International Journal of Research in Biosciences
Vol. 3 Issue 3, pp. (15-29), July 2014
Available online at http://www.ijrbs.in
ISSN 2319-2844

Research Paper

Quality assessment of compost and vermicompost derived from pressmud amended fly ash

***Niyazi Rahat[1], Chaurasia Sadhana[2], Verma Anju[1] and Singh Dharam[1]**
[1]Department of Environmental Science, Institute of Biosciences and Biotechnology, Chhatrapati Shahu Ji Maharaj University, Kanpur, 208024, Uttar Pradesh, INDIA
[2]Department of Environmental Science, Mahatma Gandhi Chitrakoot Gramodaya University, Satna, 485331, Madhya Pradesh, INDIA

(Received April 07, 2014, Accepted June 12, 2014)

Abstract

Fly ash is produced in large quantities in thermal power plants and the storage and/or spreading of this waste on land may cause contamination of the atmosphere, soil and water. The aim of the present study was to evaluate the effectiveness of the composting and vermicomposting for reducing the polluting potential and for stabilizing fly ash in the short-term. For this, the physico-chemical as well as the pathogenic characteristics of the resulting products before and after the active phase of composting and vermicomposting were analyzed. The growth and reproduction of *Eisenia foetida* was also monitored in a range of different feed mixtures after vermicomposting in laboratory under controlled experimental conditions. In all the feed mixtures, a decrease in temperature, pH, TOC, C: N ratio and faecal coliforms, but increase in EC, TKN and TAP was recorded in final composts and vermicomposts. The TK content was increased in vermicomposts but no significant change was found in composts. In vermicomposting the growth rate and cocoon production was maximum in 100% PM. The results indicated that vermicomposting was more effective in terms of stabilizing the PM amended FA and thereby producing improved substrates for agricultural use.

Keywords: Composting, vermicomposting, fly ash, pressmud, *Eisenia foetida*.

Introduction

Industrialization of the developing countries in the world of rapid economic growth has created serious problem of waste disposal due to rapid urbanization [1]. Fly ash is one of the major wastes produced by burning coal in thermal power stations. Its annual production all over the world is 300-350 million tonnes through combustion of 3000 million tonnes of coal [2, 3]. Fly ash (FA), a by-product of coal-fired electricity generation plants, is presenting acute waste disposal problems in different parts of the world with the large-scale generation from the consistently increasing numbers of coal-fired plants [4, 5]. The present outlets of fly ash disposal are as a concrete additive and in municipal land filling operation. Some possible agronomic uses of fly ash as, a fertilizer [6, 7], a liming material [8] and as a physical amendment [9] have been indicated. Soil application of fly ash waste has been associated with both the favorable [10] as well as adverse [11] effects on crop yields. The latter type effect is common at high rates of fly ash due to

increased salinity and accumulation of toxic levels of elements [12]. To overcome these adverse effect fly ash, a burnt material and therefore contains little organic matter, can be supplemented, composted and vermicomposted by mixing with an additional source of organic matter like pressmud (PM). Pressmud, a by-product of sugar industry, generates intense heat (65^0C), foul odor and takes long time for natural decomposition [13, 14]. Composting and vermicomposting are two of the best-known processes for the biological stabilization of solid organic wastes. Composting involves the accelerated degradation of organic matter by microorganisms under controlled conditions, in which the organic material undergoes a characteristic thermophilic stage that allows sanitization of the waste by the elimination of pathogenic microorganisms [15].

Two phases can be distinguished in composting: (i) the thermophilic stage, where decomposition takes place more intensively and which therefore constitutes the active phase of composting; and (ii) a maturing stage which is marked by the decrease of the temperature to the mesophilic range and where the remaining organic compounds are degraded at a slower rate. The duration of the active phase depends on the characteristics of the waste (amount of easily decomposable substances) and on the management of the controlling parameters (aeration and watering). The extent of the maturation phase is also variable and it is normally marked by the disappearance of the phytotoxical compounds. Composting is well established at the industrial scale for solid organic waste treatment [16]. Vermicomposting involves the bio-oxidation and stabilization of organic material by the joint action of earthworms and microorganisms. Although it is the microorganisms that biochemically degrade the organic matter, earthworms are the crucial drivers of the process, as they aerate, condition and fragment the substrate, thereby drastically altering the microbial activity.

Earthworms act as mechanical blenders and by comminuting the organic matter they modify its physical and chemical status by gradually reducing the ratio of C:N and increasing the surface area exposed to microorganisms – thus making it much more favorable for microbial activity and further decomposition [17]. Therefore two phases can also be distinguished here, (i) an active phase where the earthworms process the waste modifying its physical state and microbial composition [18], and (ii) a maturation-like phase marked by the displacement of the earthworms towards fresher layers of undigested waste, where the microbes take over in the decomposition of the waste. Like in composting, the duration of the active phase is not fixed, and it will depend on the species and density of earthworms, the main drivers of the process, and their ability to ingest the waste (ingestion rate). In some cases, organic residues require pretreatment before being vermicomposted as they may contain substances that are toxic for earthworms, such as acidic compounds [19]. Although several studies have addressed the optimization of either composting, vermicomposting or composting with subsequent vermicomposting [17, 20, 21, 22, 23], there are no studies concerning the efficiency of these two processes together to stabilize pressmud amended fly ash. To obtain high quality organic fertilizers, it is necessary to understand the changes that the material undergoes during the biological stabilization process. Primarily, the aim of this work was to give an overall view of research idea regarding the stabilization of pressmud amended fly ash through composting and vermicomposting and secondarily to analyze the biomass growth and cocoon production of earthworm *Eisenia foetida* in different feed mixtures after vermicomposting.

Materials and Methods

Collection of materials: Fly ash was procured from the dumping ground of Panki Thermal Power Station near Panki, Kanpur, India. Pressmud was procured from Kisan Sahkari Sugar Mill, Kayamganj, Farrukhabad, India. Earthworm species (*Eisenia foetida*) was procured from Kanpur Gaushala Society, Bhauti, Near Panki Highway, Kanpur, India and cow dung was procured from a cow farm near the university campus as a culturing material for earthworms.

Earthworms culture: The culture of earthworms (*Eisenia foetida*) was maintained under laboratory conditions by using cow dung as a culturing material. The worm's culture was needed for time to time use of earthworms for research work. Generally, *Eisenia foetida* survive on temperature range 16^oC – 28^oC and are most active on upper ends of its temperature range. In summer season worms enhance their

foraging activities and are sexually more active. So the worm's culture was produced in the summer season.

Experimental design: Eleven feed mixtures having different proportions of fly ash and pressmud were established including one feed of 100% pressmud as control (Table 1). All the fly ash and pressmud quantities were used on dry weight basis that were obtained by drying known quantities of material at 110^{o}C to constant mass in a hot air oven.

Table 1: Content (percentage) of Fly ash and Pressmud in initial feed mixtures

FEED MIXTURE NO.	FLY ASH	PRESSMUD
1	1000[a] (100)[b]	-----
2	900[a] (90)[b]	100[a] (10)[b]
3	800[a] (80)[b]	200[a] (20)[b]
4	700[a] (70)[b]	300[a] (30)[b]
5	600[a] (60)[b]	400[a] (40)[b]
6	500[a] (50)[b]	500[a] (50)[b]
7	400[a] (40)[b]	600[a] (60)[b]
8	300[a] (30)[b]	700[a] (70)[b]
9	200[a] (20)[b]	800[a] (80)[b]
10	100[a] (10)[b]	900[a] (90)[b]
11	-----	1000[a] (100)[b]

a – The figures indicate the weight content in the initial feed mixtures (d/w).
b – The figures in parentheses indicate the percentage content in the initial feed mixtures.

Composting was carried out in the trenches of 46 cm long, 32 cm wide and 25 cm deep for twelve weeks, each of which contained approximately 40 cm^3 of material. Throughout the process, the trenches were aerated through turning of the material in order to induce movement of air into the material and deliver oxygen to microorganisms. The compost was turned daily in order to homogenize the mass, and to avoid compaction of the substrate and subsequent low porosity and poor air distribution. The composting material was moist with distilled water and the moisture content was monitored daily and maintained upto 55–65%. There were three replicates for each feed mixture and no additional food was added at any stage during the study period. Vermicomposting was carried out in circular plastic containers (diameter 20 cm and depth 20 cm). One kg of feed mixture was put in each container and all the containers were kept in darkness at room temperature (22-26^{o}C). The moisture content of the feed mixture in each container was maintained at 60-80% throughout the study period by sprinkling adequate quantity of distilled water. These feed mixtures were turned manually every day for 21 days in order to eliminate volatile gases potentially toxic to earthworms. After 21 days, fifty nonclitellated hatchlings of *Eisenia foetida* of our own culture were introduced in each container. There were three replicates for each feed mixture and no additional food was added at any stage during the study period. After 60 days granular tea like vermicompost appear on the upper surface of each feed mixture excepting feed mixture no.1. The prepare vermicomposts and inoculated earthworms were used for analysis.

Physico-chemical and microbiological analysis: The samples were used for chemical analysis on a dry weight basis obtained by oven drying the known quantities of material at 110^{o}C. The temperature was measured at inside the feed mixtures with the help of mercury thermometer (Hoskin G-692), the moisture content was measured using the method of Wu and Ma [24] and the water holding capacity was measured as described by FCQAO [25] in terms of moisture content on draining under gravity. The pH and electrical conductivity was determined using a double-distilled water suspension of 1:10 (w/v) that had been agitated mechanically for 30 minutes and filtered through Whatman filter paper No.1 and determination was done by a digital pH meter (ELICO-LI 162) and conductivity meter (ELICO-180) respectively. The total organic carbon was measured by using the Walkley and Black rapid titration method [26] and the total kjeldhal nitrogen was estimated by microkjeldhal method [27]. The total available phosphorous was

analyzed by using the colorimetric method of Bray and Krutz [28] and the total potassium was determined by Flame emission technique using flame photometer (ELICO- CL 361). The pathogenic microorganisms i.e. faecal coliforms were analyzed by the Most Probable Number (MPN) method as prescribed by USEPA [29] procedure.

Growth study of earthworms: Earthworm growth parameters i.e. individual weight, earthworm weight gain, individual growth rate, cocoon production and juveniles production etc. were analyzed for growth study of *Eisenia foetia*. At the end of the vermicomposting period, the feed in the plastic bins were turned out. Earthworms, cocoons and juveniles were separated from the feed by hand sorting, after which they were counted and weighed after washing them with water and drying them by paper towels. Growth rate of earthworms was determined by using the method of Suthar [30].

All the chemicals used were analytical reagent (AR) grade supplied by Merck Limited, Mumbai. Alkali resistant borosilicate glass apparatus supplied by Borosil Glass Works Limited, Mumbai and double distilled water was used throughout the study for analytical work. All the samples were analyzed in triplicate and results were averaged. Homogenized samples of final vermicompost were stored in airtight plastic vials for further chemical analysis.

Results and Discussion

Evaluation of physical, chemical and microbiological changes: Physico-chemical and microbiological characteristics of the initial feed mixtures (after mixing different proportions of fly ash and pressmud), compost and vermicompost obtained at the offset of the experiment have been encapsulated in Table 2, Table 3 and Table 4 respectively. The physical parameters like temperature, moisture content and water holding capacity are easily controllable and indicate progress of the composting and vermicomposting process. In composting, the temperature indicated that what happened at the microscopic level. Composting material heats up because microorganisms feed degradable material. The microorganisms work effectively between 43 - 66°C. The temperature below 40^{o}C decreases the composting rate and above 70^{o}C the microorganisms die [31].

The microorganisms that convert the organic waste into a humus-like substance can only consume nutrients that are dissolved in water and they also need oxygen though, so if there is too much moisture in the compost, all of the air spaces fill with water. This causes an anaerobic environment and odor problems. Turning of the material during composting process is necessary for proper aeration and temperature control [32]. The optimum moisture content for composting is between 50 - 60% and the water holding capacity between 40 – 50% while finished compost should have 50 – 40% moisture content [33, 34]. In vermicomposting, the temperature below 16^{o}C and above 28^{o}C while moisture content below 25% and above 75% is not fit for the survival and growth of *E. foetida* [35, 36]. Water holding capacity was ranged from 31.35% - 68.38% in the initial feed mixtures.

With the exception of extreme heat or cold, nothing will kill worms faster than a lack of adequate moisture. The water holding capacity less than 40% is dangerous to the worms. Water holding capacity in final compost and vermicompost was ranged from 31.53% - 65.36% and 43.60% - 78.10% respectively. As compare to compost, the water holding capacity increased more in vermicompost due to the turning and aeration of the feed material by the worms. There were little changes in the pH of compost and vermicompost as compared to initial values (Table 3 and Table 4). In composting, the pH decreased from alkaline (7.30 – 7.80) to near neutral (6.96 – 7.30) while in vermicomposting the pH decreased to acidic (6.62 – 6.56) in all feed mixtures. The pH shift towards acidic conditions has been attributed to mineralization of the nitrogen and phosphorus into nitrites/nitrates and orthophosphate; bioconversion of the organic material into intermediate species of organic acids [37].

They have also reported that different substrates result in the production of different intermediate species and hence different wastes show a different behavior in pH shift. Haimi and Hutha [38] 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 worms.

The electrical conductivity (EC) was increased from 6.13% - 15.59% and 27.18% - 33.15% respectively for different feed mixtures after composting and vermicomposting, the variation was significant in vermicomposting among all the feed mixtures. This increase in EC might have been due to loss of organic matter and release of different mineral salts in available form such as phosphate, ammonium, potassium etc. [39]. Gunadi and Edwards [40] have reported that EC and pH of feed could be the limiting factor for survival and growth of *E. foetida.* Mitchell [41] reported that *E. foetida* was unable to survive in any material with pH of 9.5 and EC of 5.0 dsm^{-1}.

Total organic carbon (TOC) of the final compost and vermicompost were remarkably reduced as compared to the initial feed mixtures. There was a loss of 4.76% - 34.45% and 25.40% - 53.41% TOC respectively in different feed mixtures by the end of composting and vermicomposting period. Data revealed that TOC loss was higher (52.31%) in vermicompost in feed mixture no. 7. Further, TOC reduction was inversely related to the PM content in the feed mixtures, i.e. the reduction was maximum for feed mixture no. 11 (53.41%) and minimum for feed mixture no. 1 (25.40%). This finding was supported by other workers [39], who reported 45% loss of carbon during vermicomposting of municipality and industrial wastes. Suthar [30] reported that earthworms promoted such microclimatic conditions in the vermireactors that increased the loss of TOC from substrates through microbial respiration. Whereas Elvira [42] have attributed this loss to the presence of earthworms in the feed mixtures. A significant increase in the total kjeldhal nitrogen (TKN) content occurred following the vermiconversion of FA and PM into vermicompost in different vermireactors.

The initial TKN content of the different mixtures was in the range of 0.13% - 1.28% (Table 2). Total nitrogen (TKN) content increased in the range of 0.10% - 1.52% and 0.16% - 1.81% respectively in different feed mixtures after composting and vermicomposting (Table 3 and 4). There was a gain of 9.09% - 28.88% and 23.08% - 47.36% TKN respectively in different feed mixtures by the end of composting and vermicomposting period. Data revealed that TKN addition was higher (47.36%) in vermicompost in feed mixture no. 10. This confirms that if FA is mixed in appropriate quantities (upto 50% on dry weight basis) with PM, would not have antagonistic impact on the final TKN content of the vermicompost. Other workers have also reported similar observation [42, 43, 44, 45]. According to Viel [46] losses in organic carbon might be responsible for nitrogen addition. However, there are contradictory reports on nitrogen content and its variation in vermicomposting. Ndegwa [37] and Mitchell [41] found no significant difference between total nitrogen concentration in the original substrate and the resulting vermicompost. Where as Parvaresh [47] 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 and chemical composition affects mineralization of nitrogenous organic compounds and the amount of nitrogen from the compounds [48]. A significance increase in the total available phosphorus (TAP) occurred following the vermiconversion of FA and PM into vermicompost in different vermireactors. The initial TAP of the different feed mixtures was in the range of 0.28% - 1.60% (Table 2). TAP increased in the range of 0.28% - 1.90% and 0.34% - 2.37% respectively (Table 3 and 4) in different feed mixtures after composting and vermicomposting. There was a gain of 7.59% - 19.86% and 21.43% - 49.31% TAP respectively in different feed mixtures by the end of composting and vermicomposting period. Data revealed that TAP addition was higher (49.31%) in vermicomposting in feed mixture no. 10.

According to Lee [49], 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 phosphorus to plants is mediated by *phosphatase* produced within the earthworms and further release of phosphorus may be introduced by microorganisms in their casts, after their excretion. Similarly, Ghosh [50] have reported that vermicomposting can be an efficient technology for the transformation of unavailable forms of phosphorus to easily available forms for plants. The initial total potassium (TK) content was in the range of 0.06% - 0.23% in different feed mixtures (Table 2). No significant increase was found in TK content during the composting (Table 3) while TK content was increased in the range of 0.05% - 0.29% (Table 4) in different feed mixtures after vermicomposting. There

was a gain of 14.28% - 31.25% TK in different feed mixtures by the end of vermicomposting period. Data revealed that TK addition was higher (31.25%) in vermicomposting in feed mixture no. 4. Suthar [51] suggested that earthworm processed waste material contains higher concentration of exchangeable potassium due to enhanced microbial activity during the vermicomposting process, which consequently enhances the rate of mineralization. The C: N ratio is used as an index for maturity of organic wastes. As evident from the Table 2, 3 and 4 that C: N ratios decreased with time in the entire worm worked feed mixtures. Initial C: N ratio was in the range of 9.7 – 26.0 at zero day. Final C: N ratios of compost and vermicompost were in the range of 12.0 – 16.6 and 5.9 – 9.5 respectively, depicting the overall decrease of 23.71% - 42.74% and 39.2% - 67.3% respectively after composting and vermicomposting. 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 [52].

So, in the present study, a high degree of organic matter stabilization was achieved in all the feed mixtures of vermicomposting. It was found that there was a rapid decrease in C: N ratio after vermicomposting (Table 4) as compared to the value of C: N ratio in different feed mixtures of composting (Table 3). This demonstrates the role of earthworms in much more rapid decomposition and rate of mineralization of organic matter. The fly ash (FA) was not expected to contain pathogens, however the pressmud (PM) may contain pathogens and therefore microbial analyses was considered essential to assess the safety of the product. The initial samples were found to have a high numbers of faecal coliforms upto 1.7 MPN/g (Table 2). Table 4 showed that faecal coliform levels were low after vermicomposting (upto 0.2 MPN/g). The samples that were only composted, retained high level of pathogens even after 81 days (upto 0.8 MPN/g; Table 3). Thermocomposting (precomposting) prior to vermicomposting was effective in inactivating the pathogens [19, 53].

Table 2: Physico-chemical and Microbiological characteristics of initial feed mixtures

Parameter	Feed mixture No.										
	1	2	3	4	5	6	7	8	9	10	11
Temperature (^{o}C)	18.4 ± 1.6	20.4 ± 1.0	22.8 ± 0.8	26.9 ± 1.9	31.2 ± 1.5	35.4 ± 1.4	39.2 ± 2.8	41.1 ± 1.5	44.5 ± 2.6	46.8 ± 1.8	49.7 ± 1.7
Moisture Content (%) (d/w)	4.30 ± 0.38	9.22 ± 1.31	15.28 ± 1.48	20.28 ± 2.86	28.23 ± 1.83	34.25 ± 3.22	40.14 ± 2.32	46.23 ± 1.88	53.15 ± 2.85	56.39 ± 2.18	63.90 ± 2.33
Water Holding Capacity (%)	31.35 ± 4.30	32.36 ± 3.21	35.62 ± 3.19	43.48 ± 4.67	45.40 ± 2.89	53.68 ± 2.96	55.56 ± 3.87	59.10 ± 2.12	62.07 ± 3.17	64.89 ± 3.30	68.38 ± 2.51
pH	7.30 ± 0.24	7.32 ± 0.25	7.35 ± 0.23	7.41 ± 0.26	7.44 ± 0.24	7.52 ± 0.22	7.59 ± 0.26	7.66 ± 0.28	7.70 ± 0.20	7.73 ± 0.23	7.80 ± 0.28
EC (dS/m)	0.92 ± 0.13	1.02 ± 0.12	1.05 ± 0.03	1.09 ± 0.10	1.21 ± 0.04	1.23 ± 0.09	1.46 ± 0.15	1.58 ± 0.13	1.63 ± 0.06	1.75 ± 0.08	1.81 ± 0.16
Total Organic Carbon (%)	1.26 ± 0.14	4.25 ± 0.15	6.34 ± 0.12	10.51 ± 0.34	13.84 ± 0.29	15.93 ± 1.08	20.72 ± 0.66	24.06 ± 1.19	27.44 ± 1.04	30.63 ± 1.16	33.23 ± 1.06
Total Kjeldhal Nitrogen (%)	0.13 ± 0.04	0.22 ± 0.07	0.31 ± 0.06	0.45 ± 0.03	0.54 ± 0.09	0.69 ± 0.12	0.81 ± 0.07	1.02 ± 0.09	1.09 ± 0.08	1.14 ± 0.15	1.28 ± 0.11
Total Available Phosphorous (%)	0.28 ± 0.03	0.37 ± 0.08	0.51 ± 0.04	0.66 ± 0.06	0.79 ± 0.08	0.95 ± 0.11	1.09 ± 0.08	1.24 ± 0.16	1.40 ± 0.10	1.46 ± 0.06	1.60 ± 0.15
Total Potassium (%)	0.06 ± 0.01	0.07 ± 0.04	0.09 ± 0.02	0.11 ± 0.03	0.12 ± 0.03	0.15 ± 0.02	0.16 ± 0.05	0.18 ± 0.05	0.20 ± 0.03	0.21 ± 0.06	0.23 ± 0.05
C:N ratio	9.69 ± 0.30	19.32 ± 0.21	20.45 ± 0.19	23.35 ± 1.33	25.62 ± 0.62	23.08 ± 0.90	25.58 ± 1.14	23.58 ± 1.10	25.17 ± 0.87	26.86 ± 0.65	25.96 ± 0.96
Fecal Coliforms (MPN/g)	< 0.2 ± 0.2	< 0.2 ± 0.2	0.2 ± 0.2	0.4 ± 0.2	0.4 ± 0.2	0.7 ± 0.2	0.9 ± 0.2	0.9 ± 0.2	0.9 ± 0.2	1.4 ± 0.2	1.7 ± 0.2

Values are means of three replicates ±; Standard deviation

Table 3: Physico-chemical and Microbiological characteristics of final product after composting

Parameter	Feed mixture No.										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Temperature (^oC)	12.8 ± 0.74	13.6 ± 0.68	12.9 ± 0.54	13.8 ± 0.59	17.5 ± 0.57	20.6 ± 1.16	19.9 ± 1.02	23.6 ± 1.35	25.0 ± 1.07	23.3 ± 1.27	30.0 ± 1.33
Moisture Content (%) (d/w)	30.98 ± 1.71	41.25 ± 2.74	40.53 ± 2.20	46.47 ± 2.62	50.93 ± 2.55	53.62 ± 3.28	64.25 ± 4.72	60.55 ± 3.84	60.58 ± 2.53	63.33 ± 3.05	63.50 ± 2.77
Water Holding Capacity (%)	33.34 ± 2.11	31.53 ± 5.23	32.16 ± 5.05	46.72 ± 3.57	58.28 ± 3.88	61.25 ± 4.45	65.36 ± 5.78	60.80 ± 5.14	62.24 ± 4.26	60.20 ± 4.06	62.40 ± 3.65
pH	7.30 ± 0.23	7.30 ± 0.30	7.25 ± 0.20	7.20 ± 0.16	7.28 ± 0.21	7.22 ± 0.26	7.16 ± 0.30	7.11 ± 0.23	7.10 ± 0.26	6.96 ± 0.25	7.07 ± 0.20
EC (dS/m)	0.89 ± 0.11	1.15 ± 0.09	1.20 ± 0.06	1.26 ± 0.10	1.39 ± 0.16	1.50 ± 0.12	1.71 ± 0.15	1.78 ± 0.10	1.73 ± 0.14	1.95 ± 0.15	2.08 ± 0.19
Total Organic Carbon (%)	1.20 ± 0.12	3.66 ± 0.25	4.82 ± 0.24	8.23 ± 0.55	9.27 ± 0.48	11.65 ± 0.50	13.58 ± 0.63	16.30 ± 1.08	20.26 ± 0.84	22.63 ± 0.99	25.51 ± 0.95
Total Kjeldhal Nitrogen (%)	0.10 ± 0.04	0.24 ± 0.02	0.37 ± 0.08	0.58 ± 0.08	0.63 ± 0.05	0.76 ± 0.09	0.93 ± 0.08	1.18 ± 0.21	1.32 ± 0.14	1.36 ± 0.20	1.52 ± 0.16
Total Available Phosphorous (%)	0.28 ± 0.06	0.40 ± 0.05	0.55 ± 0.04	0.74 ± 0.10	0.85 ± 0.06	1.09 ± 0.08	1.25 ± 0.04	1.38 ± 0.08	1.59 ± 0.16	1.75 ± 0.09	1.90 ± 0.12
Total Potassium (%)	0.04 ± 0.01	0.05 ± 0.01	0.08 ± 0.02	0.10 ± 0.02	0.12 ± 0.01	0.13 ± 0.02	0.16 ± 0.04	0.15 ± 0.03	0.19 ± 0.04	0.17 ± 0.03	0.20 ± 0.02
C:N ratio	12.00 ± 0.30	15.25 ± 0.12	13.02 ± 0.28	14.18 ± 0.54	14.71 ± 0.33	15.32 ± 0.45	14.60 ± 0.21	13.81 ± 0.48	16.88 ± 0.56	17.01 ± 0.39	16.78 ± 0.54
Fecal Coliforms (MPN/g)	< 0.2 ± 0.2	< 0.2 ± 0.2	< 0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.4 ± 0.2	0.4 ± 0.2	0.6 ± 0.2	0.8 ± 0.2

Values are means of three replicates ±; Standard deviation

Table 4: Physico-chemical and Microbiological characteristics of final product after vermicomposting

Parameter	Feed mixture No.										
	1	2	3	4	5	6	7	8	9	10	11
Temperature (^{o}C)	15.5 ± 0.54	16.2 ± 0.51	16.5 ± 0.60	18.4 ± 0.63	19.2 ± 0.64	21.5 ± 0.88	22.8 ± 0.83	23.7 ± 0.78	24.5 ± 0.84	24.4 ± 0.93	26.9 ± 0.96
Moisture Content (%) (d/w)	39.20 ± 1.67	43.10 ± 1.75	49.26 ± 1.86	50.08 ± 2.20	62.91 ± 2.54	59.69 ± 2.65	62.42 ± 2.57	59.63 ± 2.36	62.28 ± 1.98	65.85 ± 2.40	65.62 ± 2.34
Water Holding Capacity (%)	43.60 ± 1.93	45.43 ± 1.68	48.52 ± 1.66	53.47 ± 2.17	68.58 ± 2.24	69.63 ± 2.48	73.84 ± 3.60	71.23 ± 2.76	73.80 ± 2.62	74.89 ± 3.25	78.10 ± 2.96
pH	6.62 ± 0.15	6.80 ± 0.25	6.74 ± 0.29	6.82 ± 0.21	6.85 ± 0.32	6.84 ± 0.25	6.80 ± 0.23	6.75 ± 0.21	6.69 ± 0.29	6.62 ± 0.20	6.56 ± 0.24
EC (dS/m)	1.17 ± 0.10	1.39 ± 0.09	1.41 ± 0.05	1.50 ± 0.08	1.73 ± 0.13	1.70 ± 0.09	2.08 ± 0.10	2.18 ± 0.16	2.22 ± 0.08	2.32 ± 0.19	2.41 ± 0.16
Total Organic Carbon (%)	0.94 ± 0.13	2.52 ± 0.15	3.56 ± 0.30	5.97 ± 0.21	7.04 ± 0.20	8.53 ± 0.23	9.88 ± 0.18	12.33 ± 0.13	14.08 ± 0.23	14.92 ± 0.31	15.48 ± 0.29
Total Kjeldhal Nitrogen (%)	0.16 ± 0.03	0.30 ± 0.02	0.42 ± 0.03	0.63 ± 0.07	0.77 ± 0.04	0.96 ± 0.03	1.19 ± 0.09	1.44 ± 0.05	1.53 ± 0.11	1.68 ± 0.06	1.81 ± 0.10
Total Available Phosphorous (%)	0.34 ± 0.05	0.46 ± 0.08	0.63 ± 0.03	0.87 ± 0.07	1.07 ± 0.09	1.22 ± 0.04	1.56 ± 0.10	1.71 ± 0.07	1.93 ± 0.16	2.18 ± 0.09	2.37 ± 0.14
Total Potassium (%)	0.05 ± 0.01	0.08 ± 0.01	0.11 ± 0.03	0.14 ± 0.01	0.14 ± 0.02	0.19 ± 0.02	0.21 ± 0.05	0.23 ± 0.02	0.24 ± 0.03	0.26 ± 0.05	0.29 ± 0.03
C:N ratio	5.87 ± 0.14	8.40 ± 0.17	8.47 ± 0.10	9.47 ± 0.30	9.14 ± 0.53	8.88 ± 0.21	8.30 ± 0.28	8.56 ± 0.20	9.20 ± 0.26	8.88 ± 0.45	8.55 ± 0.30
Fecal Coliforms (MPN/g)	< 0.2 ± 0.2	< 0.2 ± 0.2	< 0.2 ± 0.2	< 0.2 ±0.2	< 0.2 ± 0.2	< 0.2 ± 0.2	< 0.2 ± 0.2	< 0.2 ± 0.2	< 0.2 ± 0.2	< 0.2 ± 0.2	0.2 ± 0.2

Values are means of three replicates ±; Standard deviation

Biomass growth and cocoon production of *Eisenia foetida:* *Eisenia foetida* could not tolerate the 100% fly ash. Addition of some other organic waste was essential for the survival of the earthworms in the fly ash. The biomass production by *E. foetida* in different mixtures has been given in Figure 1. The net weight gain by *E. foetida* was highest (859 mg earthworm^{-1}) in feed mixture no. 11 and lowest (364 mg earthworm^{-1}) in feed mixture no. 1. Increasing percentage of PM in the feed mixtures promoted the increase in biomass gain by *E. foetida.* 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 [54]. The fastest growth rate (9.58 mg worm^{-1} day^{-1}) was observed in feed mixture no. 11 (Figure 2) where as feed mixture no. 1 supported the least growth (1.18 mg worm^{-1} day^{-1}). The total number of cocoons after 60 days in different feed mixtures has been represented in Figure 3. The maximum no. of cocoons was observed in feed mixture no. 11 and minimum were in feed mixture no. 4. It is evident from the figure 3 that the cocoons production was directly related to PM concentration in the studied feed mixtures. Similarly, the total number of juveniles was highest in feed mixture no. 11 and lowest in feed mixture no. 4. The results suggest that addition of FA in PM is not suitable for earthworm production (vermiculture) as the cocoon production is lesser if FA is present in the earthworm feed. Data revealed that number of cocoons and juveniles were not significant in feed mixture no. 1, 2 and 3 (Figure 3). The difference between biomass and cocoon production in different feed mixtures could be related to the biochemical quality of the feed, which was one of the important factors in determining onset of cocoon production [55, 56]. Suthar [51] 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 40% fly ash to the pressmud is acceptable during the vermicomposting of FA in terms of fertilizer quality of the vermicompost so obtained. But if prime concern is vermiculture (production of earthworms), then addition of FA in the PM is not suggested.

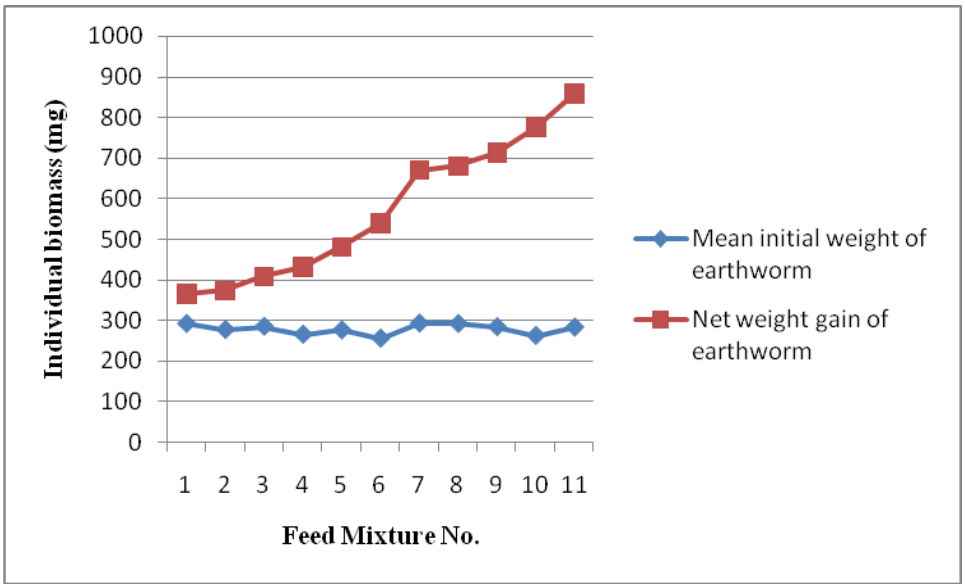

Figure 1: Growth curve of *Eisenia foetida* in different feed mixtures

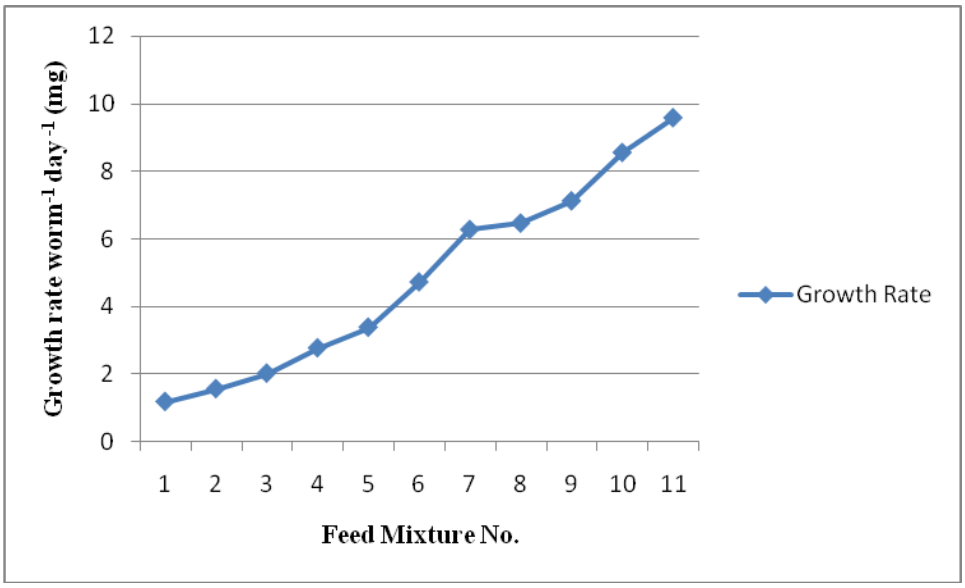

Figure 2: Growth rate of *Eisenia foetida* in different feed mixtures

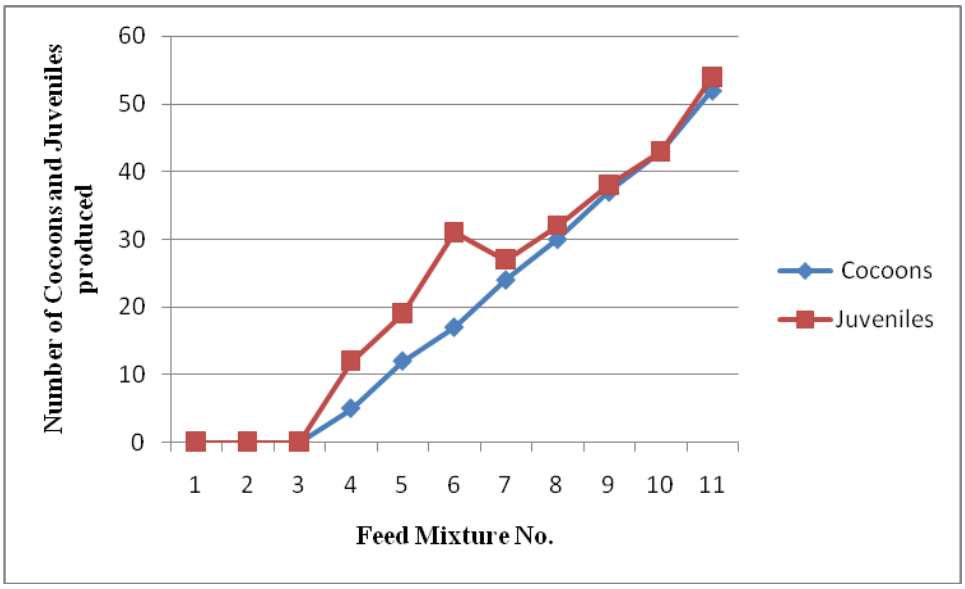

Figure 3: Total cocoons and juveniles produced by *Eisenia foetida* in different feed mixtures

Conclusion

Disposal of fly ash by environmentally acceptable means is a serious problem. Our trials have demonstrated the clear differences in the final composition of composts and vermicomposts. The PM amended FA subjected to composting did not differ significantly from the vermicompost. In addition, vermicomposting appeared to modify the degrading activity of the PM amended FA to a much greater extent than the composting. In the present study, the vermicomposting of FA amended with PM resulted in the conversion of a waste into value added product i.e. vermicompost. A high degree of FA stabilization was achieved after 60 days of worm activity. The results indicated that after the addition of FA in

appropriate quantity (upto 40%) to the PM, it can be used as a raw material in the vermicomposting. The fertilizer quality of FA based vermicomposts was almost equal to control (prepared by using the pressmud only). But addition of FA in the PM is not suggested if prime concern is vermiculture (production of earthworms) as the cocoon production is lesser if FA is present in the earthworm feed. From the current study, we can safely conclude that vermicomposting can be an alternate technology for the management of pressmud amended fly ash and made the vermicompost more suitable for agronomic purposes.

Acknowledgement

We would like to thank Dr. Ranjeev Kumar Sahu, Assisstant Registrar at Dr. Bhim Rao Ambedkar University, Lucknow, India for providing the research idea and for assistance with the statistics. This work was conducted at C.S.J.M. University, Kanpur, India.

References

1. International Solid Wastes Association and United Nations Environment Programme (ISWA and UNEP) Wastes Management: Industry as a Partner for Sustainable Development, 92(807), **(2002).**

2. Raman S., Patel A.M., Shah G.B. and Kaswala R.R., Feasibility of some industrial waste for soil improvement and crop production, J. Indian Soc. Soil Sci. 44, 147-150. **(1996).**

3. Mendki P.S., Maheshwari V.L. and Kothari R.M., Flyash as a post-harvest preservative for five commonly utilized pulses, Crop Protection. 20, 241-245. **(2000).**

4. Jamil S., Abhilash P.C., Singh N. and Sharma PN., Jatropha curcas: a potential crop for phytoremediation of coal fly ash, J. Hazard. Mater. 172(1), 269-275. **(2009).**

5. Wong J.W. and Selvam A., Growth and elemental accumulation of plants grown in acidic soil amended with coal fly ash-sewage sludge co-compost, Arch. Environ. Contam. Toxicol. 57(3), 515-523. **(2009).**

6. Rautaray S.K., Ghosh B.C. and Mittra B.N., Effect of fly ash, organic wastes and chemical fertilizer on yield, nutrient uptake, heavy metal content and residual fertility in a rice-mustard cropping sequence under acid lateritic soils, Bioresour. Technol. 90(3), 275-283. **(2003).**

7. Roy G. and Joy V.C., Dose-related effect of fly ash on edaphic properties in laterite cropland soil, Ecotoxicol. Environ. Saf. 74(4), 769-775. **(2011).**

8. Lee H., Ha H.S., Lee C.H., Lee Y.B. and Kim P.J., Fly ash effect on improving soil properties and rice productivity in Korean paddy soils, Bioresource Technol. 97(13), 1490-1497. **(2006).**

9. Campbell D.J., Fox W.E., Aitken R.L. and Bell L.C., Physical characteristics of sands amended with fly ash, Aust. J. Soils Res. 21,147–154. **(1983).**

10. Lin H.C., Tseng L.L., Kuo S., Su Y.H. and Chai M.H., Fertilizer characteristics of fly ash, J. Agric. Assoc. China. 121, 57–65. **(1983).**

11. Pandey V.C., Abhilash P.C., Upadhyay R.N. and Tewari D.D., Application of fly ash on the growth performance and translocation of toxic heavy metals within Cajanus cajan L.: implication for safe utilization of fly ash for agricultural production, J. Hazard. Mater. 166(1), 255-259. **(2009).**

12. Gupta A.K. and Sinha S., Growth and metal accumulation response of Vigna radiate L. var PDM 54 (mung bean) grown on fly ash-amended soil: effect on dietary intake, Environ. Geochem. Health. 31(4), 463-473. **(2009).**

13. Kumar R., Verma D., Singh B.L., Kumar U. and Shweta., Composting of sugar-cane waste by-products through treatment with microorganisms and subsequent vermicomposting, Bioresour. Technol. 101(17), 6707-6711. **(2010).**

14. Raj D. and Antil R.S., Evaluation of maturity and stability parameters of composts prepared from agro-industrial wastes, Bioresour. Technol. 102(3), 2868-2873. **(2011).**

15. Lung A.J., Lin C.M., Kim J.M., Marshall M.R., Nordstedt R., Thompson N.P. and Wei C.I., Destruction of Escherichia coli O157:H7 and Salmonella enteritidis in cow manure composting, J. Food Protect. 64, 1309–1314. **(2001).**

16. Eghball B., Power J.F., Gilley J.E. and Doran J.W., Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure, J. Environ. Qual. 26, 189–193. **(1997).**

17. Domínguez J., Edwards C.A. and Subler S., A comparison of composting and vermicomposting, Biocycle. 4, 57–59. **(1997).**

18. Lores M., Gómez-Brandón M., Pérez D. and Domínguez J., Using FAME profiles for the characterization of animal wastes and vermicomposts, Soil Biol. Biochem. 38, 2993–2996. **(2006).**

19. Nair J., Sekiozoic V. and Anda M., Effects of pre-composting on vermicomposting of kitchen waste, Bioresour. Technol. 97(16), 2091-2095. **(2006).**

20. Frederickson J., Butt K., Morris R.M. and Daniel C., Combining vermiculture with traditional green waste composting systems, Soil Biol. Biochem. 29, 725–730. **(1997).**

21. Ndegwa P.M. and Thompson S.A., Integrating composting and vermicomposting in the treatment and bioconversion of biosolids, Bioresource Technol. 76, 107– 112. **(2001).**

22. Tognetti C., Laos F., Mazzarino M.J. and Hernández M.T., Composting vs. vermicomposting: a comparison of end product quality, Compost Sci. Util. 13, 6–13. **(2005).**

23. Tognetti C., Mazzarino M.J. and Laos F., Cocomposting biosolids and municipal organic waste: effects of process management on stabilization and quality, Biol. Fertil. Soils. 43, 387–397. **(2007).**

24. Wu L. and Ma LQ., Effects of sample storage on biosolids compost stability and maturity evaluation, J. Environ. Quality. 30, 222–228. **(2001).**

25. FCQAO (Federal Compost Quality Assurance Organization)., Methods Book for the Analysis of Compost. Kompost-Information Nr. 230. Budesgutegemeinschaft Kompost e.V. English translation by Bidlingmaier W, Univ. of Essen, Germany, 199 **(1994).**

26. Walkley A. and Black I.A., Chromic acid titration for determination of soil organic matter, Soil Sci. 63, 251 **(1934).**

27. Singh R. and Pradhan K., Determination of nitrogen and protein by Khjeldahl method, In: Forage Evaluation Science Pvt. Publishers Ltd. New Delhi, India, 23 **(1981).**

28. Bray R.H. and Krutz L.K., Determination of total organic and available forms of phosphorous in soil, Soil Sci. 59, 39–45. **(1945).**

29. U.S. ENVIRONMENTAL PROTECTION AGENCY., National primary drinking water regulations: analytical techniques; coliform bacteria; final rule, Federal Register, 54(135), 29998. **(1989).**

30. Suthar S., Potential utilization of Guar gum industrial waste in vermicompost production, Bioresour. Technol. 97, 2474–2477. **(2006).**

31. Strom P.F., Effect of temperature on bacterial species diversity in thermophilic waste composting, Applied and Environmental Microbiology. 50, 899-905. **(1985).**

32. Hellmann B., Zelles L., Palojarvi A. and Bai Q., Emissions of climate-relevant trace gases and succession of microbial communities during open-windrow composting, Applied and Environmental Microbiology. 63, 1011-1018. **(1997).**

33. Boulter J.I., Boland G.J. and Trevors J.T., Compost: a study of the development process and end-product potential for suppression of turfgrass disease, World J. Microbiol. Biotechnol. 16, 115-134. **(2000).**

34. Gómez-Brandón M., Lazcano C. and Domínguez J., The evaluation of stability and maturity during the composting of cattle manure, Chemosphere. 70, 436– 444. **(2008).**

35. Devi S.H., Vijayalakshmi K., Jyotsna K.P., Shaheen S.K., Jyothi K. and Rani M.S., Comparative assessment in enzyme activities and microbial populations during normal and vermicomposting, J. Environ. Biol. 30(6), 1013-1017. **(2009).**

36. Fernandez-Gomez M.J., Romero E. and Nogales R., Feasibility of vermicomposting for vegetable greenhouse waste recycling, Bioresource Technol. 101(24), 9654-9660. **(2010).**

37. Ndegwa P.M., Thompson S.A. and Das K.C., Effects of stocking density and feeding rate on vermicomposting of biosolids, Bioresour. Technol. 71(1), 5-12. **(2000).**

38. Haimi J. and Hutha V., Capacity of various organic residues to support adequate earthworm biomass in vermicomposting, Biol. Fertil. Soil. 2, 23–27. **(1986).**

39. Kaviraj and Sharma S., Municipal solid waste management through vermicomposting employing exotic and local species of earthworms, Bioresour. Technol. 90, 169–173. **(2003).**

40. Gunadi B. and Edwards C.A., The effect of multiple application of different organic wastes on the growth, fecundity and survival of Eisenia fetida, Pedobiologia. 47, 321–330. **(2003).**

41. Mitchell A., Production of Eisenia foetida and vermicompost from feedlot cattle manure, Soil Biol. Biochem. 29, 763–766. **(1997).**

42. Elvira C., Goicoechea M., Sampdro L., Mato S. and Nogales R., Bioconversion of solid paper-pulp mill sludge by earthworms, Bioresour. Technol. 75, 173–177. **(1996).**

43. Bansal S. and Kapoor K.K., Vermicomposting of crop residues and cattle dung with Eisenia foetida, Bioresour. Technol. 73, 95–98. **(2000).**

44. Atiyeh R.M., Dominguez J., Subler S. and Edwards C.A., Changes in biochemical properties of cow manure during processing by earthworms (Eisenia Andrei Bouche) and the effects on seedling growth, Pedobiologia. 44, 709-724. **(2000).**

45. Wang L., Zhang Y., Lian J., Chao J., Gao Y., Yang F. and Zhang L., Impact of fly ash and phosphatic rock on metal stabilization and bioavailability during sewage sludge vermicomposting. Bioresour. Technol. 136, 281-287. **(2013).**

46. Viel M., Sayag D. and Andre L., Optimization of agricultural, industrial waste management through in-vessel composting. In: de Bertoldi M. (ed.) Compost: Production, Quality and Use. Elsevier Sci. Essex. 230–237. **(1987).**

47. Parveresh A., Movahedian H. and Hamidian L., Vermistabilization of Municipal Wastewater Sludge with Eisenia foetida, Iranian J. Environ. Health Sci. Eng. 1(2), 43-50. **(2004).**

48. Bohlen P.J., Parmelee R.W., Allen M.F. and Ketterings G.M., Differential effects of earthworms on Nitrogen cycing from various Nitrogen 15 labelled substrate, Am. J. Soil Sci. Soc. 63, 882-890. **(1999).**

49. Lee K.E., Some trends and opportunities in earthworm research, Soil Biol. Biochem. 24, 1765–1771. **(1992).**

50. Ghosh M., Chattopadhyay G.N. and Baral K., Transformation of phosphorus during vermicomposting, Bioresour. Technol. 69, 149–154. **(1999).**

51. Suthar S., Nutrient changes and biodynamics of epigeic earthworm Perionyx excavatus (Perrier) during recycling of some agriculture wastes, Bioresour. Technol. 98(8), 1608-1614. **(2007).**

52. Senesi N., Composted materials as organic fertilizers, Sci. Total Environ. 82, 521–524. **(1989).**

53. Kumar V.V., Shanmugaprakash M., Aravind J. and Namasivayam S.K., Pilot-scale study of efficient vermicomposting of agro-industrial wastes, Environ. Technol. 33(7), 975-981. **(2012).**

54. Edwards C.A., Dominguez J. and Neuhauser E.F., Growth and reproduction of Parionyx excavatus (Perr.) (Megascolecidae) as factors in organic waste management, Biol. Fertil. Soils. 27, 155–161. **(1998).**

55. Majlessi M., Eslami A., Najafi Saleh H., Mirshafieean S. and Babaii S., Vermicomposting of food waste: assessing the stability and maturity, Iranian J. Environ. Health Sci. Eng. 9(1), 25-33. **(2012).**

56. Molina M.J., Soriano M.D., Ingelmo F. and Llinares J., Stabilisation of sewage sludge and vinasse bio-wastes by vermicomposting with rabbit manure using Eisenia fetida, Bioresour. Technol. 137, 88-97. **(2013).**