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Stabilization of primary sewage sludge during vermicomposting

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Abstract

In India, over the last few decades, there has been a remarkable increase in sewage sludge production due to population increase and unplanned urbanization. The aim of the present study was to investigate the ability of an epigeic earthworm *Eisenia foetida* to transform primary sewage sludge (PSS) amended with cow dung (CD) into value added product, i.e., vermicompost in laboratory scale experiments. Two approaches investigated in the study were: (1) evaluation of vermistabilization of PSS and CD mixtures after 15 weeks in terms of fertilizer quality of the products and; (2) growth and reproduction of *Eisenia foetida* up to 11 weeks in different vermireactors. In all the PSS and CD mixtures, a decrease in pH, TOC and C:N ratio, but increase in EC, TKN, TK and TP was recorded. The heavy metals' content in the vermicomposts was higher than initial mixtures. Maximum worm biomass was attained in 10% PSS + 90% CD mixture while, the worm growth rate was highest in 30% PSS + 70% CD feed mixture. It was inferred from the study that addition of 30–40% of PSS with CD had no adverse effect on the fertilizer value of the vermicompost as well as growth of *Eisenia foetida*. The results indicated that PSS could be converted into good quality manure by vermicomposting if mixed in appropriate ratio (30–40%) with cow dung.

Keywords: Vermistabilization; Primary sewage sludge; Cow dung; *Eisenia foetida*; Fertilizer value

1. Introduction

During the recent years, discharge of untreated or semi-treated sewage water into water bodies has resulted in increased water pollution incidences in India. Due to prohibitive cost of sewage water treatment and non-availability of electricity, most of the sewage treatment plants in India have only primary wastewater treatment facilities (sedimentation) to treat the sewage water which yields huge quantities of primary sewage sludge. The environmentally accepted means of sewage sludge disposal include incineration and sanitary land-filling. The authors have observed that the primary sewage sludge is generally disposed off in agricultural fields, open dumps, along the roadside or railway tracks and poorly designed sanitary landfills 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 [1]. Moreover, the limited landfill space, more stringent national waste disposal regulations and public consciousness have made land-filling increasingly expensive and impractical [2]. The situation of sludge disposal and management in other developing countries is not different and may perhaps exist elsewhere too [3]. Therefore, there is a need of such ecologically sound technologies which are not only cost-effective, but also sustainable in terms of possible recovery of recyclable constituents from sewage sludges as they are rich in nutrients and have higher organic matter content. The usage of sewage sludge by recycling can supply nutrients to plants and also improve soil physical conditions and fertility [4]. But careful attention is required while applying the sewage sludges to soil as these may produce plant and soil toxicity and can have depressive effects on the metabolism of soil microorganisms [5]. Various researchers have recommended that bio-composting of the sewage sludges should be done prior to their application in agricultural fields in order to get a stabilized product and to avoid potential risk of pathogens [6–8].

Use of earthworms for waste management, organic matter stabilization, soil detoxification and vermicompost production has been reported [9–11]. The epigeic forms of earthworms can hasten the composting process to a significant extent with

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production of a better quality of compost as compared with those prepared through traditional composting methods [2]. During vermicomposting, earthworms ingest, grind and digest organic waste with the help of aerobic and anaerobic microflora in their gut, converting it into a much finer, humified, microbially active material [12]. The generated product is stable and homogeneous; has desirable aesthetics; may have reduced levels of contaminants and furthermore, is a valuable, marketable and superior plant growth medium [13]. During this process, important plant nutrients such as N, P, K, Ca, etc. present in the waste are converted into the forms that are much more soluble and available to plants than parent substrate [2].

The use of earthworm in sludge management has been termed as 'vermistabilization' [14]. A bibliographic survey has shown that in most of the sewage sludge related vermicomposting studies, activated sludge (a product of biological wastewater treatment) has been used as raw substrate but there is a paucity of data on the possibility of vermicomposting of primary sewage sludge which is available in huge quantities. Masciandaro et al. [8] have reported the vermicomposting of anaerobic and aerobic sludges using *Eisenia foetida*. The results showed that feeds having higher percentage of anaerobic sludge were not accepted by the worms.

Mitchell [15] demonstrated that aerobic sewage sludge can be ingested by *E. foetida* and the sludge is decomposed and stabilized about 3 times faster than non-ingested sludge. Moreover, a marked reduction in pathogenic microbial population of *Salmonella*, *E. coli* and other enterobacteriaceae was observed. Arumugam et al. [16] reported that survival of pathogenic organisms Salmonella, Shigella and Faecal coliform reduced to nil concentration after vermicomposting of sewage sludge, proving these pathogens are eliminated as they enter in the food chain of the earthworm. In addition, Contreras-Ramos et al. [17] reported that vermicomposting of sewage sludge with *E. foetida* resulted in reduction of *Salmonella* spp., faecal coliform and *Shigella* spp. and helminthes eggs. The reduction of pathogen numbers might be related to the release of coelomic fluids by the earthworms during vermicomposting, which have antibacterial properties and kill pathogens [18,19]. The transformation of primary sewage sludges 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 population and urbanization. The aim of this study was to study the stabilization of primary sewage sludge spiked with cow dung employing an epigeic earthworm *Eisenia foetida.*

2. Materials and methods

2.1. Primary sewage sludge (PSS), Cow dung (CD) and Eisenia foetida

Fresh PSS was collected from the dumping site of a sewage treatment plant situated near village Dhanwapur (Gurgaon), India. The wastewater treatment capacity of this plant is 15 MGD. PSS was foul smelling so it was dried in direct sunlight for a week with periodic turnings. Then it was screened to remove non-biodegradable materials such as brick pieces, stones, glass pieces, metal pieces, leather, plastics, polythene, etc. before its mixing with CD. Fresh CD was procured from an intensively live stocked farm at Hisar, India. The physico-chemical characteristics of PSS and CD are given in Table 1.

Table 1
Initial physico-chemical characteristics of CD and PSS

S. no.	Parameter	CD	PSS
1	pH	8.2	7.9
2	EC (ds m^{-1})	1.62	2.0
3	Ash content (g kg^{-1})	247	592.2
4	TOC (g kg^{-1})	436.8	236.5
5	TKN (g kg^{-1})	6.3	14.7
6	TP (g kg^{-1})	7.2	9.8
7	TK (g kg^{-1})	6.74	6.3
8	C:N ratio	69.3	16.1
9	Fe (mg kg^{-1})	244.3	408.5
10	Cu (mg kg^{-1})	56.0	316.8
11	Cr (mg kg^{-1})	6.7	18.6
12	Zn (mg kg^{-1})	308.2	437.4
13	Pb (mg kg^{-1})	1.6	14.7

Eisenia foetida hatchlings as well as clitellated adults, commonly known as red wigglers, were randomly picked for use in the experiments from several stock cultures containing 500–2000 earthworms in each, maintained in the laboratory by authors with CD as culturing material.

2.2. Experimental design

To achieve the objectives, two different experiments were conducted. The first experiment was established to determine the effect of PSS on the fertilizer quality of vermicompost. The second experiment was undertaken to study the growth and fecundity of *Eisenia foetida* at different PSS concentrations in the feed mixture.

2.2.1. Experiment 1

In six bench-scale vermireactors (vol. 10 L, diameter 40 cm, depth 12 cm), powdered PSS was mixed with CD in different ratios including a control vermireactor having CD only as feed mixture. One kg of feed mixture (on dry weight basis) was put in each circular plastic vermireactor. All the PSS and CD quantities were used on dry weight basis that were obtained by drying known quantities of material at 110 °C to constant mass in hot air oven. The composition of the CD and PSS in different vermireactors was as follows.

- Vermireactor No. 1: 1000 g CD + earthworms
- Vermireactor No. 2: 900 g CD + 100 g PSS + earthworms
- Vermireactor No. 3: 800 g CD + 200 g PSS + earthworms
- Vermireactor No. 4: 700 g CD + 300 g PSS + earthworms
- Vermireactor No. 5: 600 g CD + 400 g PSS + earthworms
- Vermireactor No.6: 500 g CD + 500 g PSS + earthworms

These mixtures were turned manually every day for 21 days in order to eliminate volatile gases potentially toxic to earthworms. After 21 days, 20 adult individuals of *E. foetida* (weighing between 400 and 600 mg) were introduced into each vermireactor. The moisture content was maintained at 70 ± 10% of water holding capacity by periodic sprinkling of an adequate quantity of distilled water. All the containers were kept in the dark under identical ambient conditions (room temperature 25 ± 3 °C, relative humidity 60–80%). The experiments were replicated thrice for each feed mixture. Homogenized samples (free from earthworms, hatchlings and cocoons) of the feed material were drawn at 0, 21, 42, 63, 84 and 105 days from each container. The 0 day refers to the time of initial mixing of the PSS and CD before preliminary decomposition. The samples were air dried in the shade at room temperature, ground in a stainless steel blender and stored in plastic vials for further chemical analysis.

2.2.2. *Experiment 2*

Six circular plastic containers (diameter 14 cm, depth 12 cm) were filled with CD + PSS feed mixtures having percentage composition similar to Experiment 1 (Section 2.2.1) but the total feed quantity was reduced to 150 g in each container. After 21 days, 5 non-clitellated hatchlings, each weighing 50–120 mg, were introduced in each vermireactor. Three replicates for each vermireactor were maintained. All other experimental conditions were similar to Experiment 1 (Section 2.2.1). Biomass gain and cocoon production were recorded weekly for 11 weeks. The feed in each vermireactor was turned out, and earthworms and cocoons were separated from the feed by hand sorting, after which they were counted and weighed after washing with water and drying them by paper towels. The worms were weighed without voiding their gut content. Corrections for gut content were not applied to any data in this study. Then all earthworms, cocoons and feed were returned back to the respective container. No additional feed was added at any stage during the study period.

The pH and electrical conductivity (EC) were determined using a double distilled water suspension of each vermicompost in the ratio of 1:10 (w/v). Total organic carbon (TOC) was measured using the method of Nelson and Sommers [20]. Total Kjeldhal nitrogen (TKN) was determined by Bremner and Mulvaney [21] procedure. Total phosphorus (TP) was analyzed using the colorimetric method with molybdenum in sulphuric acid. Total potassium (TK) was determined by flame photometer [Elico, CL 22 D, Hyderabad, India]. Total Fe, Cu, Cr, Pb and Zn were determined by means of atomic absorption spectrophotometer (AAS) [GBC 932, GBC Scientific Equipment Ltd., Australia] after digestion of the sample with concentrated HNO_3: concentrated $HClO_4$ (4:1, v/v).

All the chemicals used were analytically reagent (AR) grade supplied by S.D. Fine Chemicals, Mumbai, India. Alkali resistant borosilicate glass apparatus and double glass distilled water was used through out the study for analytical work. The samples were used on dry weight basis for chemical analysis. All the samples were analyzed in triplicate and results were averaged. The results were reproducible with in 3–7% error limits.

One-way ANOVA was used to analyze the significant difference between different reactors for observed parameters. Tukey's *t*-test also performed to identify the homogeneous type of the reactors for their different chemical properties and earthworm growth parameters i.e. individual weight, earthworm weight gain, individual growth rate, cocoon production, etc. The probability levels used for statistical significance were $P < 0.05$ for the tests.

3. Results and discussion

3.1. *Fertilizer quality of the vermicompost*

E. foetida could not tolerate the fresh PSS. Addition of some other organic waste was essential for the survival of the earthworms in the PSS. The vermicompost was much darker in color than originally in all the vermireactors and had been processed into homogeneous manure after 105 days of earthworms' activity. Physico-chemical characteristics of the initial feed mixtures (after mixing different compositions of CD and PSS) and vermicompost obtained at the offset of the Experiment 1 have been encapsulated in Table 2. There were little changes in the

Table 2
Physico-chemical characteristics of initial feeds and vermicompost obtained from different CD + PSS feed mixtures

Feed mixture	pH	EC	Ash content	TK	TP
Initial physico-chemical characteristics of initial feed mixtures[a]					
1	8.2	1.62	247.0	6.74	7.20
2	8.2	1.66	281.5	6.70	7.46
3	8.1	1.69	316.0	6.65	7.72
4	8.1	1.73	350.6	6.61	7.98
5	8.1	1.77	385.0	6.57	8.24
6	8.0	1.81	419.6	6.52	8.50
Physico-chemical characteristics of final vermicompost obtained from different vermireactors[b] (mean ± S.E.M., $n = 3$)					
1	6.87 ± 0.05a	1.81 ± 0.005a	702.7 ± 8.50cd	13.1 ± 0.92a	14.7 ± 0.32a
2	6.93 ± 0.05a	1.86 ± 0.028a	731.1 ± 7.25d	13.3 ± 0.33a	15.1 ± 0.40a
3	7.03 ± 0.03ab	1.86 ± 0.019a	689.9 ± 3.28c	12.9 ± 0.38a	15.2 ± 0.26ab
4	7.07 ± 0.03ab	1.92 ± 0.027a	675.2 ± 3.82c	13.4 ± 0.27a	15.7 ± 0.66ab
5	7.27 ± 0.03bc	1.89 ± 0.031a	627.2 ± 5.84b	13.8 ± 0.43a	17.1 ± 0.09b
6	7.70 ± 0.05c	1.88 ± 0.029a	580.3 ± 11.75a	13.9 ± 0.35a	16.5 ± 0.83ab

[a] Initial physico-chemical charateristics of the feed in the vermireactors have been calculated based upon the percentage of the CD and PSS in them.

[b] Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$). Units of all the parameters except pH and EC are in g kg^{-1}. The EC values are in ds m^{-1}.

pH of vermicompost as compared to initial values (Table 2). The pH decreased from alkaline (8.0–8.2) to acidic or neutral (6.87 ± 0.05 to 7.70 ± 0.05) in all the vermireactors. This corroborates with the findings of other researchers [22–25]. The pH shift towards acidic conditions has been attributed to mineralization of the nitrogen and phosphorus into nitrites/nitrates and orthophosphates; bioconversion of the organic material into intermediate species of organic acids [24]. It has also been reported that different substrates could result in the production of different intermediate species and different wastes showed a different behavior in pH shift. Haimi and Hutha [26] postulated that lower pH in the final vermicomposts might have been due to the production of CO_2 and organic acids by microbial activity during the process of bioconversion of different substrates in the feed given to earthworms. The electrical conductivity (EC) was increased in the range of 11.7–4.4% for different feed mixtures after vermicomposting but the variation was insignificant ($P < 0.05$) among all the vermireactors. This increase in EC might have been due to loss of organic matter and release of different mineral salts in available forms such as phosphate, ammonium, potassium, etc. [27]. Gunadi and Edwards [23] have reported that EC and pH of feed could be the limiting factor for the survival and growth of *Eisenia foetida*. Mitchell [22] reported that *Eisenia foetida* was unable to survive in the cattle solids with pH of 9.5 and electrical conductivity of 5.0 dS m^{-1}. Ash content of vermicompost from all the vermireactors was higher than the initial feed mixtures (Table 2). The increase in ash content was maximum for the vermireactor no. 2 (10% PSS + 90% CD), which was higher than the control (vermireactor no. 1). Thereafter, the ash content decreased substantially with the increase in PSS concentrations in the vermireactors. The results are in consistent with a previous study by Gupta et al. [28] which reported that increase in ash content may be due to the enhanced mineralization in the presence of earthworms. Total organic carbon (TOC) of the final vermicompost was remarkably reduced as compared to the initial feed mixtures (Fig. 1). There was a loss of 30.5–62.6% TOC in different vermireactors by the end of vermicomposting period. Data revealed that TOC loss was higher in vermireactor no. 2 (10% PSS + 90% CD) than control (vermireactor no. 1). Further, TOC reduction was inversely related to the PSS content in the vermireactors, i.e., the reduction was maximum for vermireactor no. 2 (62.6%) and minimum for vermireactor no. 6 (30.5%). This finding was supported by other workers [27], who reported 45% loss of carbon during vermicomposting of municipality or industrial wastes. Suthar [29] reported that earthworms promoted such microclimatic conditions in the vermireactors that increased the loss of TOC from substrates through microbial respiration. Where as, Elvira et al. [30] have attributed this loss to the presence of earthworms in the feed mixtures.

A significant increase in the TKN content occurred following the vermiconversion of sludge into vermicompost in different vermireactors. The initial TKN content of the vermireactors was in the range of 6.3–10.5 g kg^{-1} (Fig. 2). Total nitrogen (TKN) content increased in the range of 17.0 ± 0.26 to 17.9 ± 0.23 g kg^{-1} in different vermireactors (Fig. 2) after vermicomposting. The difference in the TKN content of the vermicomposts obtained from different vermireactors was not statistically significant ($P < 0.05$). This confirms that if PSS is mixed in appropriate quantities (up to 50% on dry weight basis) with cow dung, would not have antagonistic impact on the final TKN content of the vermicompost. Other workers have also reported similar observations [9,25,30]. According to Viel et al. [31] losses in organic carbon might be responsible for nitrogen addition. However, there are contradictory reports on nitrogen content and its variation in vermicomposting. Ndegwa et al. [24] and Mitchell [22] found no significant difference between total nitrogen concentrations in the original substrate and the resulting vermicompost. Where as, Parvaresh et al. [32] have reported a great variation in nitrogen concentrations over the whole vermicomposting period. The reason for discrepancies observed in total nitrogen variations in vermicomposting of different wastes lies in the fact that the quality of substrate in feeding the earthworms together with their physical structure

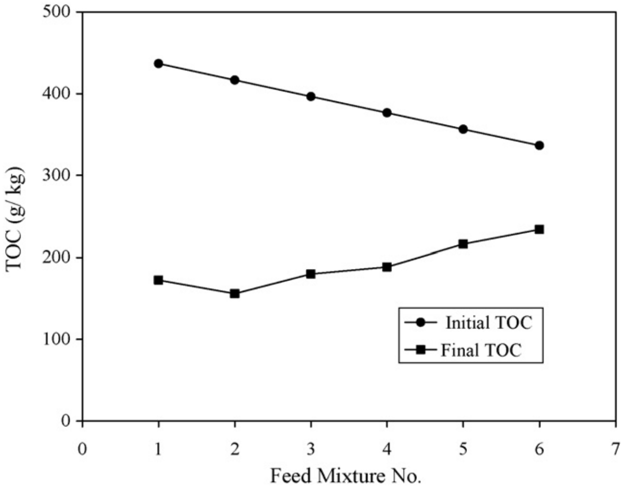

Fig. 1. Comparison of TOC change in different vermireactors. Initial TOC of the feed in the vermireactors have been calculated based upon the percentage of the CD and PSS in them.

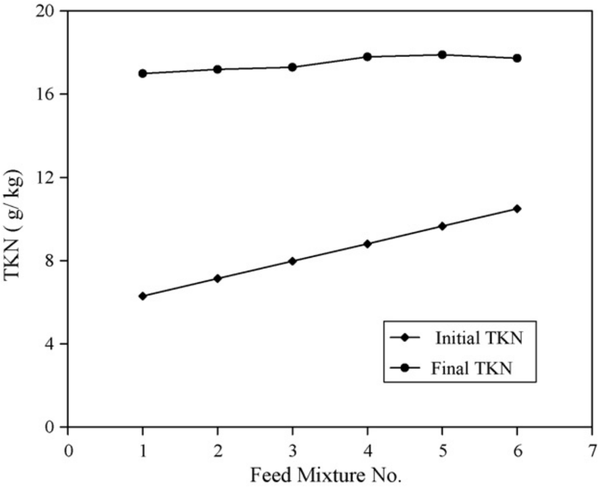

Fig. 2. Comparison of TKN change in different vermireactors. Initial TKN of the feed in the vermireactors have been calculated based upon the percentage of the CD and PSS in them.

and chemical composition affects mineralization of nitrogenous organic compounds and the amount of nitrogen from the compounds [33]. The initial TK content in the feed mixture was in the range of 6.52–6.74 g kg^{-1} (Table 2). Final TK content in all the vermireactors was about 2-fold higher than initials and was in the range of 12.9 ± 0.38 to 13.9 ± 0.35 g kg^{-1}. Data revealed that the TK content in the final vermicompost for vermireactor no. 1–6 was not significantly different from each other ($P < 0.05$). Similarly, Delgado et al. [34] have reported higher TK content in the vermicomposts prepared while using sewage sludge as feed mixture. In addition, Suthar [35] suggested that earthworm processed waste material contains higher concentration of exchangeable K due to enhanced microbial activity during the vermicomposting process, which consequently enhances the rate of mineralization. Similarly, there was about 2-fold increase in total phosphorus (TP) of the final vermicompost in all the vermireactors compared with TP content in initial feed mixtures. The overall increase in the TP content was maximum in the vermireactor no. 5 (40% PSS + 60% CD; 8.86 g kg^{-1}), and minimum increase was in the vermireactor no. 3 (20% PSS + 80% CD; 7.48 g kg^{-1}). However, the difference in TP concentrations in the vermireactor no. 1 and 6 was not significant indicating the suitability of PSS addition up to 50% with CD to achieve TP values similar to control. Also, Satchell and Martin [36] found an increase of 25% in total P of paper-waste sludge, after worm activity. According to Lee [37], if the organic materials pass through the gut of earthworms, then some of phosphorus being converted to such forms that are available to plants. Moreover, he concluded that availability of P to plants is mediated by phosphatase produced within the earthworms and further release of P may be introduced by microorganisms in their casts, after their excretion. Similarly, Ghosh et al. [38] have reported that vermicomposting can be an efficient technology for the transformation of unavailable forms of phosphorus to easily available forms for plants.

The C:N ratio is used as an index for maturity of organic wastes. As evident from the Table 3 that C:N ratios decreased with time in the entire worm worked vermireactors. Initial C:N ratio was in the range of 69.3–32.1 at 0 day. The C:N ratio was lesser in those feed mixtures which had higher percentage of PSS. Final C:N ratios of vermicompost were in the range of 13.5–9.1, depicting the overall decrease of 57.9–85.2% after 105 days of worms' activity from the initial values at 0 day. 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 wastes [39]. So, in the present study, a high degree of organic matter stabilization was achieved in all the vermireactors. The C:N ratio of farmyard manure decreased after storing for a period of three months [40]. In our experiments, decrease in C:N ratio was observed even on 21st day of the experiment confirming much more rapid decomposition (Table 3). Also, it was found that there was a rapid decrease in C:N ratios after inoculation of earthworms (i.e. at 42nd day) as compared to the values of C:N ratios during the period of without earthworms (at 21st day). This demonstrates the role of earthworms in much more rapid decomposition and rates of mineralization of organic matter.

Table 3
Changes in C:N ratio of different vermireactors during vermicomposting ($n = 3$)

Vermireactor number	Time (days)					
	0	21[a]	42	63	84	105
1	69.3f	60.1f	45.4f	33.6d	18.5c	10.2ab
2	58.4e	51.8e	36.2e	28.7c	13.3a	9.1a
3	49.7d	43.3d	32.8d	22.3b	16.8b	10.4ab
4	42.8c	36.5c	25.8b	18.5a	13.1a	10.6b
5	36.9b	33.4b	22.4a	21.5b	13.6a	12.1c
6	32.1a	29.7a	27.5c	19.2a	16.9b	13.5d

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

[a] Earthworms were introduced in the experiment on day 21.

3.2. Heavy metal concentrations in final vermicompost

Heavy metals appear in the sewage sludge from a variety of sources like batteries, consumer electronics, ceramics, light bulbs, plastics, house dust and paint chips, etc. So, the vermicompost made from sewage sludge may have higher heavy metal concentrations. In small amounts, many of these elements may be essential for plant growth, however, in higher concentrations they are likely to have detrimental effects upon plant growth [41]. So, prior to vermicompost application to the soils, there is a need to determine the heavy metal concentrations in the final vermicomposts. In the present study, initial heavy metal contents of PSS were several times higher than CD (Table 1) which resulted in higher heavy metal concentrations in PSS containing initial feed mixtures (Table 4). A comparison of the results showed that heavy metals, viz, Fe, Cu, Zn, Cr concentrations in the final vermicompost in the vermireactors no. 1–6 were higher than in the initial feed mixtures (Table 4). Where as, Pb concentration in final vermicomposts in relation to initial concentration did not follow any regular pattern. Our findings are supported by Elvira et al. [42] who reported an increase in heavy metals concentrations in vermicompost of paper mill sludge. Similarly, Hartenstein and Hartenstein [43] have attributed the greater increase in heavy metal in the castings, as opposed to in the sludge without earthworms, to the mineralization process that earthworms accelerate during sludge decomposition and stabilization. Also, Deolaliker et al. [44] suggested that weight and volume reduction due to breakdown of organic matter during vermicomposting may be the reason for increase in heavy metal concentrations in vermicompost. While considering the risks associated with heavy metal contaminations in soils, it was found that the concentrations of heavy metals studied in the final vermicompost obtained from the vermireactors containing up to 50% composition of PSS with CD were lesser than limits set for composts in USA and European countries [45] (Table 5).

3.3. Growth and cocoon production of *E. foetida* in different vermireactors

The biomass production by *E. foetida* in different vermireactors in second experiment has been given in Table 6. The growth curves of *E. foetida* in the studied vermireactors over the observation period are given in Fig. 3. The highest worm

Table 4
Heavy metal content (mg kg^{-1}) in initial feed substrates and vermicompost obtained from CD + PSS vermireactors

Vermireactors	Total-Fe	Total-Cu	Total-Zn	Total-Cr	Total-Pb
Heavy metal content in initial feed mixtures[a]					
1	244	56	308	6.70	1.60
2	261	82	321	7.89	2.91
3	277	108	334	9.08	4.22
4	298	134	347	10.27	5.53
5	310	160	360	11.46	6.84
6	326	186	373	12.65	8.15
Heavy metal content in final vermicompost obtained from different vermireactors[b] (mean ± S.E.M., $n = 3$)					
1	444 ± 4.98a	99 ± 2.33a	539 ± 15.65a	8.5 ± 0.87a	1.3 ± 0.26a
2	472 ± 9.24ab	118 ± 3.28a	557 ± 6.89ab	8.8 ± 0.72a	1.5 ± 0.18a
3	492 ± 7.5 bc	164 ± 4.26b	594 ± 9.87ab	13.7 ± 2.39c	2.5 ± 0.07a
4	519 ± 12.90cd	187 ± 4.93b	636 ± 9.82bc	12.7 ± 0.96b	6.6 ± 0.18b
5	537 ± 11.32de	230 ± 8.88c	465 ± 18.09bc	13.6 ± 1.01b	7.5 ± 0.46b
6	567 ± 9.85e	293 ± 10.48d	664 ± 14.93c	13.7 ± 0.17c	10.0 ± 0.22c

[a] Initial heavy metals charateristics of the feed in the vermireactors have been calculated based upon the percentage of the CD and PSS in them.

[b] Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$).

Table 5
Heavy metal limits (mg kg^{-1}) for compost in USA and European countries

Heavy metal	EU limit range	USA biosolids limit
Chromium	70–200	1200
Copper	70–600	1500
Cadmium	0.7–10	39
Mercury	0.7–10	17
Nickel	20–200	420
Lead	70–1000	300
Zinc	210–4000	2800

biomass was observed in vermireactor no. 2 (10% PSS + 90% CD; 993.0 ± 23.5 mg earthworm^{-1}) and the lowest in the 50% PSS + 50% CD feed mixture (715.0 ± 28.35 mg worm^{-1}). The worm biomass attained in control (vermireactor no. 1) was lesser than in 10% PSS + 90% CD feed mixture (vermireactor no. 2) but statistically insignificant ($P < 0.05$). Increasing percentage of PSS in the vermireactors promoted a decrease in biomass gain by *E. foetida*. The net biomass gain by *E. foetida* was higher in vermireactor no. 2 and 3 than control. The maximum worm biomass was attained in the 5th or 6th week in all the vermireactors (Fig. 3). Initial increase in biomass was followed by stabilization, and, later weight loss was observed in all the vermireactors. The loss in worm biomass can be attributed to the exhaustion of food. When *E. foetida* received the food below a maintenance level, it lost weight at a rate which depended upon the quantity and nature of its ingestible substrates [46]. 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 except vermireactor no. 6. The growth rate expressed in terms of mg weight gained day^{-1} worm^{-1} has been considered as a good index to compare the growth of earthworms in different feeds [47]. The fastest growth rate was observed in vermireactor no. 4 (30% PSS + 70% CD) (22.3 ± 0.93 mg worm^{-1} day^{-1}); where as 50% PSS + 50% CD supported the least growth (17.2

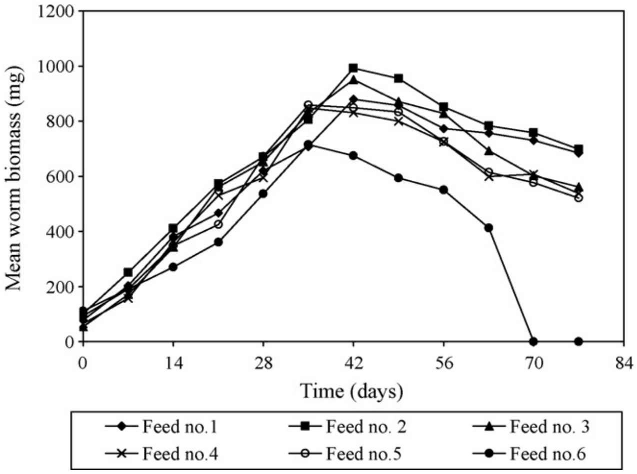

Fig. 3. Biomass growth of *Eisenia foetida* in CD + PSS feed mixtures with time.

Table 6
Biomass production by *Eisenia foetida* in different vermireactors (mean ± S.E.M., $n = 3$)

Feed mixture no.	Mean initial biomass worm^{-1} (mg)	Maximum biomass worm^{-1} (mg)	Maximum biomass achieved in (week)	Net biomass gained worm^{-1} (mg)	Growth rate worm^{-1} day^{-1} (mg)
1	78.7 ± 1.76bc	880.0 ± 18.29bc	6th	802.3 ± 18.20bc	19.1 ± 0.44 ab
2	102.0 ± 3.05d	993.0 ± 23.50c	6th	891.0 ± 21.65bc	21.2 ± 0.52 b
3	54.0 ± 2.0a	950.0 ± 32.02bc	6th	896.0 ± 31.0c	21.2 ± 0.74 b
4	66.0 ± 4.58ab	848.0 ± 31.0b	5 and 6th	782.0 ± 32.72bc	22.3 ± 0.93 b
5	94.0 ± 4.16cd	858.0 ± 17.24b	5 and 6th	764.0 ± 20.0b	21.8 ± 0.58 b
6	111.6 ± 8.25d	715.0 ± 28.35a	5 and 6th	603.3 ± 35.36a	17.2 ± 1.01 a

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P < 0.05$). The experiment was terminated on 77th day.

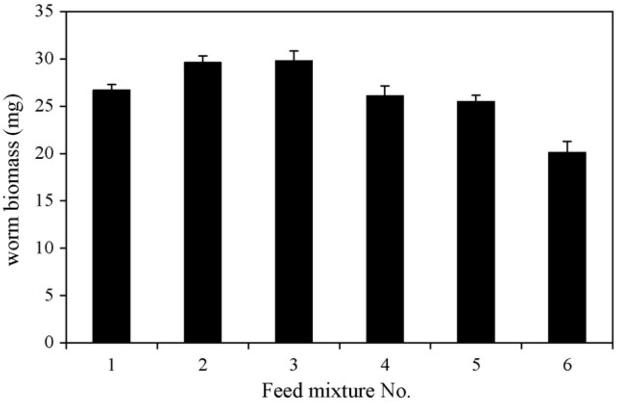

Fig. 4. Worm biomass gained per unit waste (mg g^{-1}) in different feed mixtures.

± 1.01 mg $worm^{-1}$ day^{-1}). A comparison of the data revealed that the growth rate $worm^{-1}$ day^{-1} was not significantly different in the vermireactor no. 1–5, inferring that up to 40% addition of PSS in CD can support effective growth rate of earthworms. Worm biomass gained per unit of the waste was highest in vermireactor no. 3 (29.8 ± 1.02 mg g^{-1}), but the values were not significantly different from other vermireactors except vermireactor no. 5 and 6 (Fig. 4). The total number of residual cocoons after 77 days in different vermireactors has been represented in Fig. 5. The maximum no. of cocoons was observed in vermireactor no. 1 and minimum were in vermireactor no. 6. It is evident from the Fig. 5 that the cocoons production was inversely related to PSS concentration in the studied vermireactors. The results suggest that addition of PSS in CD is not suitable for earthworm production (vermiculture) as the cocoon production is lesser if PSS is present in the earthworm feed. The difference between biomass and cocoon production in different vermireactors could be related to the biochemical quality of the feed, which was one of the important factors in determining onset of cocoon production [48]. Recently, Suthar [35] summarized that except to the chemical properties of waste, the microbial biomass and decomposition activities during vermicomposting were also important. Finally the results indicated that the addition of 30–40% primary sewage sludge to the cow dung is acceptable during the vermicomposting of PSS in terms of fertilizer quality of the vermicompost so obtained. But if prime concern is vermiculture (production of earthworms), then addition of PSS in the CD is not suggested.

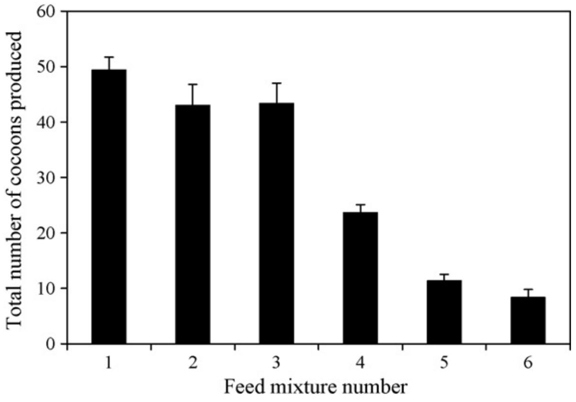

Fig. 5. Total number of cocoons produced in different feed mixtures.

4. Conclusions

Disposal of sewage sludge by environmentally acceptable means is a serious problem. Our trials have demonstrated that vermicomposting can be an alternate technology for the management of primary sewage sludge mixed with cow dung. In the present study, the vermicomposting of PSS amended with CD resulted in the conversion of a waste into value added product, i.e. vermicompost. A high degree of PSS stabilization was achieved after 105 days of worm activity. The results indicated that after the addition of primary sewage sludge in appropriate quantities (30–40%) to the cow dung, it can be used as a raw material in the vermicomposting. The fertilizer quality of PSS-based vermicomposts was almost equal to control (prepared by using the cow dung only). But addition of PSS in the CD is not suggested if prime concern is vermiculture (production of earthworms) as the cocoon production is lesser if PSS is present in the earthworm feed. The study also inferred that the application of PSS-based vermicompost in the agricultural fields as a soil conditioner or manure, would not have any adverse effect due to heavy metals.

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