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Vermiconversion of industrial sludge for recycling the nutrients

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ABSTRACT

The aim of the present study was to investigate the transformation of sugar mill sludge (PM) amended with biogas plant slurry (BPS) into vermicompost employing an epigeic earthworm *Eisenia fetida*. To achieve the objectives experiments were conducted for 13 weeks under controlled environmental conditions. In all the waste mixtures, a decrease in pH, TOC, TK and C:N ratio, but increase in TKN and TP was recorded. Maximum worm biomass and growth rate was attained in 20% PM containing waste mixture. It was inferred from the study that addition of 30–50% of PM with BPS had no adverse effect on the fertilizer value of the vermicompost as well as growth of *E. fetida*. The results indicated that vermicomposting can be an alternate technology for the management and nutrient recovery from press mud if mixed with bulking agent in appropriate quantities.

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1. Introduction

The sugar industry occupies a vital place in Indian economy and contributes substantially to its exports earnings. Amongst the 83-cane sugar producing countries in the world, India is the second largest producer of sugarcane and sugar (Rao, 2005). The industry achieved a spectacular growth as it has 1062 sugar mills of large to medium capacities (Sangwan et al., 2008) as compared to 138 during 1950–1951. According to Department of Agriculture and Co-operation, sugarcane production in 2004–2005 was estimated at 232.3 MT. But it has been identified as one among the most polluting industries. Sugarcane mills mainly use activated sludge process for wastewater treatment, which generates huge quantity of sludge commonly known as press mud (PM). Murty et al. (2006) have reported pollution status for some factories in India. For about 134 million tonnes of sugarcane crushed, 4.0 million tonnes of press mud are generated (Yadav, 1995). According to Parthasarthi (2006) approximately 12 million tonnes press mud is produced in India annually. Due to the prohibitive cost of sludge disposal, it is either dumped in open or along roadsides or railway tracks or stored in the sugar mill premises where it causes adverse impacts on the ambient environment. 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., 1985).

Press mud has significant fertilizer value as it is a rich source of organic matter, organic carbon, sugar, protein, enzymes, micronutrients (N, P and K) and macronutrients (Zn, Fe, Cu, Mn, etc.) and microbes (Sangwan et al., 2008; Yaduvanshi and Yadav, 1990; Ranganathan and Parthasarathi, 1999). Farmers are reluctant to apply it directly due to its bad odor, transportation cost and fear that its application may lead to crust formation, pH variation and pollution problem. Wax content of press mud (8.15%) affects the soil property by direct application (Thopate et al., 1997) and its high rate of direct application (upto 100 tonnes/acre) leads to soil sickness and water pollution (Bhawalkar and Bhawalkar, 1993). Conventional composting of press mud takes about 6 months and also does not remove the foul odor completely (Sen and Chandra, 2006). The compost so obtained has less nutritive value and more compactness. Therefore, appropriate press mud management technology is desired which not only protect and conserve the environment and land resources but also to recover the nutrients present in it.

Earthworms have been used in the vermiconversion of urban, industrial and agro-industrial wastes to produce biofertilizers (Elvira et al., 1998; Gupta and Garg, 2008; Suthar, 2006). It is well established that a large number of organic wastes can be ingested by earthworms and egested as peat like material termed as vermicompost. It is much more fragmented, porous and microbially active than parent material (Edwards et al., 1998; Edwards and Bohlen, 1996) due to humification and increased decomposition. Kaushik and Garg (2003, 2004) have reported the vermicomposting of textile mill sludge using *Eisenia fetida*. Butt (1993) showed that solid paper mill sludge was a suitable feed for *Lumbricus terrestis* under laboratory conditions. Elvira et al. (1998) have reported vermicomposting of paper mill sludge using *Eisenia andrei* under laboratory as well as field conditions. Nogales et al. (2005) have reported the vermicomposting of winery waste using

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E. andrei under laboratory conditions. Gajalakshmi et al. (2002) studied the vermicomposting of paper waste using anecic earthworm *Lampito mauriti*. Suthar (2006) has reported the vermicomposting of guar gum industrial waste using *Perionyx excavatus*. Sugarcane processing mill wastewater treatment plant sludge contains a significant percentage of organic matter and is a rich source of nitrogen. In our laboratory, the work is in progress to explore the potential of earthworms in management of industrial sludges (Kaushik and Garg, 2003, 2004; Garg and Kaushik, 2005). The present contribution reports the results of laboratory-based experiments performed to investigate the ability of earthworms for the management of press mud. It was hypothesized that the viability of different vermicomposters would be affected by different percentages of press mud and BPS.

2. Methods

2.1. Eisenia fetida, cow dung (CD), biogas plant slurry (BPS) and press mud (PM)

Healthy clitellated specimen of *E. fetida* weighing 350–400 mg live biomass were randomly picked up for the experiment from stock culture maintained in the laboratory taking cow dung as culturing medium by authors.

Fresh CD was collected from an intensively live stocked farm situated at Hisar, India. Anaerobically digested BPS was collected from post-methanation storage tank of an on-farm biogas plant situated at *Agroha*, Hisar, India. Sugar mill sludge (PM) was procured from effluent treatment plant of a sugar mill (The Jind Cooperative Sugar Mill Ltd.) located at Jind, India. The main characteristics of CD, BPS and PM are given in Table 1.

2.2. Experimental set-up

Seven waste mixtures having different ratios of BPS and PM were prepared including one with cow dung and biogas plant slurry each. One hundred and fifty grams of each waste mixture were filled in 1-l circular plastic containers (diameter 16 cm, depth 10 cm), called vermicomposter, on dry weight basis. The composition of different waste mixtures is given in Table 2.

Table 1
Initial physico-chemical characteristics of different feed materials

Parameter	Cow dung	Biogas plant slurry	Press mud
pH	8.20 ± 0.3	8.10 ± 0.2	7.10 ± 0.2
TOC (g/kg)	499 ± 22	464 ± 21	440 ± 19
TKN (g/kg)	12.8 ± 0.5	15.8 ± 0.9	24 ± 0.7
TP (g/kg)	4.6 ± 0.3	5.50 ± 0.4	5.1 ± 0.6
TK (g/kg)	20.9 ± 1.6	17.4 ± 0.8	8.3 ± 0.9
C:N ratio	39.0 ± 4.5	29.4 ± 3.8	18.3 ± 0.7

Table 2
Initial content (percentage) of different wastes in different vermicomposters

Vermicomposter number	Biogas plant slurry (BPS) (g)	Press mud (PM) (g)	Cow dung (g)
1	0	0	150 (100)[a]
2	150 (100)[a]	0	0
3	135 (90)[a]	15 (10)[a]	0
4	120 (80)[a]	30 (20)[a]	0
5	105 (70)[a]	45 (30)[a]	0
6	90 (60)[a]	60 (40)[a]	0
7	75 (50)[a]	75 (50)[a]	0

[a] The figures in parentheses indicate the percentage content in initial feed mixtures.

All waste mixtures were turned over manually for 15 days in order to pre-compost it so it becomes palatable to earthworms. After 15 days of pre-composting, 5 adult clitellated earthworms of *E. fetida* species were inoculated in each vermicomposter. All the vermicomposter were operated in dark at a laboratory temperature of (25 ± 3 °C). The moisture content was maintained at 70 ± 10% by periodic sprinkling of distilled water. During the experimental period no extra waste mixture was added at any stage in any vermicomposter. The worms were separated from vermicomposter by hand sorting, counted, washed, dried by paper towels and weighed weekly and transferred back to the respective vermicomposters. No corrections for gut content were applied to any of the data. All the vermicomposters were maintained in triplicate with earthworm density of five in each container. Same set up for each vermicomposter was established without worms, which acted as a control.

At the end of experiment worms, cocoons and hatchlings were removed and so produced vermicompost was air dried at room temperature and packed in airtight plastic bottles for further physico-chemical and nutrient content analysis.

2.3. Physico-chemical analysis

All the vermicomposters were operated for 13 weeks and homogenized samples of all feed substrates were drawn at 0, 15, 30, 45, 60, 75 and 91 days. Here 0 day refer to the day of inoculation of earthworms after pre-composting. The physico-chemical analysis was done on dry weight basis. All the chemicals used were analytical reagent (AR) grade. Double distilled water was used for analytical work. All the samples were analyzed in triplicate and results were averaged.

The pH was determined using double distilled water suspension of each mixture in ratio of 1:10 (w/v). Total organic carbon (TOC) was measured using the method of Nelson and Sommers (1982), Total Kjeldhal nitrogen (TKN) was determined by digesting the samples with conc. H_2SO_4 and $HClO_4$ (9:1, v/v) by Bremner and Mulvaney (1982) procedure. Total phosphate was analyzed by using the spectrophotometric method with molybdenum in sulphuric acid. Total potassium (TK) was determined by flame photometer (Elico, CL 22 D, Hyderabad, India) after digesting the sample in diacid mixture (conc. HNO_3, conc. $HClO_4$; 4:1, v/v) (Kaushik and Garg, 2004; Bansal and Kapoor, 2000).

One-way ANOVA was used to analyze the significant differences among different vermicomposters for studied parameters. Tukey's test was performed to identify the homogeneous type of vermicomposters for the various parameters. The probability levels used for statistical significance of tests were $p < 0.05$.

3. Results and discussion

3.1. Nutrient quality of the waste mixtures in different vermicomposters

Table 3 shows the nutritional quality of different waste mixtures and their final products. A decrease in pH was observed in all the waste mixtures during vermicomposting (Table 3). Most of other reports on vermicomposting (Sangwan et al., 2008; Gunadi and Edwards, 2003; Garg and Kaushik, 2005) have also reported similar results. The decrease in pH may be due to mineralization of nitrogen and phosphorus into nitrites/nitrates and orthophosphates and bioconversion of the organic material into intermediate species of organic acids (Ndegwa and Thompson, 2000). Different waste mixtures could result in the production of different intermediate species and hence different waste mixtures show a different behavior in pH shift. Decrease in pH in vermicomposter no. 2, 4, 5,

Table 3
Physico-chemical characteristics of initial waste mixtures and vermicompost obtained from different vermicomposters (g/kg)

Vermicomposters number	pH	TP	TOC	TKN	TK	Ash content
Initial physico-chemical characteristic of waste mixtures in different vermicomposters after pre-composting of 15 days						
1	8.0 ± 0.2	4.9 ± 0.2	499 ± 21.6	14.9 ± 1.4	20.7 ± 1.1	140 ± 8.0
2	7.8 ± 0.3	3.8 ± 0.1	464 ± 20.6	16.3 ± 1.2	20.9 ± 1.4	200 ± 12
3	7.7 ± 0.1	4.7 ± 0.4	475 ± 14.6	16.5 ± 1.1	17.6 ± 1.2	180 ± 10
4	7.6 ± 0.2	4.9 ± 0.2	464 ± 17.5	17.5 ± 1.5	17.4 ± 1.2	200 ± 14
5	7.6 ± 0.2	4.3 ± 0.3	452.3 ± 19.6	17.8 ± 1.4	15.3 ± 0.9	220 ± 16
6	7.4 ± 0.1	5.4 ± 0.5	452.4 ± 15	18.1 ± 1.7	13.8 ± 0.7	220 ± 13
7	7.4 ± 0.3	3.5 ± 0.3	440 ± 11.1	18.5 ± 1.9	13.2 ± 1.3	240 ± 17
Nutrient content in the vermicompost obtained from different vermicomposters[A] *(mean ± SE, n = 3)*						
1	7.4 ± 0.1a	8.5 ± 0.2a	429 ± 21.6a	21.8 ± 4.3a	18.1 ± 0.3a	260 ± 20a
2	6.8 ± 0.1bc	5.9 ± 0.2b	423 ± 17.6a	24 ± 2.6a	18.5 ± 0.5a	270 ± 26.4a
3	7.1 ± 0.2ab	9.5 ± 0.15d	417 ± 19.6a	21 ± 3.6a	15.4 ± 0.4b	280 ± 20a
4	6.7 ± 0.15c	6.9 ± 0.2c	429.3 ± 25.4a	20.8 ± 2.4a	15.6 ± 0.8b	260 ± 10a
5	6.6 ± 0.2c	6.7 ± 0.4bc	440 ± 21.9a	23.3 ± 1.5a	14.5 ± 0.4b	240 ± 10a
6	6.7 ± 0.1c	6.5 ± 0.3bc	417.6 ± 18.6a	26.5 ± 1.5a	12.3 ± 0.6c	280 ± 30a
7	6.8 ± 0.06ac	6.7 ± 0.5bc	417.6 ± 20a	23 ± 2.6a	12.2 ± 0.7c	280 ± 20a

[A] Mean values followed by different letters in same column are statistically different (ANOVA; Tukey's test, $p < 0.05$).

6 and 7th was insignificant with each other and significant with 1 and 3. Total phosphate (TP) was higher in vermicompost than the waste mixtures. It was highest in vermicomposter no. 3 followed by 1 and lowest in no. 2 (Table 3). Vermicomposting can be an efficient technology for the transformation of unavailable forms of phosphorus to easily available forms for plants (Ghosh et al., 1999). TOC was lesser in all vermicomposters by the end of the vermicomposting. TOC loss was 5–14% in different vermicomposters (Table 3). TOC losses were insignificant ($p < 0.05$) with each other in all the vermicomposters. TOC loss was higher in earthworm containing vermicomposters than controls without worms (Fig. 1). Tripathi and Bhardwaj (2004) too have reported a lesser decrease of TOC in controls than earthworm inoculated vermicomposters. There was an increase in Total Kjeldhal nitrogen (TKN) in all vermicomposters. Final TKN content of the vermicomposts was in the range of 26.5 ± 1.5 to 20.8 ± 2.4 g/kg in different vermicomposters. The increase was in the range of 1.4 ± 0.3-fold in different vermicomposters. The increase in TKN content was higher in earthworm-inoculated vermicomposters than controls without earthworms (Fig. 2). According to Viel et al. (1987) losses in organic carbon might be responsible for nitrogen addition. Addition of nitrogen in the form of mucous, nitrogenous excretory substances has been reported which were not initially present in feed substrates. A decrease in total potassium (TK) was reported in the vermicompost than the initial feed mixtures (Table 3). Our data is supported by Orozco et al. (1996) and Kaushik and Garg (2003) who reported a decrease in TK in coffee pulp and textile mill sludge, respectively, during vermicomposting. This decrease may be due to leaching of soluble potassium by excess water. The ash content in the final vermicompost was higher than the initial feed substrates (Table 3). This may be due to mineralization during vermicomposting (Gupta et al., 2007; Gupta and Garg, 2008).

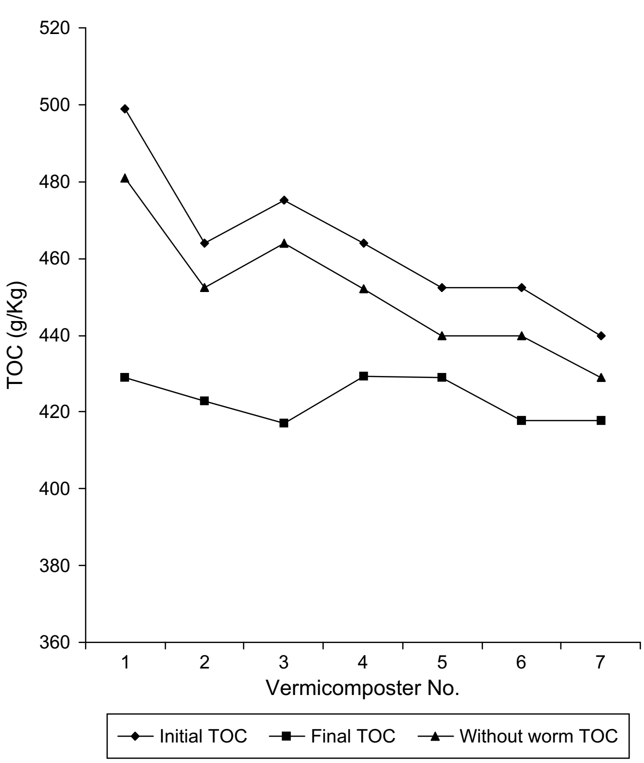

Fig. 1. Changes in TOC during vermicomposting.

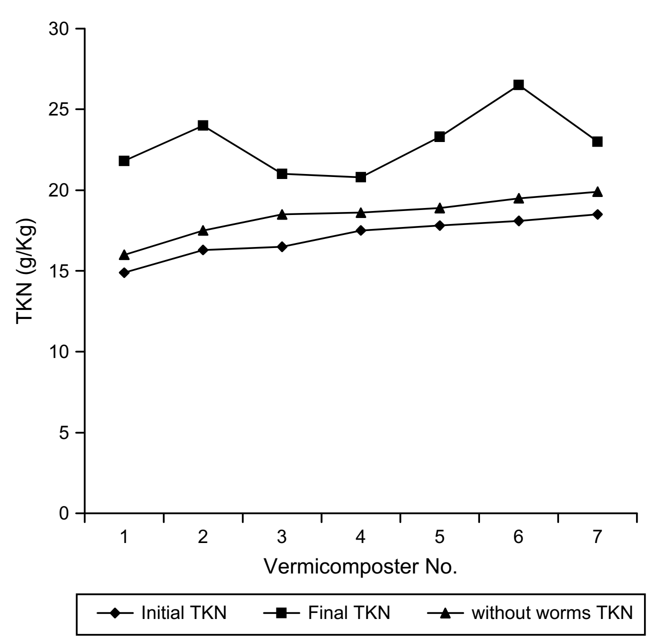

Fig. 2. Changes in TKN during vermicomposting.

Table 4
Changes in C:N ratio of different vermicomposters during vermicomposting

Vermicomposters number	Time (days)				
	0	30	75	91	Without worms
1	33.5 ± 6.9a	29.7 ± 6.8a	26.3 ± 8.5a	19.6 ± 4.0a	30.2 ± 7.3a
2	28.5 ± 6.1a	22.6 ± 5.0a	21.4 ± 6.3a	17.6 ± 3.5a	25.9 ± 4.6a
3	28.8 ± 5.9a	26.5 ± 6.2a	26.2 ± 7.6a	19.8 ± 3.2a	25.1 ± 4.2a
4	26.5 ± 7.9a	25.7 ± 5.7a	22.8 ± 5.5a	20.1 ± 3.8a	24.3 ± 4.2a
5	25.4 ± 5.3a	24.1 ± 4.8a	22.1 ± 6.1a	18.4 ± 3.9a	23.3 ± 5.0a
6	25.0 ± 6.1a	20 ± 6.0a	17.1 ± 4.5a	18.9 ± 2.8a	22.6 ± 2.5a
7	23.8 ± 5.5a	20.8 ± 6.8a	19.9 ± 4.4a	15.8 ± 2.8a	21.5 ± 4.5a

Mean values followed by different letters are significantly different (ANOVA; Tukey's test, $p < 0.05$).

The variation in C:N ratio in different vermicomposters with time has been encapsulated in Table 4. The C:N ratio, which is the indicator of maturity of organic matter, decreased with time in all the feed mixtures. Initial C:N ratios of different waste mixtures were in the range of 23.8 ± 5.5 to 33.5 ± 6.9 and final C:N ratios were in the range of 15.8 ± 2.8 to 20.1 ± 3.8. The C:N ratios of worm-inoculated vermicomposters were lesser than controls without worms. The differences in C:N ratios of the final product obtained from different vermicomposters were insignificant ($p < 0.05$). The loss of carbon as carbon dioxide in the process of respiration and production of mucus and nitrogenous excreta enhance the level of nitrogen, which lower the C:N ratio (Senapati et al., 1980).

3.2. Growth and fecundity of E. fetida in different vermicomposters

All the vermicomposters were operated for 13 weeks and there was no mortality in any vermicomposter during this period. But earthworms' showed different behavior in terms of growth and reproduction in different vermicomposters. Fig. 3 shows the weekly growth curves of *E. fetida* in different vermicomposters. Maximum earthworm biomass was observed in the vermicomposter no. 4 (1264 ± 33.4 mg/earthworm) which was significantly higher ($p < 0.05$) from all other vermicomposters. The minimum biomass was observed in vermicomposter no. 2 (918 ± 22 mg/earthworm). The biomass variation in vermicomposters no. 2 and 1 was insignificant (Table 5). Maximum biomass was attained in 7th week in all vermicomposters except vermicomposter no. 1. After this period a consistent decrease in biomass was observed in all vermicomposters which might be due to exhaustion of food (Fig. 3). The maximum net biomass gain was observed in vermicomposter no. 4 (886 ± 42 mg/earthworm) and minimum was observed in vermicomposter no. 1 (522 ± 29.3 mg/worm). The worm biomass gain in vermicomposter no. 4 was 1.4 ± 0.3-fold greater than other vermicomposters (Table 5).

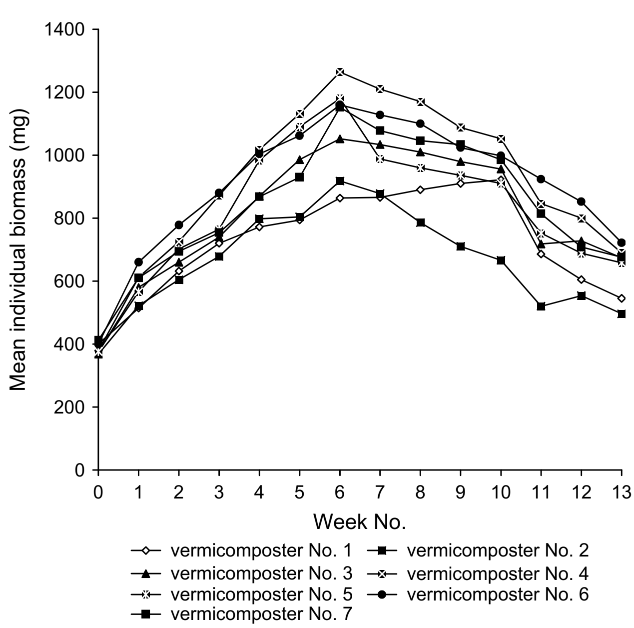

Fig. 3. Growth curves of *Eisenia fetida* in different vermicomposters.

The growth rate (mg biomass gained/worm/day) has been considered a good comparative index to compare the growth of earthworms in different feeds (Edwards et al., 1998). The highest growth rate (18.1 ± 0.85 mg/worm/day) was observed in vermicomposter no. 4. The lowest growth rate was obtained in vermicomposter no. 1 (6.8 ± 0.38 mg/worm/day) (Table 5). Average biomass production per unit of feed mixture was also highest in vermicomposter no. 4 and minimum in vermicomposter no. 1.

Table 6 describes the reproductive potential of *E. fetida* in different vermicomposters. All the worms were clitellated and sexually mature in all vermicomposters. Cocoon production was started in 3rd week in vermicomposters no. 1–3 but in 4th week in vermicomposters no. 4–7. After 13 weeks maximum number of cocoons was observed in vermicomposter no. 6 (228 ± 15.7), followed by 7, 5 and 4, 3, 2 and 1 (Table 5). The variation in the number of cocoons in vermicomposter no. 4–7 was insignificant ($p < 0.05$). The cocoon production in vermicomposter no. 6 was 3.6, 2.9, 1.3, 1.3, 1.1 and 1.1 times greater than the vermicomposter no. 1–5 and 7, respectively.

The mean number of cocoons produced per worm per day was highest in vermicomposter no. 6 and minimum was in vermicomposter no. 1. The maximum number of hatchlings was observed in vermicomposter no. 5 followed by vermicomposter no. 4, 3, 6, 7, 2 and 1 (Table 6). The maximum numbers of clitellated hatchlings were reported in vermicomposter no. 7. Maximum biomass of hatchlings was also reported in vermicomposter no. 7 followed by no. 5. It was due to the more growth of hatchlings in these vermicomposters (Table 6). The difference between biomass and cocoon production in different vermicomposters could be related to the biochemical quality of the waste mixtures, which is one of the important factors in determining onset of cocoon production (Flack and Hartenstein, 1984). Recently, Suthar (2007) reported that along with feed quality the microbial biomass and decomposition activities are also important. After the 11th week biomass decrease was observed in all vermicomposters. It may be due to the exhaustion of food. When *E. fetida* received food below a maintenance level, it lost weight at a rate, which depended upon the quantity and nature of its ingestible substrates (Neuhauser et al., 1980). The feeds that provide earthworms with a sufficient amount of easily metabolizable organic matter and non-assimilated carbohydrates favor the growth and reproduction of the earthworms (Edwards, 1988). The results showed higher growth and reproduction of earthworms in vermicomposters containing BPS and press

Table 5
Growth of *E. fetida* (mean ± SD) in different vermicomposters ($n = 3$)

Vermicomposter number	Mean initial biomass/earthworm (mg)	Maximum biomass achieved/earthworm (mg)	Maximum biomass achieved in (week)	Net biomass gain/earthworm (mg)	Growth rate/worm/day (mg)	Biomass gained per unit feed waste (mg/g)
1	400 ± 17.4ab	922 ± 19.7a	11th	522 ± 29.3a	6.8 ± 0.38a	3.4 ± 0.21a
2	368 ± 16.5a	918 ± 22a	7th	550 ± 27.0abc	11.2 ± 0.55b	3.7 ± 0.18a
3	374 ± 12.5ab	1052 ± 23.1b	7th	678 ± 33.7bd	13.8 ± 0.68d	4.5 ± 0.23b
4	378 ± 10.4ab	1264 ± 33.4c	7th	886 ± 42c	18.1 ± 0.85c	5.9 ± 0.28c
5	378 ± 8.7ab	1180 ± 21.3d	7th	804 ± 25.1ce	16.4 ± 0.51ce	5.4 ± 0.16cd
6	400 ± 14.8ab	1160 ± 27.8d	7th	760 ± 34.7de	15.5 ± 0.71de	5.1 ± 0.23bd
7	412 ± 11.8b	1152 ± 11.8d	7th	740 ± 20.4de	15.1 ± 0.42de	4.9 ± 0.14bd

Mean values followed by different letters in same column are statistically different (ANOVA; Tukey's test, $p < 0.05$).

Table 6
Reproduction by *E. fetida* (mean ± SD) in different vermicomposters ($n = 3$)

Vermicomposter number	Cocoon production started in (week)	Total no. of cocoons after 91 days	Reproduction rate (cocoons/worm)	Total no. of hatchlings	No. of clitellated hatchlings	Biomass of hatchlings (g)
1	3rd	63 ± 7.5a	12.6 ± 1.5ab	20 ± 3.0a	Nil	0.5 ± 0.03a
2	3rd	79 ± 12.3a	15.8 ± 2.5a	31.6 ± 6.6a	2 ± 0.1	0.7 ± 0.06a
3	3rd	177 ± 14.1b	35.4 ± 2.8c	177.3 ± 18.0b	4 ± 0.3	2.6 ± 0.4b
4	4th	180 ± 20.0b	36 ± 4.0c	179.3 ± 16.2b	5 ± 0.6	1.8 ± 0.2c
5	4th	201 ± 18.5bc	40.2 ± 3.7bcd	195 ± 23.6b	7 ± 0.9	3.4 ± 0.2d
6	4th	228 ± 15.7c	45.6 ± 3.14d	175 ± 19.1b	5 ± 0.4	2.4 ± 0.3bc
7	4th	204 ± 18.3bc	40.8 ± 3.7cd	161 ± 17.5b	10 ± 2.0	6.3 ± 0.4e

Mean values followed by different letters are statistically different (ANOVA; Tukey's test, $p < 0.05$).

mud than control. Sangwan et al. (2008) have observed similar results in waste mixtures of filter cake and horse dung.

4. Conclusion

Press mud has significant fertilizer value but due to prohibitive cost of sludge disposal, it is dumped in open where it adversely affects the ambient environment. Apart from this, such practices entail wastage of organic and inorganic nutrients present in the pres mud that might be put to good use. The management and nutrient recovery from press mud has been attempted by vermicomposting after mixing it with biogas plant slurry in appropriate quantities. The final products was nutrient rich, odour free, more mature and stabilized. The results showed that carbon content was decreased during the process and nitrogen content was enhanced. The C:N ratio decreased with time in all the feed mixtures indicating a stabilization of the waste. The product so obtained can be used in agricultural fields as manure. Maximum earthworm biomass was observed in the vermicomposter 80% BPS + 20% PM feed mixture which was significantly higher ($p < 0.05$) from all other feeds. This study provides a platform for the utilization of press mud amended with BPS for the process of vermicomposting. Our results demonstrate that if press mud is mixed 30–50% with BPS and vermicomposted employing *E. fetida*, its manurial value can be increased, so avoiding its harmful effects on the environment.

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