POTENTIAL OF *EISENIA FOETIDA* FOR SUSTAINABLE AND EFFICIENT VERMICOMPOSTING OF FLY ASH

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Abstract. Vermicomposting of fly ash has been attempted, using red earthworm, *Eisenia foetida*. Fly ash, which was obtained from thermal power station, was mixed with cowdung in different proportions (20, 40, 60 and 80%). These mixtures were used as feed for earthworms, and after 30 days, vermicast recovery, worm zoomass and numbers of juveniles produced were recorded. A total of six runs each of 30 days were conducted during the whole study. Concentrations of heavy metals in different mixtures of fly ash–cowdung, before and after vermicomposting and in the earthworms used in the study were also estimated. Results show maximum output of vermicasts and maximum number of juveniles produced was in reactors with 40% fly ash while maximum weight gain by earthworm was in 20% fly ash vermireactors. Performance of vermireactors up to 60% fly ash was more or less similar but at 80% fly ash, there is a marked reduction in overall performance of the reactors. Chemical analysis of different samples of fly ash–cowdung mixtures prior to vermicomposting revealed high concentrations of zinc, chromium, lead, nickel and copper. Chemical analysis of vermicomposted samples showed 30–50% reduction in heavy metals up to 60% fly ash and 10–30% reduction in 80% fly ash. Metal analysis of earthworms revealed considerable bioaccumulation of heavy metals in their body. The Present study indicates the feasibility of *E. foetida* for mitigating the toxicity of metals and up to 60% fly ash–cowdung mixtures can be used for sustainable and efficient vermicomposting.

Keywords: *Eisenia foetida*, fly ash, heavy metals, vermicomposting

1. Introduction

Fly ash, which contains silica, aluminium, oxides of iron, calcium, magnesium, arsenic, chromium, lead, zinc, nickel and other toxic metals is a by-product of coal-fired electricity generation plants. Fly ash is a serious source of air pollution since it remains air borne for a long period of time and causes health hazards (T.E.R.I., 1998). Besides being a health hazard, fly ash also degrades the environment. It clogs natural drainage and reduces the pH and potability of water, making it turbid. Fly ash interferes with the photosynthesis of aquatic plants and thus disturbs the food chain. Fly ash poses a serious problem for its disposal. The magnitude of the problem is evident from the fact that fly ash generated during 2000–2001 was about 150 million tonnes in India. To prevent fly ash from being air borne, the dumping ground needs to be kept wet all time. Thermal power plants in India are reportedly spending seven billion rupees annually on this activity.

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 (Mulford and Martens, 1971; Giedrojc *et al*., 1980), a liming material (Hoodgsen *et al*., 1982) and as a physical amendment (Campbell *et al*., 1983) have been indicated. Soil application of fly ash waste has been associated with both the favourable (Lin *et al*., 1983) as well as adverse (Mulford and Martens, 1971) 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 (Lobi *et al*., 1971). However, in India where 150 million tones of fly ash is produced annually, there is an urgent need to develop methods for use of fly ash, on a small scale as well as on a large scale. Each new application has to be evaluated from the environmental point of view.

Some species of earthworms are known to be potential accumulators of heavy metals and therefore they have been successfully demonstrated in mitigating the toxicity of industrial and municipal waste by vermicomposting technology (Saxena *et al*., 1998). Keeping this view in mind, in the current study, vermicomposting of fly ash has been attempted. The advantages of this utilization option are (a) it is capable of handling very low to very high quantities of fly ash, (b) it is simple and cost-effective, thus appropriate for small scale as well as for large scale utilization and (c) the vermicasts have a very popular and ready markets as enrichers of soil (Abbasi and Ramasamy, 1999; Ismail, 1997). Vermicasts are believed to have several components which improve the soil to which they are applied (Kumar, 1994). Vermicasts are also believed to contain enzymes and hormones that stimulate plant growth and discourage pathogens (Abbasi and Ramasamy, 1999; Szczeck, 1999). The main objectives of the present study were i) to find out the appropriate proportion of fly ash–cowdung for sustainable and efficient vermicomposting, ii) to analyze the heavy metal status in fly ash mixtures before and after vermicomposting, and iii) to determine the concentration of heavy metals accumulated in earthworm tissues.

2. Material and Methods

2.1. Fly ash – cowdung mixtures

Fly ash was procured from a thermal power station, while cowdung was obtained from nearby villages. The fly ash in 20, 40, 60 and 80% (w/w) was thoroughly mixed with cowdung. All these fly ash–cowdung mixtures were maintained at 60% moisture content with tap water.

2.2. Vermicomposting of fly ash mixtures

Circular 9 L plastic containers (dia 25 cm, depth 18 cm) were filled from bottom up with successive layers of sawdust, river sand and garden soil of depths of 1, 2 and 4 cm, respectively. The reactors, all runs in duplicates were started with 2 kg of feed consisting of different proportions of fly ash in cowdung (20–80%). In each reactor, 125 healthy and adult animals of *Eisenia foetida* of our own culture were introduced. The vermireactors were moistened by sprinkling the required quantities of water. All quantities of feed and castings reported represent dry weight (taken after oven drying at 105 °C to constant weight). The earthworm biomass is reported as live weight, taken after rinsing adhering material off the worms and blotting them dry. The castings were carefully sieved to separate other particles and dried (105 °C) to a constant weight.

After 30 days, the castings and the earthworms were kept in separate containers for quantification while the rest of the reactor contents were discarded. The juveniles, if any, generated in the previous run, were separated, and the 125 worms with which the reactors had been started, were weighed and reintroduced into the freshly prepared reactors. It was very easy to distinguish “parent” worms as they were much larger in size than the juveniles produced during the run. All subsequent measurements were taken once in 30 days in the manner described above, resetting the vermireactors each time so that the same sets of worm with which the rectors were started continued to be the principal producers of vermicasts. A total of six runs each of 30 days were conducted during the whole study.

2.3. Metal estimation

At the end of the sixth run, heavy metal concentrations in the pre- and post-vermicomposted samples and in the earthworm tissues were estimated. The earthworms were rinsed free of soil particles and starved on moistened filter paper for 5 days to eliminate the organic and inorganic content of the alimentary canals. They were then oven dried at 65 °C for 4 days and crushed. All samples of known weight were wet digested in a mixture of $HClO_4$:HNO_3 (1:6 v/v) till a white residue remain at the bottom. This residue was then dissolve in 0.1N HNO_3 (Berman, 1980). The concentrations of Cr, Cu, Pb, Ni and Zn were determined with an inductively coupled plasma emission spectrometry system (ICP, Labtam Plasmalab, 8440).

3. Results and Discussion

3.1. Performance of vermireactors

The performance of vermireactors with different proportions of fly ash in terms of vermicast output, worm zoomass and number of juveniles produced during the study period is summarized in Tables I–IV. Since there was good agreement among the repeat vermireactors, only the average values of duplicate have been reported in these tables. In vermireactors with 20% of feed as fly ash, the average vermicast

TABLE I

Performance of *E. foetida* with 20% fly ash

Days	Vermicast recovery (g)	Mean worm zoomass (g)	No. of juveniles produced
30	1300.6 ± 11.7	115.2 ± 2.7	124 ± 7.7
60	1340.2 ± 8.3	127.7 ± 4.6	133 ± 4.1
90	1358.0 ± 5.1	135.9 ± 3.6	137 ± 4.1
120	1328.0 ± 6.1	148.3 ± 4.9	130 ± 3.7
150	1346.0 ± 6.8	151.7 ± 4.6	135 ± 3.0
180	1364.9 ± 7.3	159.4 ± 4.4	138 ± 2.8
Average	1339.6	139.7	133

Mean value of 2 replicates ± S.E.

TABLE II

Performance of *E. foetida* with 40% fly ash

Days	Vermicast recovery (g)	Mean worm zoomass (g)	No. of juveniles produced
30	1296.6 ± 10.3	112.4 ± 3.7	130 ± 5.7
60	1318.2 ± 8.7	124.9 ± 4.1	142 ± 6.1
90	1357.4 ± 5.7	133.7 ± 4.4	143 ± 6.3
120	1359.8 ± 6.4	147.4 ± 5.0	139 ± 4.8
150	1368.6 ± 7.4	149.9 ± 4.7	134 ± 3.1
180	1374.2 ± 4.9	158.9 ± 3.9	139 ± 4.3
Average	1345.8	137.8	137.8

Mean value of 2 replicates ± S.E.

TABLE III

Performance of *E. foetida* with 60% fly ash

Days	Vermicast recovery (g)	Mean worm zoomass (g)	No. of juveniles produced
30	1269.0 ± 10.4	107.9 ± 4.7	128 ± 4.1
60	1327.4 ± 7.4	119.3 ± 5.1	137 ± 3.4
90	1354.8 ± 8.5	124.8 ± 4.6	133 ± 2.7
120	1347.6 ± 7.9	132.6 ± 4.3	134 ± 3.5
150	1361.8 ± 6.3	140.8 ± 3.8	129 ± 2.4
180	1377.4 ± 7.1	146.1 ± 6.1	131 ± 2.1
Average	1339.6	128.5	132

Mean value of 2 replicates ± S.E.

output during each run was 1339.6 g while the average zoomass was 139.7 g and average number of juveniles produced during each run was 132.8. In vermireactors with 40% fly ash these values are 1345.8 g, 137.8 g and 137.8 respectively. Similarly, the average vermicast output, average worm zoomass and average number of

TABLE IV

Performance of *E. foetida* with 80% of feed as fly ash

Days	Vermicast recovery (g)	Mean worm zoomass (g)	No. of juveniles produced
30	1118.2 ± 7.8	109.4 ± 3.8	121 ± 2.1
60	1164.6 ± 9.4	113.2 ± 4.1	114 ± 2.4
90	1093.4 ± 11.7	101.3 ± 2.7	97 ± 3.3
120	1042.6 ± 8.4	94.5 ± 4.3	91 ± 1.7
150	1025.0 ± 9.7	85.9 ± 3.8	79 ± 2.9
180	1004.2 ± 6.6	73.1 ± 1.9	58 ± 1.8
Average	1074.6	96.23	93.3

Mean value of 2 replicates ± S.E.

juveniles produced during each run was 1339.6 g, 128.5 g and 132 with 60% fly ash and 1074.6 g, 96.23 g and 93.3 with 80% fly ash respectively.

From Tables I–IV, it is clear that the maximum output of vermicasts and maximum number of juveniles produced was in reactor with 40% fly ash while maximum weight gain by earthworm was in 20% fly ash vermireactors. Performance of vermireactors containing 20, 40 and 60% fly ash was more or less similar, but as the concentration of fly ash was increased from 60 to 80%, there is marked reduction in overall performance of the reactor. In reactors with 80% fly ash, there was 19.7% reduction in average vermicast output, 24.0% reduction in average worm zoomass and 29.3% reduction in average number of juveniles produced as compared to reactors containing 60% fly ash.

3.2. Heavy metals in different samples

Heavy metal status in cowdung and fly ash used in this study are summarized in Table V. Table VI shows the heavy metal status in different mixtures of fly ash and cowdung before vermicomposting. The results show elevation of metal

TABLE V

Heavy metal concentrations (mg/kg) in cowdung and fly ash used in this study

Metals	Cowdung	Fly ash
Cr	5.3	101.7
Cu	10.7	68.3
Ni	0.8	78.1
Pb	1.1	86.9
Zn	12.1	113.7

TABLE VI

Concentrations of different heavy metals in different proportions of fly ash:cowdung mixtures before vermicomposting

	Concentration of metals (mg/kg) in diff. ratios of fly ash:cowdung			
Metals	20%	40%	60%	80%
Cr	23.7	42.7	62.1	81.3
Cu	22.1	33.3	42.8	57.9
Ni	15.7	31.0	46.3	62.6
Pb	17.7	34.9	53.1	68.3
Zn	33.4	53.7	72.8	93.7

TABLE VII

Concentrations of different heavy metals in vermicast samples after vermicomposting

	Concentration of metals (mg/kg)			
Metals	20%	40%	60%	80%
Cr	12.8	24.1	36.8	60.9
Cu	13.9	21.2	27.8	51.1
Ni	10.1	19.3	24.4	53.7
Pb	9.9	20.6	28.9	54.5
Zn	17.6	28.1	38.4	72.1

concentrations with increase in fly ash proportions. Zn was present in highest concentrations in all mixtures followed by Cr, Pb, Ni and Cu. Postvermicomposted samples analysis revealed considerable decline in metal concentrations in all vermireactors except in vermireactors with 80% fly ash (Table VII). In reactors with 20, 40 and 60% fly ash, all the heavy metals were found to be declined from 30 to 50%, but in reactors with 80% fly ash, the decrease was only 10–30%.

Results from chemical analysis of earthworms revealed considerable accumulation of heavy metals in their body (Table VIII). When the concentration factors (CF) were calculated in relation to the total metal concentrations in different fly ash–cowdung mixtures, the highest value came from Zn. In this case, the CF were higher than 1 for Zn, Pb and Cr but lower than 1 for Cu and Ni in mixtures upto 60% fly ash, whereas in earthworms from 80% fly ash vermireactors the CF were lower than 1 for all metals except Zn, for which CF here is also greater than 1.

The average vermicast recovery was low during the first run, in all types of reactors indicating that the earthworms, which had been cultured with cowdung as the principal feed, took some time to acclimatize with the change over to fly ash as feed. After first run there is an increase in average vermicast recovery in

TABLE VIII

Heavy metals accumulated by earthworms reared in different proportions of fly ash:cowdung mixtures

Metals	Concentrations of metals (mg/kg dry weight)			
	20%	40%	60%	80%
Cr	26.45	52.9	73.7	79.3
Cu	7.49	12.9	14.6	21.1
Ni	11.7	25.1	38.2	43.4
Pb	21.1	41.8	55.7	52.6
Zn	70.14	102.8	130.3	140.1

all reactors except reactors containing 80% fly ash. In reactors with 80% fly ash, after second run there is gradual decrease in average vermicast output This may be due to chronic toxicity of some heavy metals present in the fly ash. This chronic toxicity in earthworm is also seen in the average zoomass data where there is gradual increase in average zoomass in all types of reactors except reactors containing 80% fly ash, but there was no mortality in any of the reactors during the whole study. Average number of juveniles produced in each run are nearly constant in reactors with 20, 40 and 60% fly ash, but in reactors with 80% fly ash number of juveniles produced during each run decreased by 52% at the end of sixth run. This may be due to the action of some heavy metals like Cr, Pb and Cu present in the fly ash. Cu alters the physiology of protein by reacting with thiol group of membrane proteins and labilizes cellular membranes (Aesth *et al*., 1986; Scheinberg, 1992). Since the cocoon membrane becomes permeable, a large proportion of copper ions may enter the cocoon by diffusion and interact with the proteinaceous material filled inside the cocoon as a reserve for developing embryos. Chromium ions also reduce the electrical potential across the cell membrane causing reduced capability to transport essential metabolites (Brun *et al*., 1987) and this may also be the cause of toxicity to the developing embryo. In earthworm, lead is accumulated in muscles, nerve cord, cerebral ganglion, seminal vesicles and chloragocytes. At the time of cocoon production, the lead of clitellar muscles may pass to cocoon or bio-available lead may enter the cocoon and disturb the development of the embryo. It is clear that reactors containing maximum up to 60% of feed as fly ash performs good in terms of vermicast output, worm zoomass and number of juveniles produced, but when the fly ash constitutes 80% of feed, there is gradual decline in the performance of vermireactors.

The results from chemical analysis of fly ash samples, consistent to previous findings, indicated the considerable concentrations of heavy metals like Pb, Ni, Cr, Cu and Zn (Chang *et al*., 1977; Kuiker *et al*., 1994; Su and Wong, 2002). Such a high percentage of heavy metals in fly ash may reach human beings through plants and can cause serious adverse effects (I.A.R.C., 1980, 1987, 1990).

Chemical analysis of vermicomposted samples displayed considerable reduction in heavy metals concentrations, particularly up to 60% fly ash mixtures and moderate reduction was observed at 80% fly ash mixture (Figure 1). Metal estimation in earthworm's body also revealed considerable accumulation of heavy metals in their tissues. The highest concentration factors occurred for Zn and Pb (Figure 2).

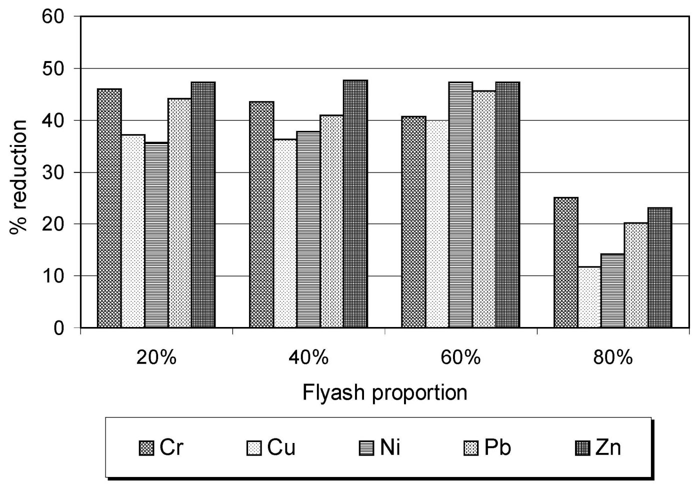

Figure 1. % reduction of heavy metals in different ratios of flyash-cowdung mixture after vermicomposting.

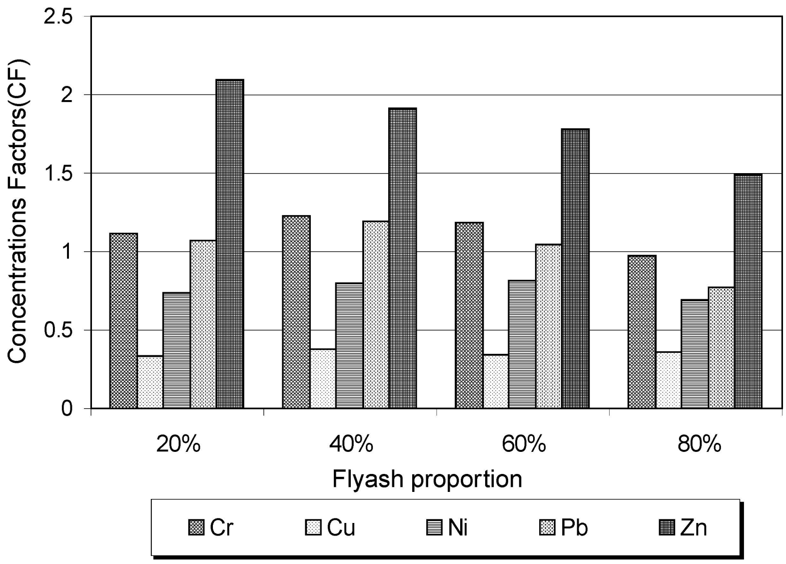

Figure 2. Concentration factors of different heavy metals accumulated in earthworm body in relation to metal concentrations in flyash-cowdung mixtures.

Previous reports available on the metal accumulation ability of earthworms state that the metals like Cu and Ni are not bioaccumulated by the earthworms (Barerra, 2001), but present results indicated considerable bioaccumulation of these metals in earthworms. From the current study it is clear that the use of *E. foetida* to mitigate toxicity of metals seems to be feasible technology and up to 60% fly ash–cowdung mixtures can be used for sustainable and efficient vermicomposting, without showing any toxicity to earthworms. However, further research on the effects of vermicomposting of such waste on the bioavailability of heavy metals should be carried out before utilizing this option for fly ash waste management.

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