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Earthworm species and their feeding substances have great role on the quantity and quality of produced vermicompost

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Abstract A study was conducted to find out suitable earthworm species as well as respective feeding materials in the way of producing quality vermicompost. Two earthworm species, i.e., *Eisenia fetida* and *Eudrilus eugeniae* were used to produce vermicompost from four selected combinations of feeding materials. The study was carried out in the vermicompost shed of the Department of Soil Science in Sylhet Agricultural University, Bangladesh, using completely randomized design. Earthworm species *E. fetida* has performed better than *E. eugeniae* in terms of the amount of vermicompost produced. On the other hand, using sole cow dung as feeding material produced the highest amount of vermicompost and induced for the highest increase in earthworm number comparing with the other feeding materials used. Cow dung as feeding materials and the interaction of *E. fetida* and cow dung was suitable for the highest earthworm biomass. There was an indication of vermiremoval of cadmium and lead from the feeding materials while vermicomposting. The earthworm species *E. fetida* was found to be more efficient in removing cadmium and lead from contaminated feeding materials. Cow dung containing feeding mixtures has resulted higher content of K, S, and B in vermicompost than the others. Considering all above aspects, it can be said that vermicompost produced from cow dung using *E. fetida* is a suitable option for higher production of quality vermicompost.

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Introduction

Quality manure can help to heal up the degraded soil health and vermicompost is one of the good options for that. Vermicomposting is a bio-oxidative process in which detritivorous earthworms interact with some microorganisms and other fauna within the decomposer community, accelerating the stabilization of organic matter and greatly modifying its physical and biochemical process (Domínguez 2004). It is very effective, cheap, environment friendly, and easy method of recycling biodegradable waste using selected species of earthworms. Through eating, burrowing, and casting, earthworms modify the physical, chemical, and biological properties of organic matter and soil.

The epigeics among the three ecological categories of earthworms is used in vermicomposting. The biochemical decomposition of organic matter is primarily accomplished by the microbes; however, earthworms are the crucial drivers of the process by fragmenting and conditioning the substrate, and by increasing the surface area of organic substance available for microbial attack after comminution (Domínguez et al. 2010). In vermicomposting process, earthworms add various intestinal microflora in matrix; moreover, gut enzymes play dominant role in this process (Whiston and Seal 1988). They also change pH and organic matter dynamics in terms of quality and quantity, microbial and invertebrate activity, and the abundance, biomass, species composition, and diversity of the microflora and fauna (Lavelle et al. 1998).

Different organic substances have different palatability, nutrient content, and constituents which may influence the growth and performances of earthworms (Suthar 2007). These factors may also affect the quantity and quality of vermicompost produced. Yan et al. (2013) found that nutrients in initial organic waste material affects the nutrient contents of vermicompost and there was a positive correlations between nutrient contents in raw plant residues and vermicompost for N, K, and Ca. Vermicompost is proving to be highly nutritive organic fertilizer and more powerful growth promoter against the destructive chemical fertilizers which has destroyed the soil properties and decreased its natural fertility over the years. Higher content of nutrients in vermicompost have been reported by numerous researchers (Lourduraj and Yadav 2005; Gurav and Pathade 2011; Abdelmonem et al. 2016).

Among the commonly used feeding materials, water hyacinth is an important one. It is a hydrophyte that uptakes heavy metals and stores in its biomass. These plants are called bio-accumulators as they accumulate the contaminants in their tissues (Boyd 1970). Water hyacinth has high tolerance against contaminants like heavy metals and is able to absorb large quantities. Heavy metal content of cow dung and poultry manure depends on the feed stuffs supplied for those cattle and poultry. Again, source materials which used as poultry litter have effects on the heavy metal content of that poultry litter. During vemicomposting, the heavy metal content decreases to some extent that resulted reduced content of those metals in vermicompost. Numerous research findings supported the issue (Kagi and Kojima 1987; Jain et al. 2004; Pattnaik and Reddy 2011; Singh and Kalamdhad 2013; Suthar et al. 2014). On the other hand, some researchers have reported the increased total heavy metal concentrations in vermicomposts than the feeding substances (Khwairakpam and Bhargava 2009; Suthar 2010; Hait and Tare 2012).

Soil health is one of the key factors for sustainable farming and food security. In some cases, degraded soil quality is hampering crop cultivation seriously. Application of vermicompost can be a good option to heal up the soil health when these vermicomposts would be quality assured, i.e., rich in plant nutrients, level of toxic element, and/or heavy metal lies within the tolerable range. The variations in quality of vermicompost produced from the different organic substances offer an insight into the effect of initial feeding materials on the nutrient content of vermicompost produced. Research is needed to assess productivity and quality of vermicompost produced from different sources using various earthworm species. Hence, the present study was undertaken to evaluate the performance of earthworm species to produce quality vermicompost as well as suitability of feeding materials used in vermicomposting.

Materials and methods

Experimental location

The experiment was carried out in the vermicompost shed of the Department of Soil Science, Sylhet Agricultural University (SAU) of Bangladesh. The chemical analysis was done in the departmental laboratory at SAU and partially in the regional laboratory, Soil Resource Development institute (SRDI), Sylhet.

Experimental design

The study was carried out using *chari* (cement-made bowl shaped jar) following factorial CRD with three replications. A total of 24 *chari* was used and kept in 3 sets; 12 *chari* for *E. fetida* and 12 for *E. eugeniae*.

Treatments

Eight treatment combinations using the following two factors were tested.

Factor-A: 2 (Earthworm species)

– Two species of earthworms: *Eisenia fetida* and *Eudrilus eugeniae*

Factor-B: 4 (Feeding materials/substrate)

The feeding materials used in the experiments were cow dung, cow dung + water hyacinth, cow dung + poultry litter, and poultry litter + water hyacinth. The ratio of substrate is presented in Table 1. The treatment combinations were as follows:

- T_1: *E. fetida*-cow dung, (ECD)
- T_2: *E. fetida*-cow dung + water hyacinth, (ECDWH)
- T_3: *E. fetida*-cow dung + poultry litter, (ECDPL)

Table 1 Substrate (feeding materials) ratio used for different treatment combinations

Substrate mixture	Amount of substrates used	Ratio
Cow dung (CD)	CD (3.0 kg)	100
Cow dung (CD): water hyacinth (WH)	CD (2.10 kg): WH (0.90 kg)	70:30
Cow dung (CD): poultry litter (PL)	CD (2.10 kg): PL (0.90 kg)	70:30
Poultry litter (PL): water hyacinth (WH)	PL (2.10 kg): WH (0.90 kg)	70:30

All feeding materials were adjusted to 70% moisture content

- T_4: *E. fetida*-poultry litter + water hyacinth, (EPLWH)
- T_5: *E. eugeniae*-cow dung, (EuCD)
- T_6: *E. eugeniae*-cow dung + water hyacinth, (EuCDWH)
- T_7: *E. eugeniae*-cow dung + poultry litter, (EuCDPL)
- T_8: *E. eugeniae*-poultry litter + water hyacinth, (EuPLWH)

Collection of earthworm species

Eisenia fetida

The earthworm species *E. fetida* was collected from "Mon Vermicompost" of South Surma upazila (sub-district) under Sylhet district of Bangladesh. It is commonly known as redworm or red wiggler worm. They are epigeic and rarely found in soil. They are actually native to Europe, but have been introduced to every other continent except Antarctica.

Eudrilus eugeniae

This species was collected form "Annopurna Agro Service" of Domar, Nilphamari district of Bangladesh. *E. eugeniae* popularly known as the "African Night Crawler" is a large, rapidly growing, prolific, and ideal epigeic vermicomposting worm under tropical conditions.

Collection and thermophilic pre-composting of feeding materials

Among the feeding materials, cow dung and poultry litter were collected from nearby commercial dairy and poultry farm, respectively. In those farms, cattle and poultry are fed with controlled supply of fixed feed stuff. The main feed stuff used in the respective dairy farm is rice straw, green grasses collected from surrounding fields, mustard oilcake, etc. Again, sawdust is the bedding material used in the poultry farm from where the poultry litter was collected. Fresh water hyacinth was collected from a canal beside BSCIC (Bangladesh Small and Cottage Industries Corporation) industrial area at Khadimnagar, Sylhet. Each of the feeding stuff was allowed for 21 days of pre-composting. The materials were placed in the form of heaps under shady place. Watering was done regularly twice in a day in order to maintain the optimum temperature and moisture. Following pre-composting, respective amounts of the feeding materials were collected randomly for each treatment and mixed thoroughly for use in the experiment. Each of the feeding materials was sampled at the starting and at end of the pre-composting process for chemical analysis.

Processing and chemical analysis of feeding material sample

The collected feeding material samples were air-dried first in a shady place followed by oven drying for 24 h at 65 °C. To obtain homogenous powder, the samples were finely ground by using a grinding mill to pass through a 60-mesh sieve. Such processed samples were analyzed chemically to determine cadmium and lead contents using the methods described in Table 2.

Acclimatization of earthworms

The collected earthworms of both species were kept first in earthen *chari* for a period of 21 days, in order to allow them to adapt to the weather of the experimental site. During this period of acclimatization, the worms were fed with cow dung. After that, sufficient amount of the worm species was transferred for a short period of 10 days in the respective pre-composted feeding materials or mixture of feeding materials as stated in the

Table 2 Methods used for chemical analyses of feeding materials and vermicompost

Elements/ parameters	Analytical methods
pH	pH of vermicompost was determined by glass-electrode pH meter maintaining 1:2.5 vermicompost-water ratio (McLean 1982).
Total N	Total N content of vermicompost was determined by micro-Kjeldahl method (Bremner and Mulvaney 1982). Sample was digested with conc. H_2SO_4 in the presence of catalyst mixture (K_2SO_4:$CuSO_4.5H_2O$:Se = 10:1:0.1). Nitrogen in the digest was estimated by distilling the digest with 10 N NaOH followed by titration of the distillate trapped into H_3BO_3 indicator solution with 0.01 N H_2SO_4.
Available P	The sample was digested with di-acid mixture (HNO_3-$HClO_4$) and this digest was used to determine P, K, S, and Zn contents. The concentration of P in the digest was determined colorimetrically using molybdovanadate solution yellow color method (Yoshida et al. 1976).
Exchangeable K	The concentration of K in the digest was determined directly by flame photometer (Yoshida et al. 1976).
Available S	The S concentration in the digest was determined by developing turbid using $BaCl_2$ (Chapman and Pratt 1961).
Total Zn	The concentration of Zn in the acid digest was determined directly by atomic absorption spectrophotometer (Yoshida et al. 1976).
Available B	The B concentration in the digest in terms of color was determined by spectrophotometer following azomethine-H method (Keren 1996).
Total Cd and Pb	Vermicompost sample was digested with HNO_3-$HClO_4$ (4:1) for 1.5 h at 190°C and determined by atomic absorption spectrophotometer, Model UNICAM 969, England (Yoshida et al. 1976).

treatment section of this manuscript. This was done for adapting themselves to the experimental feeding materials prior to starting actual experiment.

Experimental set up

Earthworms of similar sizes were carefully selected from the earthen pots for further studies. A total of 100 g earthworms were introduced in each of the *chari*. The *chari* was covered with wet gunny bags to maintain the optimal moisture. Distilled water was sprinkled on the materials when necessary, to maintain moisture level of 70% (wet weight basis). The experiment was set in shed to avoid direct sunlight. Each of the *chari* was monitored every day. Three replicates were maintained for each of the treatments.

All the *chari* were maintained in the shed for an incubation period of 45 days. The appearance of black granular powder on top of feeding stuff indicates harvest stage of compost. Watering was stopped for at least 5 days before this stage. After completion of the incubation period, all of the earthworms were removed from the *chari* manually by hand sorting. Following separation from vermicompost, the total number and biomass of live earthworms were measured through quantification and weighing scale. Then the materials in each *chari* were made to pass through a bamboo made sieve to separate vermicompost from other residual debris. All the sieved samples were gently mixed to achieve homogeneity. The samples were spread on a brown paper in the laboratory for air-drying. The processed samples were kept in polythene bags for subsequent chemical analysis.

Data collected

1. Amount of vermicompost produced: The separated vermicompost were air-dried and weighed to get the amount of vermicompost produced in each of the treatments.
2. Collection and chemical analysis of vermicompost samples: Vermicompost samples were collected replication wise for each of the treatments randomly from the freshly harvested vermicompost heap. The collected samples were then air-dried and preserved for chemical analysis. Chemical analysis was done to determine the chemical properties of vermicomposts using the methods cited in Table 2. Vermiremoval of cadmium and lead from the feeding materials was calculated using the contents of these metals in feeding materials and vermicomposts. The total content of heavy metals (cadmium and lead) in organic materials before and after pre-composting was found almost the same. Hence, vermiremoval of cadmium and lead

from the feeding materials was thus calculated using the contents of these metals in feeding materials (pre-composted) and vermicomposts.

3. Change in weight of earthworm populations: After the completion of the experiment, earthworms in each *chari* were separated from vermicompost carefully and were weighed to get their live weight. The differences between initial and final weights of the earthworm were calculated to estimate the changes in weight of earthworm populations.
4. Change in number of earthworm populations: At the start of experimentation, the number of earthworms comprising in 100 g of weight for each *chari* was counted. Accordingly, at the end of the study, the final numbers were counted to find out the changes taking place in the number of earthworm population during experimentation.

Statistical analysis

Data recorded on different parameters were subjected to statistical analysis through computer-based statistical program R following the basic principles, as outlined by Gomez and Gomez (1984). Significant effects of treatments were determined by analysis of variance (ANOVA) and treatment means were compared at 5% level of significance by Duncan's Multiple Range Test (DMRT).

Results

Effect of earthworm species and feeding materials on vermicompost productivity and earthworm biomass

Vermicompost productivity

The vermicompost productivity was affected significantly by the earthworm species used in the study (Table 3). The highest amount of vermicompost was produced by *E. fetida* (456.7 g kg^{-1}) and the lowest amount (414.9 g kg^{-1}) was produced by *E. eugeniae*. Feeding materials used in the study had significant role in vermicompost productivity. The highest productivity was recorded by using cow dung (512.9 g kg^{-1}) followed by cow dung–poultry litter (484.1 g kg^{-1}), and the lowest productivity was found from using poultry litter–water hyacinth (387.2 g kg^{-1}) as feeding materials. Accordingly, interactions of earthworm species and feeding materials were found to affect significantly the vermicompost productivity. The highest productivity was observed from the interaction of *E. fetida*–cow dung (534.4 g kg^{-1}) followed by *E. eugeniae*–cow dung (491.4 g kg^{-1}), and *E. eugeniae*–cow dung + poultry litter (487.0 g kg^{-1}) interactions.

Increase in earthworm biomass

During the incubation period, the weight of earthworm population increased at different rates in different treatments (Table 3). Earthworm species affected significantly the rate of such increase in biomass. The highest increase in biomass was found for *E. eugeniae* (20.17%) and the lowest was in *E. fetida* (12.00%). Earthworm biomass was also significantly increased by the feeding materials used. Among the feeding materials, cow dung influenced for the highest biomass (28.83%) and cow dung–water hyacinth helped for the lowest biomass of earthworm (10.00%). Cow dung + poultry litter (13.00%) and poultry litter + water hyacinth (12.50%) had statistically similar role in biomass production. Interaction of earthworm species and feeding materials affected earthworm biomass significantly during the experiment. The highest role in earthworm biomass production (31.67%) was played by *E. fetida* when the feeding material was cow dung and it was followed by *E. eugeniae* (26.00%). The lowest biomass was produced by *E. fetida* when fed with poultry litter + water hyacinth (2.67%).

Increase in earthworm number

Like earthworm biomass, earthworm number was also significantly increased by earthworm species, feeding materials, and also by their interaction (Table 3). *E. fetida* and *E. eugeniae* influenced for the highest and lowest increase in earthworm number (16.67 and 5.24%, respectively). Cow dung influenced for the highest increase in earthworm number (14.38%) followed by cow dung + water hyacinth (10.70%) and the lowest increase was in poultry litter–water hyacinth (9.13%) as feeding materials. *E. fetida*–cow dung interaction showed the highest increase in earthworm number (23.23%) followed by *E. fetida*–cow dung + water hyacinth (17.48%). *E. fetida*–cow dung + poultry litter and *E. fetida*–poultry litter + water hyacinth had

Table 3 Effects of earthworm species, feeding materials, and their interactions on vermicompost production and dimension of earthworm population

Species/feeding materials/interactions	Vermicompost productivity (g kg^{-1})	Increase in earthworm biomass (%)	Increase in earthworm number (%)
Species:			
Eisenia fetida	456.7a	12.00b	16.67a
Eudrilus eugeniae	414.9b	20.17a	5.24b
Significance level	0.001	0.001	0.001
CV (%)	4.23	10.61	10.55
Feeding materials			
CD	512.9a	28.83a	14.38a
CDWH	359.0d	10.00c	10.70b
CDPL	484.1b	13.00b	9.62bc
PLWH	387.2c	12.50b	9.13c
Significance level	0.001	0.001	0.001
CV (%)	4.23	10.61	10.55
Species × Feeding materials			
Eisenia fetida–CD	534.4a	31.67a	23.23a
Eisenia fetida–CDWH	405.6c	9.67d	17.48b
Eisenia fetida–CDPL	481.1b	4.00e	13.27c
Eisenia fetida–PLWH	405.6c	2.67e	12.73c
Eudrilus eugeniae–CD	491.3b	26.00b	5.53de
Eudrilus eugeniae–CDWH	312.4e	10.33d	3.92e
Eudrilus eugeniae–CDPL	487.0b	22.00c	5.97d
Eudrilus eugeniae–PLWH	369.0d	22.33c	5.54de
Significance level	0.01	0.001	0.001
CV (%)	4.23	10.61	10.55

Means followed by the same letter in a column are not significantly different at 5% level by DMRT. *CV* co-efficient of variation; *CD* cow dung; *CDWH* cow dung + water hyacinth; *CDPL* cow dung + poultry litter; *PLWH* poultry litter + water hyacinth

statistically similar effects on earthworm number (13.27 and 12.73%, respectively).

Effect of earthworm species and feeding materials on vermiremoval of cadmium and lead from organic feeding materials

Vermiremoval of cadmium from feeding materials

Significant reduction in cadmium content of different vermicomposts as compared with that of respective feeding materials was recorded due to earthworm species used in the study (Table 4). Lower cadmium content was recorded for vermicompost produced by using *E. fetida* (0.135 ppm) than *E. eugeniae* (0.310 ppm). While comparing with the cadmium content of feeding materials, significantly higher removal was found in using *E. fetida* (60.43%) than *E. eugeniae* (8.18%). Cadmium content of vermicompost and its vermiremoval, both parameters varied markedly with the feeding materials used in the experiment. The lowest content (0.198 ppm) was recorded in vermicompost produced from poultry litter–water hyacinth while the highest content (0.267 ppm) was found in case of cow dung + water hyacinth substrate. Again, the highest removal of cadmium was observed in vermicompost from cow dung + poultry litter (41.41%) followed by poultry litter–water hyacinth (34.39%) and cow dung (32.86%) as feeding materials. The interaction effects of earthworm species and feeding materials (substrate) on cadmium content and its vermiremoval varied significantly (Table 3). The lowest cadmium content (0.107 ppm) as well as the

Table 4 Effects of earthworm species, feeding materials, and their interactions on the content of cadmium and lead in vermicomposts, and their vermiremoval from feeding materials

Species/feeding materials/interactions	Concentration in vermicompost (ppm)		Vermiremoval from feeding materials (%)	
	Cadmium	Lead	Cadmium	Lead
Species				
Eisenia fetida	0.135	4.31b	60.43a	48.18a
Eudrilus eugeniae	0.310	6.38a	8.18b	22.33b
Significance level	0.001	0.001	0.001	0.001
CV (%)	7.31	7.02	14.39	14.94
Feeding materials				
CD	0.237b	2.42d	32.86b	67.31a
CDWH	0.267a	7.76a	28.57b	22.76b
CDPL	0.188c	4.65c	41.41a	27.57b
PLWH	0.198c	6.54b	34.39b	23.39b
Significance level	0.001	0.001	0.01	0.001
CV (%)	7.31	7.02	14.39	14.94
Species × Feeding materials				
Eisenia fetida–CD	0.147ef	1.92g	58.57ab	74.16a
Eisenia fetida–CDWH	0.167e	6.86b	55.53b	31.74d
Eisenia fetida–CDPL	0.120fg	3.64e	62.5ab	43.38c
Eisenia fetida–PLWH	0.107g	4.83d	65.12a	43.44c
Eudrilus eugeniae–CD	0.327b	2.93f	7.14d	60.46b
Eudrilus eugeniae–CDWH	0.367a	8.67a	1.62d	13.78e
Eudrilus eugeniae–CDPL	0.257d	5.67c	20.31c	11.76ef
Eudrilus eugeniae–PLWH	0.290c	8.26a	3.65d	3.34f
Significance level	0.10	0.001	0.1	0.01
CV (%)	7.31	7.02	14.39	14.94

Means followed by same letter in a column are not significantly different at 5% level by DMRT. *CV* co-efficient of variation; *CD* cow dung; *CDWH* cow dung + water hyacinth; *CDPL* cow dung + poultry litter; *PLWH* poultry litter + water hyacinth

highest vermiremoval (65.12%) was recorded for vermicompost produced from the interaction effect of *E. fetida* and poultry litter + water hyacinth. On the other hand, the highest content (0.367 ppm) as well as the lowest vermiremoval of cadmium (1.62%) was found from *E. eugeniae* and cow dung + water hyacinth interaction.

Vermiremoval of lead from feeding materials

Earthworm species had significant role on the removal of lead from organic substrate through vermicomposting process (Table 4). *E. fetida* was found to be more efficient in removing lead (48.18%) through vermicomposting which produced vermicompost having less content of lead (4.31 ppm) than *E. eugeniae* that showed 22.33% of lead removal from the feeding materials and a content of 6.38 ppm lead in vermicompost. Different feeding materials were found to have significant role on the vermiremoval of lead. The use of cow dung has resulted in the highest removal of lead (67.31%) from the feeding materials and hence the lowest content of lead (2.42 ppm) in vermicompost was observed. Again, the lowest removal of lead (22.76%) and the highest content (7.76 ppm) was recorded while using cow dung + water hyacinth as feeding material. Significant variations were found in vermiremoval of lead from feeding materials and the content of lead in vermicomposts due to the interaction of earthworm species and feeding materials used. The highest removal was noticed in *E. fetida*–cow dung interaction (74.16%) followed by *E. eugeniae*–cow dung (60.46%), *E. fetida*–poultry litter + water hyacinth

(43.44%), and *E. fetida*–cow dung + poultry litter (43.38%) interaction. Accordingly, the lowest content of lead in vermicompost was observed in *E. fetida*–cow dung interaction (1.92 ppm) followed by *E. eugeniae*–cow dung (2.93 ppm), *E. fetida*–cow dung + poultry litter (3.64 ppm), and *E. fetida*–poultry litter + water hyacinth (4.83 ppm) interaction.

Effect of earthworm species and feeding materials on pH and nutrient content of vermicompost

Measurement of pH of vermicompost

The pH values of vermicomposts varied significantly due to earthworm species, feeding materials, and their interactions in the study (Table 5). Slightly alkaline pH (7.39) was observed for *E. fetida* while slightly acidic pH was noticed for *E. eugeniae*. Due to the effect of feeding materials, pH of vermicomposts ranged from 6.81 to 7.31. The highest value of pH was recorded for cow dung + water hyacinth while the lowest value was found for poultry litter + water hyacinth feeding material. The interactions of earthworm species and feeding materials also affected for the highest pH value (7.65) by the *E. fetida*–cow dung interaction followed by *E. fetida*–cow dung (7.63) interaction. These two interactions had statistically similar effects on pH of vermicompost. Again, the lowest pH value (6.63) was found in the *E. eugeniae*–cow dung interaction. Vermicomposts derived from interactions of *Eudrilus eugeniae* and feeding materials have considerably lower pH value than vermicomposts from interactions of *E. fetida* and feeding materials.

Total nitrogen content of vermicompost

Different feeding materials used in the study significantly influenced the nitrogen content of vermicomposts where the highest content (1.91%) was found for using cow dung and the lowest (1.71%) was for poultry litter + water hyacinth as feeding material (Table 5). The earthworm species as well as the interaction between earthworm species and feeding materials did not affect the nitrogen content of vermicompost at all.

Available phosphorus content of vermicompost

Earthworm species had significant role on available phosphorus content of vermicompost (Table 5). The highest phosphorus content was observed with *E. eugeniae* (0.557%) where the lowest was found with *E. fetida* (0.474%). Again, the feeding materials also had significant effect on the available phosphorus content where it ranged from 0.365 to 0.622%. The highest content was measured for poultry litter + water hyacinth feeding materials and it was statistically similar with that of cow dung + poulty litter (0.580%). The lowest content of phosphorus was found in cow dung as feeding materials. The interactions between earthworm species and feeding materials have no significant role on the phosphorus content of vermicomposts where it ranged from 0.323 to 0.650%.

Exchangeable potassium content of vermicompost

Exchangeable potassium content of vermicomposts was not significantly varied with earthworm species where it ranged from 1.033 to 1.045% (Table 5). The feeding materials used in the experiment significantly affected the potassium content of vermicompost. The highest content was observed for cow dung + water hyacinth (1.289%) feeding materials followed by poultry litter + water hyacinth (1.013%) and cow dung + poultry litter (0.952%). The lowest content was observed for cow dung (0.902%) as feeding materials. The interaction between earthworm species and feeding materials did not affect significantly the potassium content of vermicompost where it varied from 0.877 to 1.350%.

Available sulfur content of vermicompost

Available sulfur content of vermicompost did not vary significantly by the earthworm species used in the study and it ranged from 0.209 to 0.217% (Table 5). On the other hand, it was significantly influenced by the use of different feeding materials. The highest sulfur content was recorded for cow dung + poultry litter (0.322%). The other three feeding materials have statistical at par effects on sulfur content of vermicomposts. The interactions between earthworm species and feeding materials did not play any significant role on the sulfur content of vermicomposts where it ranged from 0.141 to 0.337%.

Available zinc content of vermicompost

Earthworm species, those used in the experiment, did not influence significantly the zinc content of vermicomposts (Table 5). The highest zinc content was found 55.21 ppm while the lowest content was observed as 54.66 ppm. Accordingly, the interactions of earthworm species and

Table 5 Effects of earthworm species, feeding materials, and their interactions on different parameters/nutrients in vermicompost

Earthworm species/feeding materials/ interactions	Measurement of different parameters/nutrient elements in vermicompost						
	pH	Total N (%)	Available P (%)	Exchangeable K (%)	Available S (%)	Available Zn (ppm)	Available B (ppm)
Species							
Eisenia fetida	7.39a	1.80	0.474b	1.045	0.217	54.66	59.0
Eudrilus eugeniae	6.64b	1.83	0.557a	1.033	0.209	55.21	58.5
Significance level	0.001	NS	0.01	NS	NS	NS	NS
CV (%)	2.11	4.74	12.66	16.11	15.18	3.41	2.53
Feeding materials							
CD	7.00b	1.91a	0.365c	0.902b	0.192b	52.88b	59.4ab
CDWH	7.31a	1.87ab	0.495b	1.289a	0.182b	56.40a	58.2b
CDPL	6.93b	1.76bc	0.580a	0.952b	0.322a	53.73b	61.3a
PLWH	6.81b	1.73c	0.622a	1.013b	0.155b	56.75a	56.2c
Significance level	0.001	0.01	0.001	0.01	0.001	0.01	0.001
CV (%)	2.11	4.74	12.66	16.11	15.18	3.41	2.53
Species × Feeding materials							
Eisenia fetida–CD	7.65a	1.93	0.323	0.927	0.199	51.60	60.0
Eisenia fetida–CDWH	7.63a	1.88	0.470	1.350	0.162	56.40	57.8
Eisenia fetida–CDPL	7.30b	1.73	0.510	0.877	0.337	54.40	61.7
Eisenia fetida–PLWH	6.99c	1.67	0.593	1.023	0.169	56.25	56.4
Eudrilus eugeniae–CD	6.36d	1.89	0.407	0.877	0.186	54.15	58.8
Eudrilus eugeniae–CDWH	7.00c	1.85	0.520	1.227	0.202	56.40	58.5
Eudrilus eugeniae–CDPL	6.55d	1.79	0.650	1.023	0.306	53.05	60.8
Eudrilus eugeniae–PLWH	6.64d	1.78	0.650	1.000	0.141	57.25	56.0
Significance level	0.001	NS	NS	NS	NS	NS	NS
CV (%)	2.11	4.74	12.66	16.11	15.18	3.41	2.53

Means followed by same letter in a column are not significantly different at 5% level by DMRT. *CV* co-efficient of variation; *CD* cow dung; *CDWH* cow dung + water hyacinth; *CDPL* cow dung + poultry litter; *PLWH* poultry litter + water hyacinth

feeding materials did not show any significant effect on zinc content of vermicomposts. On the other hand, different feeding materials used in the experiment affected significantly the zinc content of vermicomposts produced in the experiment. The highest zinc content was observed for poultry litter + water hyacinth (56.75 ppm) and similar effect was noticed for cow dung + water hyacinth (56.40 ppm) feeding materials. The lowest zinc content was observed for cow dung (52.88 ppm) which is followed by cow dung + poultry litter (53.73 ppm) as feeding materials.

Available boron content of vermicompost

Available boron concentration in produced vermicomposts varied significantly due to the feeding materials used in the study where it ranged from 56.2 to 61.3 ppm (Table 5). The highest content was noticed for using cow dung + poultry litter as feeding materials and it had statistical similarities with that of using only cow dung. Use of different earthworm species and their interaction with feeding materials had offered no significant role in the boron content of vermicomposts produced.

Discussion

Between the two earthworm species, *E. fetida* has performed better than *E. eugeniae* in terms of the amount of vermicompost produced. On the other hand, using only cow dung as feeding materials produced the highest amount of vermicompost comparing the other three combinations of feeding material. Accordingly, interaction of *E. fetida*–cow dung has also produced the highest amount of vermicompost among the interactions used in the study. Higher increase in earthworm biomass was found for *E. eugeniae* than for *E. fetida*. Larger body weight and voracious intake of food might be contributed to the issue. On the other hand, cow dung as feeding materials, has influenced for the highest number and biomass production of earthworm species. It might be due to the palatability of cow dung as feeding materials. Again, the interaction of *E. fetida*–cow dung had the highest role in earthworm biomass production. The influence of *E. fetida* as earthworm species was the highest increase in earthworm number. The interaction of *E. fetida*–cow dung showed the highest increase in earthworm number. Yadav and Garg (2011) described that the higher growth rate in a particular feeding substrate may be due to the more delectability and desirability of feed by worms. Suthar (2007) also realized that substrates that are easily decomposable and have excess nutrients will be more acceptable to earthworm. *E. eugeniae* escalated in total biomass much more rapidly than *E. fetida*, a species which grows relatively well in most organic wastes (Edwards 1988).

Vermiremoval of cadmium was found due to the use of both earthworm species and feeding materials as well as their interaction effects. In this context, the effect of earthworm species *E. fetida*, cow dung + poultry litter as feeding material and the interaction effects of *E. fetida* and poultry litter + water hyacinth were found promising. Again, *E. fetida* was found to be more efficient in removing lead from contaminated feeding materials. Accordingly, using cow dung as feeding materials and the effect of *E. fetida*–cow dung interaction have also resulted in the highest removal of lead from the feeding materials. It is assumed that earthworms' gut has some mechanisms which bind different heavy metals like lead to form complexes or other unavailable forms. During vermicomposting, the heavy metals forms complex, aggregates with humic acids, and other polymerized organic fractions resulting in lower availability of these heavy metals to the plant, which are otherwise phytotoxic (Dominguez and Edwards 2004). The lower removal of those heavy metals from feeding materials, i.e., the higher content of those metals in vermicomposts might be contributed by the higher content of those metals in the feeding materials. Another reason might be contributed to the issue; several studies have shown that earthworms have a high potential for biological bioremediation of contaminated soils (Suthar et al. 2008; Nahmani et al. 2009; Li et al. 2010; Hirano and Tamae 2011). Although there are some contradictory reports available (Khwairakpam and Bhargava 2009; Hait and Tare 2012) but it is also reported that earthworms have some mechanisms to accumulate a high concentration of heavy metals like cadmium and lead in their body while the feeding material passes through their gut (Shahmansouri et al. 2005; Li et al. 2010; Brewer and Barrett 1995; Bamgbose et al. 2000). Again, some of the heavy metals are essential micronutrients for plants at lower doses, but in higher doses they may cause metabolic disorders and growth inhibition in most plant species (Sinha et al. 2005). Azizi et al. (2013) found that concentrations of heavy metals, namely Cr, Cd, and Pb in vermicompost were lower than initial concentrations in the raw materials while that of Cu and Zn were found to have increased compared with initial concentrations.

There was a reduced pH value observed in the vermicomposts than in the feeding materials used. It might be due to the different biochemical reactions occurred in the earthworms' gut. Besides this, the pH values of vermicomposts were guided by that of the feeding materials used as the trend of pH in vermicomposts has similarities with that of the feeding materials. Regarding this issue, Ndegwa et al. (2000) opined that different substrate would result in the formation of a different intermediate; hence, there is a difference in pH of the vermicompost formed. Slightly alkaline pH was observed for *E. fetida* while slightly acidic pH was noticed for *E. eugeniae*. Vermicomposts derived from interactions of *E. eugeniae* and feeding materials have considerably lower pH value which lies in neutral or below neutral pH value. On the other hand, vermicomposts from interactions of *E. fetida* and feeding materials have pH that mostly lie in the upper ranges from neutral. Such findings indicate that *E. eugeniae* has some capability to reduce pH of alkaline substrate through composting.

The earthworm species *E. eugeniae* and poultry litter + water hyacinth as feeding material influenced for higher available phosphorus content. This feeding material, i.e., poultry litter + water hyacinth also showed the highest zinc content in vermicompost though cow dung + water hyacinth had the similar effect. This might be due to the nutrient content of feeding materials; in each case, there was an inclusion of water hyacinth which has higher content of P and Zn as found from the analytical results.

It should be noted here that in most cases the Zn content in the vermicomposts is comparatively higher than that of the respective feeding materials. The findings of this study are in accordance with the study who found increased Zn content in the vermicompost (Sainz et al. 1998). For exchangeable potassium content of vermicomposts, cow dung + water hyacinth performed better as feeding materials while cow dung + poultry litter was found promising for sulfur and boron content of vermicompost. Here, it can also be assumed that the S and B content of feeding materials contributed for the higher content of those nutrient elements in vermicomposts. It is because the higher content of S and B was found in the chemical analysis of poultry litter which was one of the components of those higher S and B producing feeding materials. Yan et al. (2013) showed that nutrient in initial wastes material affects the nutrient contents of vermicompost. Vermicompost contains enzymes like amylase, lipase, cellulase, and chitinase, which can break down the organic matter in the soil to release the nutrients and make it available to the plant roots (Chaoui et al. 2003).

Conclusions

Both the earthworm species, i.e., *E. fetida* and *E. eugeniae* are promising in vermicomposting though there are some variability regarding quantity and quality of produced vermicompost. The choice of feeding materials used in vermicomposting is also important for quality concern of vermicompost.

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References

Abdelmonem MEM, Kuttyammoo M, Hassanein K, Zayed AEZ (2016) Vermicomposting: analysis of soil nutrients enrichment with indigenous species from Jazan province of Saudi Arabia. Int J Adv Res Biol Sci 3(10):131–137

Azizi AB, Lim MPM, Noor ZM, Abdullah N (2013) Vermiremoval of heavy metal in sewage sludge by utilizing *Lumbricus rubellus*. Ecotox Environ Safe. https://doi.org/10.1016/j.ecoenv.2012.12.006i

Bamgbose O, Odukoya O, Arowolo T (2000) Earthworms as bioindicators of metal pollution in dump sites of Abeokuta City, Nigeria. Rev Biol Trop 48:229–234

Boyd CE (1970) Vascular aquatic plants for mineral nutrient removal from polluted waters. Econ Bot 24:95–103

Bremner JM, Mulvaney CS (1982) Nitrogen total. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Agron. No. 9, part 2: chemical and microbiological properties, 2nd edn. American Society of Agronomy, Madison, pp 595–624

Brewer S, Barrett G (1995) Heavy metal concentrations in earthworms following long-term nutrient enrichment. Bull Environ Contam Toxicol 54:120–127

Chaoui HI, Zibilske LM, Ohno T (2003) Effects of earthworm's casts and compost on soil microbial activity and plant nutrient availability. Soil Biol Biochem 35:295–302

Chapman HD, Pratt PF (1961) Methods of analysis for soil, Plant and Water. Division of Agricultural Sciences, University of California, USA

Domínguez J (2004) State of the art and new perspectives on vermicomposting research. In: Edwards CA (ed) Earthworm ecology. CRC Press, Boca Raton, pp 401–424

Dominguez J, Edwards CA (2004) Vermicomposting organic wastes: a review. In: Shakir Hanna SH, Mikhail WZA (eds) Soil zoology for sustainable development in the 21st century, Cairo, pp 369–395

Domínguez J, Aira M, Gómez-Brandón M (2010) Vermicomposting: earthworms enhance the work of microbes. In: Insam H, Franke-Whittle H, Goberna M (eds) Microbes at work: from wastes to resources. Springer, Berlin, pp 93–114

Edwards CA (1988) Breakdown of animal, vegetable and industrial organic wastes by earthworms. In: Edwards CA, Neuhauser EF (eds) Earthworms in waste and environmental management SPB, The Hague, pp 21–31

Gomez KA, Gomez AA (1984) Statistical procedures for agricultural research. John Wiley and Sons, New York

Gurav MV, Pathade GR (2011) Production of vermicompost from temple waste (Nirmalya): a case study. Univers J Environ Res Technol 1:182–192

Hait S, Tare V (2012) Transformation and availability of nutrients and heavy metals during integrated composting-vermicomposting of sewage sludges. Ecotoxicol Environ Saf 79(1):214–224. https://doi.org/10.1016/j.ecoenv.2012.01.004

Hirano T, Tamae K (2011) Earthworms and soil pollutants. Sensors 11:11157–11167

Jain K, Singh J, Chauhan LKS, Murthy RC, Gupta SK (2004) Modulation of flyash-induced genotoxicity in *Vicia faba* by vermicomposting. Ecotox Environ Safe 59(1):89–94. https://doi.org/10.1016/j.ecoenv.2004.01.009

Kagi JHR, Kojima Y (1987) Chemistry and biochemistry of metallothionein. In: Kagi JHR, Kojima Y (eds) Metallothionein II. Birkhauser Verlag, Basel, pp 25–61

Keren R (1996) Boron. In: Sparks DL, Page AL, Helmke PA, Loeppert RH, Soltanpour PN, Tabatabai MA, Johnston CT, Sumner ME (eds) Methods of soil analysis. Part 3: chemical methods. American Society of Agronomy, Madison, pp 603–626

Khwairakpam M, Bhargava R (2009) Vermitechnology for sewage sludge recycling. J Hazard Mater 161:948–954. https://doi.org/10.1016/j.jhazmat.2008.04.088

Lavelle P, Barois I, Blanchart E, Brown G, Brussaard L, Decaens T, Fragoso C, Jimenez JJ, Kajondo KK, Martinez MA, Moreno A, Pashanasi B, Senapati B, Villenave C (1998) Earthworms as a resource in tropical agroecosystems. Nat Resour 34:26–41

Li L, Xu Z, Wu J, Tian G (2010) Bioaccumulation of heavy metals in the earthworm *Eisenia fetida* in relation to bioavailable metal concentrations in pig manure. Bioresour Technol 101: 3430–3436

Lourduraj AC, Yadav BK (2005) Effect of vermicompost application on soil and plant growth. In: Kumar A (ed) Verms and vermitechnology, SB Nangia. APH Publishing Corp, New Delhi, pp 81–96

McLean EO (1982) Soil pH and Lime Requirement. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Part 2: chemical and microbiological properties, 2nd edn. American Society of Agronomy, Madison, pp 199–224

Nahmani J, Hodson ME, Devin S, Vijver MG (2009) Uptake kinetics of metals by the earthworm *Eisenia fetida* exposed to field-contaminated soils. Environ Pollut 157:2622–2628

Ndegwa PM, Thompson SA, Das KC (2000) Effects of stocking density and feeding rate on vermicomposting of biosolids. Bioresour Technol 71:5–12

Pattnaik S, Reddy MV (2011) Heavy metals remediation from urban wastes using three species of earthworm (*Eudrilus eugeniae*, *Eisenia fetida* and *Perionyx excavatus)*. J Environ Chem Ecotoxicol 3(14):345–356

Sainz MJ, Taboada-Castro MT, Vilariño A (1998) Growth, mineral nutrition and mycorrhizal colonization of red clover and cucumber plants grown in a soil amended with composted urban wastes. Plant Soil 205:85–92

Shahmansouri M, Pourmoghadas H, Parvaresh A, Alidadi H (2005) Heavy metals bioaccumulation by Iranian and Australian earthworms (*Eisenia fetida*) in the sewage sludge vermicomposting. Iran J Environ Health Sci Eng 2:28–32

Singh J, Kalamdhad AS (2013) Reduction of bioavailability and leachability of heavy metals during vermicomposting of water hyacinth. Environ Sci Pollut Res 20:8974–8985

Sinha S, Pandey K, Gupta AK, Bhatt K (2005) Accumulations of metals in vegetables crops grown in the area irrigated with river water. Bull Environ Contam Toxicol 74:210–218

Suthar S (2007) Nutrient changes and biodynamics of epigeic earthworm *Perionyx excavatus* (Perrier) during recycling of some agricultural waste. Bioresour Technol 98(8):1608–1614

Suthar S (2010) Recycling of agro-industrial sludge through vermitechnology. Ecol Eng 36(8):1028–1036. https://doi.org/10.1016/j.ecoleng.2010.04.015

Suthar S, Singh S, Dhawan S (2008) Earthworms as bio-indicator of metals (Zn, Fe, Mn, Cu, Pb and Cd) in soils: is metal bioaccumulation affected by their ecological category? Ecol Eng 32:99–107

Suthar S, Sajwan P, Kumar K (2014) Vermiremediation of heavy metals in wastewater sludge from paper and pulp industry using earthworm *Eisenia fetida*. Ecotox Environ Safe 109:177–184

Whiston RA, Seal KJ (1988) The occurrence of cellulases in the earthworm *Eisenia fetida*. Biol Wastes 25:239–242

Yadav A, Garg VK (2011) Recycling of organic wastes by employing *Eisenia fetida*. Bioresour Technol 102:2874–2880

Yan YW, Azwady AAN, Shamsuddin ZH, Muskhazli M, Aziz SA, Teng SK (2013) Comparison of plant nutrient contents in vermicompost from selected plant residues. Afr J Biotechnol 12(17):2207–2214

Yoshida S, Forno AD, Cock JA, Gomez KA (1976) Physiological studies of rice, 2nd edn. International Rice Research Institute, Manila