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Research

VERMISTABILIZATION OF THERMAL POWER PLANT FLY ASH USING *EISENIA FETIDA*

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ABSTRACT

Present work provides an opportunity to utilize the potential to bioconversion and recovering nutrients from thermal power plant fly ash with the help of earthworm *Eisenia fetida*. The fly ash (FA) was mixed with cattle dung (CD) with and without earthworms at different proportions 0:100, 25:75, 50:50, 75:25 and 100:0. In all these proportions changes in physico-chemical properties and population growth of earthworms were observed. Minimum mortality and maximum population buildup of earthworm were observed in 25:75 mixture. Vermistabilization caused decrease in pH (8.0% to 15.7%), electrical conductivity (16.2% to 53.6%), total organic carbon (15.6% to 32.5%) and C:N ratio (43.2% to 97.4%). A significant range of increase in total potassium (6.2% to 58.9%), total available phosphate (33.0% to 53.2%) and total nitrogen (43.4% to 92.7%) was observed after conversion by earthworms. Reduction of heavy metals Cu (24.6% to 45.9%), Pb (28.8% to 38.3%), Mn (19.3% to 35.4%) and Cr (15.7% to 40.0%) was also observed at variable range in the end products of feed mixtures with earthworms. Earthworms increase the plant available nutrients and mitigate the metal toxicity in the fly ash. Vermiconversion might be useful in efficient management of hazardous solid waste produced from thermal power plants.

INTRODUCTION

In India 60% to 75% of electricity production is dependent upon coal based thermal power plants. At present about 120 thermal power plants are in operational condition and produce 150 MT per year fly ash and are further expected to produce 440 MT per year by 2030 (Ram, *et al*., 2008). Present level of atmospheric pollution in many urban areas is so high that there is a severe threat to the public health. Fly ash is one of most concerning air pollutants due to its resistivity in air and its toxic nature. Fly ash disturbs the natural food chain of terrestrial and aquatic plants of surrounding area of thermal power plants by interference with photosynthesis process. In India for proper management and safe disposal of fly ash, commissioned a "Fly Ash Mission" in 1994 under the department of science and technology, but the government has been unable to tackle the menace of fly ash pollution due to dearth of appropriate technologies, finance and space. Therefore, environment friendly and cost effective technologies for nutrient recycling of fly ash are being advocated as an alternative means for conserving and replenishing natural resources of the ecosystems. Presently there are various bio processing technologies, and among them vermiconversion has been recommended as a preferable option to stabilize various kinds of solid wastes (Suthar, *et al*., 2012; Bhat, *et al*., 2016a, 2016b). Earthworm *E. fetida* are natural colonizers of organic material and have short maturity life cycle, high rates of feed consumption, digestion, assimilation of feed with high of cocoon production and higher adaptability to organic waste (Tripathi and Bhardwaj, 2004). Ecobiotechnology vermiconversion process has attracted significant attention for aerobic biostabilization of waste material worldwide due to easy, cost efficient and natural process (Khwairakpam and Bhargava, 2009).

Keeping in view the above facts, the present work was conducted to assess the growth of earthworm

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E. fetida during vermicomposting of fly ash in 90 days. Efficiency of *E. fetida* for enriching nutrients in the end product was evaluated by physico-chemical parameters in the waste with and without earthworms before and after vermicomposting.

MATERIALS AND METHODS

The present work was conducted to assess the growth and development of earthworm *E. fetida* during vermicomposting of thermal power plant fly ash. Young non-clitellated *E. fetida* were randomly picked from a stock culture maintained in the vermicomposting unit of the department of botanical and environmental sciences, Guru Nanak Dev University, Amritsar, Punjab, India. Thermal power plant fly ash was obtained from Rajiv Gandhi thermal power project (RGTPP), Khedar, Hisar, Haryana. The collected sample was air dried for moisture removal. Cattle dung (CD) was obtained from a dairy farm situated in the vicinity of the university.

EXPERIMENTAL DESIGN

In the present work thermal power plant fly ash (FA) was fed to *E. fetida* with cattle dung (CD) at different ratios on dry weigh basis (Table 1). Plastic trays were filled with mixtures containing different percentages of FA/CD with and without earthworms in duplicates each on dry basis. The total weight of each tray was kept at 1 kg and according to the above mentioned proportions mixing of waste and cattle dung was done. The trays were covered with jute mat and were kept in a shed located in the botanical garden of guru Nanak Dev University, Amritsar. The mixtures were turned over manually every 24 h for 15 days in order to eliminate the volatile toxic gases. After 15 days, 20 young non-clitellated *E. fetida* were released in trays. The moisture content was maintained to 60% to 70% throughout the study period by periodic sprinkling of adequate quantities of water. Earthworms cocoons and hatchlings were sorted and counted manually at the interval of 15 days. At the end of the experiment (90 days), worms, cocoons and hatchlings were removed. The vermicompost (end product) was sieved, air dried and physico-chemical parameters were analysed. The initial physicochemical characteristics of fly ash and cattle dung are given in Table 2.

Physico-chemical analysis

Physico-chemical analysis was done to determine the availability of total nutrient content in final fly ash feed mixtures with and without earthworms. pH and electrical conductivity (EC) were determined in double distilled water suspensions of each concentration in the ratio of 1:10 (W/V) using Systronics µ pH system 362 and Systronics conductivity meter-304, respectively. Total organic carbon (TOC) was measured after igniting the 0.5 g of sample in a muffle furnace at 550°C for 60 minutes as described by Nelson and Sommers (1996). Micro-Kjeldhal method of AOAC (2000) was used for measuring total Kjeldhal nitrogen (TKN) after digestion. The method described by John (1970) was used for measuring total available phosphorus (TAP) using Systronics spectrophotometer 2202, total sodium (TNa) was measured by using a Systonics flame photometer-128 after digesting the samples in diacid mixture ($HClO_4$:HNO_3 in 4:1 ratio). Heavy metals (Copper, Lead, Manganese and Chromium) were measured by Agilent 240 FS AA model atomic absorption spectrophotometer in the digested samples.

Statistical analysis

The experimental data was presented as mean ± SE of triplicate experiments. One-way ANOVA was used to calculate the differences among various feed mixtures. Tukey's HSD test was used as a post-hoc analysis to compare the means. Student's paired t-test was used to evaluate differences between initial and final values of various physico-chemical parameters. Statistical analysis was done with the help of SPSS computer software program.

Table 1. Percentages of fly ash and cattle dung in different proportions with and without earthworms

Feed mixtures		Fly ash (FA)	Cattle dung (CD)
With earthworms	Without earthworms		
FE_0	FW_0	0	100
FE_{25}	FW_{25}	25	75
FE_{50}	FW_{50}	50	50
FE_{75}	FW_{75}	75	25
FE_{100}	FW_{100}	100	0

Table 2. Initial physicochemical properties of fly ash and cattle dung

Physico-chemical parameters	Fly ash (FA)	Cattle dung (CD)
pH	8.60 ± 0.02	8.44 ± 0.05
EC (mS/cm)	0.74 ± 0.02	3.63 ± 0.05
TKN (%)	0.87 ± 0.01	3.18 ± 0.02
TOC (%)	37.7 ± 0.53	42.8 ± 0.37
C:N ratio	42.7 ± 1.10	13.4 ± 0.22
TAP (%)	1.42 ± 0.00	3.01 ± 0.04
TK (%)	6.45 ± 0.05	2.78 ± 0.03
TNa (%)	2.09 ± 0.01	0.94 ± 0.01
Cu (mg/kg)	24.2 ± 0.34	6.05 ± 0.77
Pb (mg/kg)	24.8 ± 0.20	8.60 ± 0.40
Mn (mg/kg)	210 ± 2.81	36.5 ± 0.45
Cr (mg/kg)	48.0 ± 0.26	12.1 ± 0.92

RESULTS AND DISCUSSION

Growth and reproduction of earthworms

Population buildup in the form of number of worms, cocoons and hatchlings formation showed a significant pattern. In our findings, the number of earthworms was increased till 90 days for feed mixtures FE0, FE25, FE50 and FE75 (Fig. 1). Maximum number of earth worm's population was observed in feed mixture FE25 (42.5) followed by FE0 (36.1), FE50 (32.0) and FE75 (26.1). In the feed mixture FE75 the number of earthworms first decreased till 75th day of experiment and then increased and in feed mixture FE100, where only 100% ash was used all the earthworms were found to be dead on 30th day of experiment due to high toxicity and cementing properties of fly ash. The earthworms were increased till 90th day of experiment and then started to decrease due to exhaustion of food in the feed mixtures. Anbalagan and Manivannan, 2012, also reported that the earthworm *Eudrilus eugeniae* was able to convert fly ash generated as solid waste from thermal power plant into nutrient rich vermicompost.

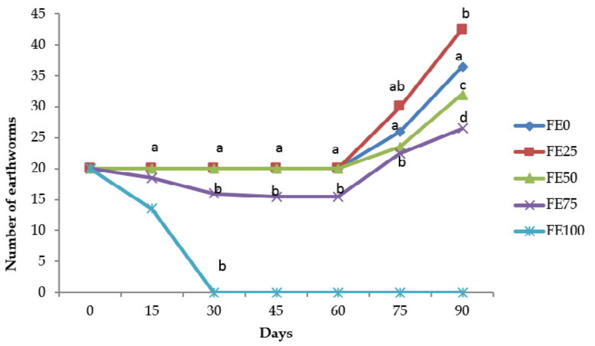

Fig. 1 Number of earthworms in different proportions of fly ash with cattle dung. Different letters in a same day are significantly different (one-way ANOVA; Tukey's test, $p \leq 0.05$).

The development of clitellum in earthworms appeared after the 30th day of experiment in all the feed mixture except FE100 and the formation of cocoon was observed in 45th day in all the feed mixtures. Total cocoon productions in all the feed mixtures varied significantly on 90th day of experiment (Fig. 2). The maximum number of cocoons was observed in FE25 (44.5) on 90th day. Cocoon production were relatively less in higher proportions of fly ash like FE50 (33.5) and FE75 (24.5). Higher percentage of fly ash in feed mixtures declined rate of decomposition of waste and also delayed as well as declined cocoon production.

Hatchling formations were found to be significantly different in all feed mixtures (Fig. 3). The first hatchlings were observed on 60th day in FE0, FE25, FE50 and FE75. The maximum number of hatchling was observed on 90th day in feed mixture FE25 (37.0) followed by FE0 (28.5), FE50 (24.0) and FE75 (15.5). As expected hatchlings formation was correlated with the production of cocoons in different mixtures. Increase in hatchling formation during the present study was supported by (Chauhan and Singh, 2013).

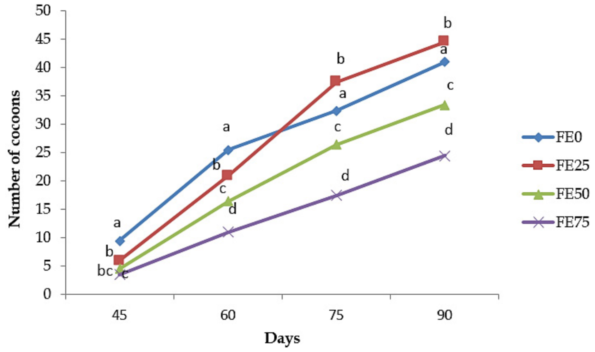

Fig. 2 Number of cocoons in different proportions of fly ash with cattle dung. Different letters in a same day are significantly different (one-way ANOVA; Tukey's test, $p \leq 0.05$).

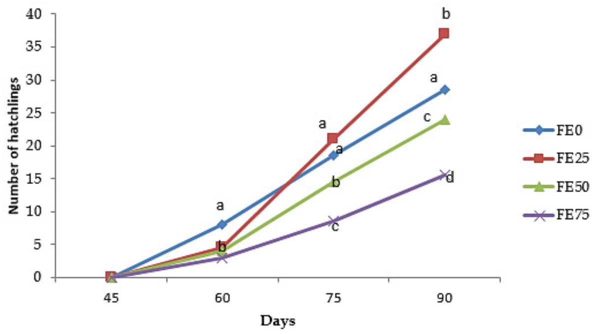

Fig. 3 Number of hatchlings in different proportions of fly ash with cattle dung. Different letters in a same day are significantly different (one-way ANOVA; Tukey's test, $p \leq 0.05$).

Physico chemical analysis

The physicochemical parameters of different proportions of fly ash and cattle dung with and without earthworms are given in Table 3. There was a significant decrease in pH of final vermicompost as compared to initial feed mixtures with earthworms. The maximum decrease in pH with earthworms was in FE25 (15.7%) and minimum in feed mixture FE100 (8.0%). A significant range of decrease in pH (8.02% to 15.70%) was observed after conversion by earthworms. The percent decrease in pH was in an order of FE25>FE75>FE0>FE50>FE100. Feed mixtures without earthworms also showed small decrease in pH in final compost. The maximum and minimum decrease in pH in feed mixture was FW100 (9.8%) and FW25 (3.6%) respectively. A slight range of decrease in pH (3.60% to 9.02%) was also observed after simple composting. Decrease in pH in feed mixtures without earthworms was significantly less than feed mixtures with earthworms. The reduction

Table 3. Initial and final nutrient content (mean ± S.E.) and percent change over initial nutrient content of different proportions of fly ash and cattle dung with and without earthworms

Nutrient		FE_0	FW_0	FE_{25}	FW_{25}	FE_{50}	FW_{50}	FE_{75}	FW_{75}	FE_{100}	FW_{100}
pH	Initial	8.44 ± 0.05	8.57 ± 0.03	8.37 ± 0.02	8.34 ± 0.03	8.21 ± 0.01	8.24 ± 0.04	8.47 ± 0.02	8.38 ± 0.03	8.6 ± 0.02	8.65 ± 0.04
	Final	7.19 ± 0.02*	8.2 ± 0.07*	7.06 ± 0.04**	8.05 ± 0.04	7.13 ± 0.01	8.1 ± 0.05	7.15 ± 0.11**	7.99 ± 0.02	7.91 ± 0.05	7.87 ± 0.025
	% change	-14.8	-4.32	-15.7	-3.6	-13.15	-4.25	-15.57	-4.65	-8.02	-9.02
EC (mS/ cm)	Initial	3.63 ± 0.05	3.66 ± 0.05	3.05 ± 0.05	3.11 ± 0.01	2.14 ± 0.04	2.17 ± 0.03	1.08 ± 0.01	1.16 ± 0.06	0.74 ± 0.02	0.81 ± 0.01
	Final	2.27 ± 0.01**	3.2 ± 0.11	1.41 ± 0.03**	2.83 ± 0.03**	1.17 ± 0.00**	1.8 ± 0.08	0.82 ± 0.03**	0.98 ± 0.02	0.62 ± 0.02*	0.6 ± 0.01
	% change	-37.41	-12.57	-53.6	-9	-45.09	-16.82	-24.42	-15.52	-16.21	-25.92
TKN[a]	Initial	3.18 ± 0.02	3.1 ± 0.01	2.43 ± 0.04	2.47 ± 0.02	1.37 ± 0.03	1.63 ± 0.04	1.03 ± 0.04	1.1 ± 0.01	0.87 ± 0.01	0.93 ± 0.00
	Final	4.56 ± 0.03*	3.47 ± 0.05	4.18 ± 0.01**	3.07 ± 0.03*	2.64 ± 0.06*	1.83 ± 0.04*	1.81 ± 0.06**	1.29 ± 0.01	1.31 ± 0.03**	1.13 ± 0.03
	%change	43.4	11.93	72.02	24.29	92.7	12.27	75.73	17.27	50.57	21.5
TOC[a]	Initial	42.87 ± 0.37	43.97 ± 0.21	41.33 ± 0.57	41.4 ± 0.19	38.37 ± 0.75	38.99 ± 0.81	37.83 ± 0.42	37.11 ± 0.51	37.75 ± 0.53	36.85 ± 0.25
	Final	6.33 ± 0.09*	35.36 ± 0.39**	30.29 ± 0.21**	35.78 ± 0.62**	30.59 ± 0.26**	34.94 ± 0.14	31.18 ± 0.22**	35.6 ± 0.40	31.9 ± 0.25	34.42 ± 0.43*
	% change	-32.56	-19.58	-26.71	-13.57	-20.28	-10.39	-17.58	-4.07	-15.6	-6.59
C/N ratio	Initial	13.46 ± 0.22	14.19 ± 0.11	16.98 ± 0.55	16.73 ± 0.24	28.01 ± 0.06	23.88 ± 1.15	36.79 ± 1.84	33.56 ± 0.03	42.79 ± 1.10	39.42 ± 0.47
	Final	6.33 ± 0.09*	10.19 ± 0.03*	7.23 ± 0.07**	11.66 ± 0.31*	11.78 ± 0.18*	19.06 ± 0.54	17.28 ± 0.80**	27.6 ± 0.52**	24.27 ± 0.45*	30.34 ± 0.55
	% change	-52.97	-28.19	-57.42	-30.3	-97.94	-20.18	-53.03	-17.76	-43.28	-23.03
TAP[a]	Initial	3.01 ± 0.04	2.96 ± 0.01	2.69 ± 0.01	2.72 ± 0.00	2.23 ± 0.01	2.21 ± 0.01	1.67 ± 0.03	1.68 ± 0.05	1.42 ± 0.00	1.37 ± 0.01
	Final	4.16 ± 0.01*	3.39 ± 0.02*	3.91 ± 0.03*	3.47 ± 0.01*	3.12 ± 0.02*	2.49 ± 0.02**	2.56 ± 0.01*	2.04 ± 0.06	1.89 ± 0.01**	1.7 ± 0.02*
	% change	38.2	14.33	45.35	27.57	39.91	12.67	53.29	21.73	33.09	24.09
TK[a]	Initial	2.78 ± 0.03	2.81 ± 0.01	3.13 ± 0.02	3.13 ± 0.01	4.26 ± 0.02	4.13 ± 0.03	5.71 ± 0.03	5.62 ± 0.03	6.45 ± 0.05	6.42 ± 0.04
	Final	4.42 ± 0.04**	3.51 ± 0.04**	4.42 ± 0.02**	3.61 ± 0.01**	5.31 ± 0.06**	4.63 ± 0.04	6.57 ± 0.03**	6.07 ± 0.06**	6.85 ± 0.02**	6.63 ± 0.01
	% change	58.99	24.91	41.21	15.33	24.65	12.11	15.06	8	6.2	3.27
TNa[a]	Initial	0.94 ± 0.01	0.91 ± 0.01	1.21 ± 0.04	1.29 ± 0.01	1.5 ± 0.02	1.4 ± 0.01	1.75 ± 0.02	1.77 ± 0.02	2.09 ± 0.01	2.14 ± 0.01
	Final	0.48 ± 0.01*	0.69 ± 0.00**	0.76 ± 0.01**	0.95 ± 0.01*	1.03 ± 0.04**	1.14 ± 0.03	1.33 ± 0.05**	1.5 ± 0.02**	1.86 ± 0.01*	1.99 ± 0.01
	% change	-48.93	-24.17	-37.19	-26.35	-31.33	-18.57	-24	-16.67	-11	-7
Cu[b]	Initial	6.05 ± 0.77	5.8 ± 0.09	11.12 ± 0.39	11.94 ± 0.27	13.82 ± 0.17	13.72 ± 0.1	23.15 ± 0.34	22.80 ± 0.7	24.27 ± 0.34	24.89 ± 0.25
	Final	3.27 ± 0.17**	4.48 ± 0.16*	6.38 ± 0.46**	8.54 ± 0.04	8.64 ± 0.21**	11.62 ± 0.42	15.13 ± 0.13**	20.11 ± 0.36	18.28 ± 0.16*	22.14 ± 0.1
	% change	-45.95	-22.75	-42.62	-28.47	-37.48	-15.3	-34.64	-11.79	24.68	-11.04
Pb[b]	Initial	8.6 ± 0.4	9.29 ± 0.09	11.61 ± 0.43	12.79 ± 0.65	15.95 ± 0.25	15.19 ± 0.21	19.95 ± 0.15	21.09 ± 0.55	24.86 ± 0.20	25.91 ± 0.11
	Final	5.3 ± 0.14**	6.71 ± 0.26**	7.36 ± 0.26**	9.73 ± 0.19*	10.71 ± 0.39*	13.19 ± 0.09	13.79 ± 0.70*	18.47 ± 0.07*	17.21 ± 0.06*	22.33 ± 0.26
	%change	-38.37	-27.77	-36.6	-23.92	-32.85	-13.16	-30.87	-12.42	-28.88	-13.81
Mn[b]	Initial	36.55 ± 0.45	37.17 ± 0.2	66.76 ± 1.66	69.91 ± 0.36	90.97 ± 1.27	92.23 ± 1.06	129.9	124.8 ± 0.6	210 ± 2.81	207.8 ± 1.24
	Final	23.6 ± 0.59**	32.36 ± 0.21*	48.12 ± 0.72**	57.27 ± 0.5	69.42 ± 1.52*	84.3 ± 0.2**	93.36 ± 1.21*	113.1 ± 0.6	169.3 ± 0.85*	191.4 ± 0.73
	% change	-35.43	-12.94	-27.92	-18.08	-23.68	-8.59	-28.12	-9.35	-19.38	-7.89

Cr[b]	Initial	12.17 ± 0.92	12 ± 0.2	19.17 ± 0.57	19.8 ± 0.25	26.59 ± 0.61	24.98 ± 0.3	34.02 ± 1.57	26.9 ± 0.19	48.06 ± 0.26	46.67 ± 1.12
	Final	7.29 ± 0.11**	9.25 ± 0.15*	12.27 ± 0.37**	14.57 ± 0.27	18.1 ± 0.15*	22.12 ± 0.72*	26.98 ± 0.58*	23.92 ± 0.17**	40.5 ± 0.7*	43.57 ± 0.42
	% change	-40.09	-22.91	-35.99	-26.41	-31.92	-11.44	-20.69	-11.07	-15.73	-6.64

a Concentrations in %
b Weight in mg/kg
Significance level was determined by student's paired t-test. *p ≤ 0.05, **p ≤ 0.01.

in pH of final vermicompost has also been confirmed by other authors (Garg, *et al*., 2006; Suthar and Singh, 2008; Bhat, *et al*., 2015). The decrease in pH during vermicomposting process could be attributed to the production of metabolic compounds of aerobic digestions of organic material, e.g. CO_2, ammonia, NO_3^- and organic acids (Lopez, *et al*., 1997; Niyazi and Chaurasia, 2014) also confirmed a significant pH reduction in fly ash vermiconversion.

Electrical conductivity (EC) was declined significantly in the final products of vermicompost ($p<0.05$). Maximum and minimum percent declines in EC were in FE25 (53.60) and FE100 (16.21) with earthworm feed mixtures. A significant range of decrease in EC (16.21% to 53.60%) was observed after conversion by earthworms. The percent decrease in EC was in order of FE25>FE50>FE0>FE75>FE100. A slight range of decrease in EC (9.0% to 25.92%) was also observed after simple composting. The decrease in EC was mainly due to the production of soluble metabolites such as ammonium and the precipitation of dissolved salts in the final product (Singh, *et al.,* 2010; Lim, *et al.,* 2012) also supported that a significant reduction in EC was observed in the final products of beverage industry sludge.

Total organic carbon (TOC) of the final vermicompost was declined significantly ($p<0.05$) over initial feed mixtures with earthworms. The maximum and minimum decline in TOC in final vermicompost was in FE0 (32.5%) and FE100 (15.6%) respectively. A significant range of decrease in TOC (15.60% to 32.56%) was observed after conversion by earthworms. The percent decrease in TOC of the final product was in order of FE0>FE25>FE50>FE75>FE100. In feed mixtures without earthworms a slight decrease in TOC was noticed. The decrease in TOC was maximum in FW0 (19.5%) and minimum in FW75 (4.0%). A slight range of decrease in TOC (4.07% to 19.58%) was also observed after simple composting. In vermiconversion process earthworm and gut associated microorganisms enhanced the carbon mineralization in vermibeds which leads to TOC reduction (Dominguez, 2004; Suthar and Sharma, 2013) also suggested that biological mutuality caused carbon loss in the form of CO_2 from the substrates during the decomposition of organic feed mixture. The conversion of some part of organic fractions of feed into worm biomass can also reduce the carbon loss from the feed mixtures.

Total Kjeldhal nitrogen (TKN) of the final product obtained from different feed mixtures was significantly increased ($p<0.05$). The maximum increase in TKN was in FE50 (92.7%) and minimum in FE0 (43.4%) feed mixtures with earthworms. A significant range of increase in TKN (43.40% to 92.70%) was observed after conversion by earthworms. The percent increase in TKN was in order of FE50>FE75>FE25>FE100>FE0. Feed mixtures without earthworms only showed slight increase in TKN. The maximum increase in TKN was in FW25 (24.2%) and minimum in FW0 (11.9%). Slight range of increase in TKN (11.93% to 24.29%) was only observed after simple composting. According to (Bhat, *et al.,* 2015) losses in organic carbon may be a responsible for nitrogen addition. Earthworms also have a significant impact on nitrogen mineralization. (Atiyeh, *et al.,* 2001) also supported that loss of organic carbon during vermiconversion could be due to mineralization and due to CO_2 production during respiration so that nitrogen was retained in the nitrate form which is usable by plant roots as a mineral for their growth. Enhancement of nitrogen in the form of mucus, nitrogenous excretory substances, growth stimulating hormones and enzymes from earthworms has been reported (Suthar, 2006).

C:N ratio decreased significantly with time in all the feed mixtures in the presence of earthworms ($p<0.05$). Decline in C:N ratio was maximum in FE50 (97.4%) and minimum in FE100 (43.2%) feed mixtures with earthworms. A significant range of decrease in C:N ratio (43.28% to 97.94%) was observed after conversion by earthworms. The percent decrease in C:N was in order of FE50>FE25>FE75>FE0>FE100. In feed mixtures without earthworms a slight decrease in C:N was observed. The maximum and minimum decrease in C:N ratio was shown in FW25 (30.3%) and FW75 (17.7%) respectively. A slight range of decrease in C:N ratio (17.76% to 30.30%) was also observed after simple composting. C:N ratio is an indicator parameter for maturity of compost and its value less than 20 indicates maturity for agronomic use of compost. (Bhat, *et al.,* 2013) and (Yadav, *et al.,* 2013) also reported that the significant decline in C:N ratio is due to loss of carbon as carbon dioxide in respiration and enhancement in nitrogen due to nitrogenous excreta, which lowered the C:N ratio of the feed mixtures with earthworms. Change in C:N ratio is understandable and proportional to changes in TOC and TKN.

The total potassium (TK) content was increased significantly in the final vermicompost feed mixtures with earthworms. Maximum increase in potassium content was in feed mixture FE0 (58.9%) and minimum in FE100 (6.2%). A significant range of increase in TK (6.20% to 50.99%) was observed after conversion by earthworms. The percent increase in TK was in order of FE0>FE25>FE50>FE75>FE100. In feed mixtures without earthworms a slight increase in TK was observed which was not upto the level of earthworm's compost. Maximum increase in TK was observed in feed mixture FW0 (24.9%) and minimum was in FW100 (3.2). A slight range of increase in TK (3.27% to 24.91%) was also observed after simple composting. (Kaviraj and Sharma, 2003) reported that increased enzymatic and microorganism's activity in earthworm's gut might have play significant role in increased amount of TK in vermicompost. Delgado, *et al.*, reported a higher amount of TK in the final vermicompost of organic waste mixtures with earthworms.

Total available phosphorus (TAP) increased significantly with time in all the feed mixtures with earthworms ($p<0.05$). Maximum increase in TAP content was in FE75 (53.2%) and minimum in FE100 (33.0%) feed mixture with earthworms. A significant range of increase in TAP (33.29% to 53.29%) was observed after conversion by earthworms. The percent increase in TAP content was in order of FE75>FE25>FE50>FE0>FE100. Slight increase in TAP content was also observed in feed mixtures without earthworms. The maximum increase in TAP was in FW25 (27.5%) and minimum in FW50 (12.6%) feed mixtures without earthworms. A slight range of increase in TAP (12.67% to 27.57%) was also observed after simple composting. The increase in TAP in the final feed mixtures with earthworms may be due to mineralization and mobilization of phosphorus due to bacterial and fecal phosphate activity of earthworms (Edwards and Lofty, 1972; Suthar, 2010) suggested the role of P-solubilizing bacteria in phosphorous enhancements in deposited casts of earthworms. (Ghosh, *et al.*, 1999) also reported that the increase in TAP probably might be attributed towards variations in earthworm growth and multiplication rate in different organic feed mixtures, which resulted in a differential pattern of uptake of the nutrient for their body synthesis and subsequent release of the remaining P in a mineralized form.

Total sodium (TNa) decreased significantly from initial in all the feed mixtures with earthworms ($p<0.05$). Decline in total sodium was maximum in FE0 (48.9%) and minimum in FE100 (11.0%) feed mixtures with earthworms. A significant range of decrease in TNa (11.0% to 48.93%) was observed after conversion by earthworms. The percent decrease in TNa was in order of FE0>FE25>FE50>FE75>FE100. In simple composting a slight decrease in TNa was observed which was not upto the level of earthworm's compost. The maximum and minimum decrease in TNa were in FW25 (30.3%) and FW75 (17.7%) respectively. A slight range of decrease in TNa (7.0% to 26.35%) was also observed after simple composting.

Heavy metals

The metal toxicity is not caused by the mere presence of metals, but depends on metal concentration, toxicity, mobility in free form, the rate of uptake mechanisms and bioavailability if it is accumulated in plants (Alloway and Ayers, 1994). The metal contents in the initial feed mixture and final vermicompost are given in Table 3. The four heavy metals copper (Cu), lead (Pb), manganese (Mn) and chromium (Cr) decreased significantly over initial in different feed mixtures with earthworms. Cu decreased significantly from initial in different feed mixtures with earthworms ($p<0.05$). Maximum decrease in Cu was in FE0 (45.9%) and minimum in FE100 (24.6%). A significant range of decrease in Cu (24.68% to 45.95%) was observed after conversion by earthworms. The percent decrease in Cu was in order of FE0>FE25>FE50FE75>FE100. A small fraction of decrease in Cu was also observed in feed mixtures without earthworms. Maximum decrease in Cu in feed mixture was in FW25 (28.4%) and minimum (11.0%) in FW100 feed mixture. A slight range of decrease in Cu (11.04% to 28.47%) was also observed after simple composting. Pb content was also decreased significantly with maximum decrease in FE0 (38.3%) and minimum in FE100 (28.8%) feed mixtures with earthworms. A significant range of decrease in Pb (28.88% to 38.37%) was observed after conversion by earthworms. The percent decrease in Pb was in order of FE0>FE25>FE50FE75>FE100. Feed mixtures without earthworms also showed some decrease in Pb content. The maximum decrease in Pb was observed in FW0 (23.9%) and minimum (12.2%) in FW100. A slight range of decrease in Pb (12.42% to 27.77%) was also observed after simple composting. Mn decreased significantly from initial in different feed mixtures with earthworms ($p<0.05$). Maximum and minimum decrease in Mn was observed in FE0 and FE100, (35.4%) and (19.3%) respectively. A significant range of decrease in Mn (19.38% to 35.43%)

was observed after conversion by earthworms. The percent decrease in the Mn was in the order of FE0>FE75>FE25>FE50>FE100. A slight decrease in Mn content was also observed in feed mixtures without earthworms. The maximum decrease in the Mn was observed in feed mixture FW25 (18.0%) and minimum in feed mixture FW100 (7.8%). A slight range of decrease in Mn (7.89% to 18.08%) was also observed after simple composting. Cr decreased significantly from initial in different feed mixtures with earthworms ($p<0.05$). Maximum decrease in Cr was in FE0 (40.0%) and minimum in FE100 (15.7%) feed mixture. A significant range of decrease in Cr (15.73% to 40.09%) was observed after conversion by earthworms. The percent decrease in Cr was in order of FE0>FE25>FE50>FE75>FE100. A slight fraction of decrease in Cr was also observed in feed mixtures without earthworms. Maximum decrease in Cr was in FW25 (26.4%) and minimum (6.6%) in FW100 feed mixture. A slight range of decrease in Cr (6.64% to 26.41%) was also observed after simple composting. Body tissues (chloragocytes) of earthworms and the intestinal microflora have the capacity to detoxify most of the heavy metals and in the present study reduction may be due to the accumulation of these heavy metals by earthworms. (Bhattacharya and Chattopadhyay, 2006) also supported our results through his findings that the earthworms helped to reduce the solubility of heavy metals due to formation of various organic metal complexes and bioaccumulation of these metals in earthworms's body. With increasing time, reduction of heavy metals in the final vermicompost of sewage sludge has also been observed by Shahmansouri, *et al.*, 2005; Gupta, *et al.*, 2007 also observed that water hyacinth based vermireactor using *E. fetida* decreased heavy metals in the final vermicompost.

CONCLUSION

The best growth of *Eisenia fetida* was observed in 25:75 (FE25) mixture of FA and CD. The vermicompost produced from fly ash with the help of *E. fetida* possessed higher percent of plant nutrients (NPK), lower organic carbon, C:N ratio, electrical conductivity and total sodium content as compared to traditional composting. The study also showed that the final vermicompost produced from *E. fetida* reduces concentrations of heavy metals (Cu, Pb, Mn and Cr). Results also showed that earthworms helped to reduce the bioavailability and leachability of these heavy metals in vermicompost. The feasibility of earthworms to mitigate the metal toxicity and to enhance the nutrient profile in fly ash, vermicomposting might be useful if mixed maximum at 50% with CD.

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Competing interests

The authors declare that they have no competing interests.

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