.82	59.7 \pm 4.19	32.2 \pm 3.17	20.0 \pm 1.36	17.0 \pm 0.45
4	106 \pm 0.87	93.5 \pm 6.84	45.1 \pm 3.17	27.3 \pm 2.86	20.8 \pm 1.98	16.9 \pm 2.12
5	106 \pm 9.03	81.3 \pm 7.38	46.0 \pm 4.42	37.3 \pm 2.16	26.6 \pm 0.76	18.7 \pm 0.35
6	78.8 \pm 2.45	36.9 \pm 4.71	33.8 \pm 4.28	21.6 \pm 3.12	15.6 \pm 0.49	14.8 \pm 0.43
7	53.3 \pm 3.25	31.3 \pm 3.62	25.8 \pm 3.15	20.8 \pm 2.84	16.4 \pm 1.73	12.5 \pm 0.89
8	60.0 \pm 1.11	53.3 \pm 5.41	43.8 \pm 4.65	38.5 \pm 1.95	25.4 \pm 0.96	19.2 \pm 0.38
9	64.0 \pm 2.80	55.9 \pm 4.52	44.0 \pm 3.77	37.6 \pm 3.28	35.3 \pm 2.21	26.4 \pm 1.35

Table 9: Nutrient content (g/kg) in the initial feed mixture (IM) and the final product (FP) of STMS+BPS feed mixtures

Feed No.	pH		TOC		TKN		TAP		TK	
	IM	FP	IM	FP	IM	FP	IM	FP	IM	FP
10	7.9± 0.2	6.7± 0.1	497± 34	355± 12	7.1± 0.5	13.6± 1.2	5.3± 0.7	5.6± 0.5	10.7± 1.3	18.5± 2.6
11	8.3± 0.2	7.1± 0.1	416± 32	301±15	5.2± 0.5	8.3± 1.0	5.3± 0.5	6.8± 0.7	11.2± 1.6	13.7± 15
12	8.0± 0.1	6.6± 0.1	402± 23	298±23	5.0± 0.6	8.1± 0.8	5.2± 0.7	6.8± 0.8	7.3± 0.9	9.2± 1.2
13	7.9± 0.1	6.8± 0.1	369± 21	276± 26	4.1± 0.3	6.9± 0.5	5.0± 0.7	6.4± 0.7	7.3± 0.0	10.0± 1.5
14	7.4± 0.1	6.5± 0.1	346± 23	256± 36	2.7± 0.5	6.3± 0.6	4.1± 0.4	4.5± 0.5	6.1± 0.7	8.1± 0.9
15	7.2± 0.2	6.3± 0.1	323± 14	207± 21	2.5± 0.6	5.4± 0.7	3.9± 0.6	4.2± 0.4	4.9± 0.7	6.4± 0.8