Effect of feeding materials on productivity and quality of vermicompost produced by two earthworms species

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Submission: 27 September 2022 Revised: 27 December 2022 Accepted: 28 December 2022

ABSTRACT

Vermicompost is a nutrient-enriched organic fertilizer that is promising for crops' vigorous growth and soil environment maintenance. The purpose of the present study was to evaluate the vermicompost productivity and efficiency of two earthworm species (*Eisenia fetida* and *Eudrilus eugeniae*) to produce quality vermicomposts from different organic feeding substrates. The experiment was carried out using a 2 × 4 factorial in a completely randomized design where factor A comprised of two earthworm species viz., *E. fetida* and *E. eugeniae*, and factor B consisted of four feeding materials viz., cowdung, cowdung + water lettuce (3:1), cowdung + poultry litter (3:1), and cowdung + rice straw (3:1). Each treatment replicated thrice. Earthworms were inoculated on chari (cement-made jars), having cowdung as feeding materials. Each chari was monitored regularly, and moisture was maintained within the range of 60–80%. Data were recorded on the number and biomass of earthworms and vermicompost productivity. Initial feeding materials and produced vermicompost were chemically analyzed following standard methods. Results showed that *E. fetida* performed significantly better than *E. eugeniae* in terms of the number of earthworms (215.08 ± 6.34 chari^{-1}), vermicompost productivity (1.41 ± 0.11 kg chari^{-1}), and production efficiency (47.66 ± 3.09%). The biomass of earthworms was found to be higher in *E. eugeniae* (58.01 ± 2.80 g chari^{-1}). Cowdung was the best feeding material in the case of vermicelli as well as vermicompost productivity (1.52 ± 0.10 kg chari^{-1}). Chemical analyses confirmed that N, P, K, and S increased, whereas pH values were reduced in produced vermicompost. The vermicompost productivity and number of earthworms were higher in *E. fetida*, whereas biomass was higher in *E. eugeniae.* Cowdung showed as the best feeding material with nutrient enrichment in produced vermicompost.

Keywords: *Eisenia fetida, Eudrilus eugeniae,* vermicompost, productivity, efficiency

Thai J. Agric. Sci. (2022) Vol. 55(3): 185−196

INTRODUCTION

Vermicomposting is a biooxidative mesophilic process of transforming organic waste into vermicompost where detritivorous earthworm species interact with microorganisms, intensely affect the breakdown processes, accelerate the steadiness of organic matter, and significantly improve its physical, chemical, and biological properties (Domínguez and Gómez-Brandón, 2013). Vermicompost is widely used as a biofertilizer, soil activator, fertility booster, and soil conditioner because it contains essential plant nutrients, enzymes, vitamins, growth hormones, and beneficial microbes such as nitrogen-fixing, phosphate-solubilizing, denitrifying, and decomposing bacteria (Jemal and Abebe, 2020; Murunga *et al*., 2020). The contents of total NPKS as well as micronutrients are higher in vermicompost than in surrounding soil, along with a higher cation exchange capacity (Abdelmonem *et al*., 2016; Sherman, 2017; Biruntha *et al*., 2020). In Bangladesh, soil organic matter is declining as a consequence of

high cropping intensity, inappropriate use of synthetic fertilizers, soil erosion, overgrazing, burning crop residues, etc. (Scialabba and Müller-Lindenlauf, 2010; Bhattacharyya *et al*., 2015). The application of quality vermicompost can be a better option for increasing the percentage of soil organic matter and enhancing soil fertility (Kumar *et al*., 2018).

Many factors are responsible for the success of the vermicomposting process. The effectiveness of vermicomposting process extensively depends on the utilization of efficient earthworm species; availability, suitability, and quality of feeding materials for earthworms; maintenance of temperature as well as the moisture content in the system (Yadav and Garg, 2011; Ali *et al*., 2015). Earthworm species that are used for commercial vermicomposting purposes are very few. These vermicomposting species have variability in their production efficiency and also in the quality of vermicompost produced. Feeding materials also have variability in palatability, particle size, pH, protein, crude fibre, etc. (Suthar, 2008). Vermiculture and vermicomposting are getting popular day by day at the farmers' level in Bangladesh. *Eisenia fetida* and *Eudrilus eugeniae,* these two earthworms are the most commonly rearing species in Bangladesh. There are various organic sources of feeding materials such as cowdung, water hyacinth, poultry manure, rice straw, etc., that are easily available, cost-effective, and commonly used for vermicompost production. Feeding material variations have a direct impact on the quantity and quality of produced vermicompost (Hřebečková *et al*., 2019; Sarker and Kashem, 2020). As a consequence, research is needed to evaluate vermicomposting productivity, efficiency, and the quality of vermicompost produced from different feeding materials. Hence, the current study sought to assess the vermicomposting efficiency of *Eisenia fetida* and *Eudrilus eugeniae* in producing high-quality vermicomposts from various organic feeding substrates.

MATERIALS AND METHODS

The experiment was carried out in the vermicompost production shed at the Department of Soil Science at Sylhet Agricultural University in Sylhet from August to October 2020. Below stated steps were followed during the experimentation.

Collection of Earthworm Species and Feeding Materials

Eisenia fetida and *Eudrilus eugeniae* were used from the stock in the vermicompost production shed. Cowdung was collected from Sylhet Government Dairy Farm and poultry litter was collected from a local farm nearby at Sylhet Agricultural University. Water lettuce was collected from a pond and rice straw was also collected from farmers' rice fields at South Sunamganj Upazila under Sunamganj district, Sylhet. The rice straw was cut into small pieces (around 1 inch). Each of the feeding materials was gone through the pre-composting process for 3 weeks. Feeding materials were partially decomposed and ready for use as treatment following pre-composting.

Experimental Design

Chari (cement-made jar), having an internal diameter of 24 inches and height of 12 inches was used for vermicomposting. The experiment was carried out using a 2 × 4 factorial in a completely randomized design with 3 replications.

Factor A: Two earthworm species: i) *Eisenia fetida* and ii) *Eudrilus eugeniae*

Factor B: Four feeding materials: i) cowdung (3 kg), ii) cowdung (2.25 kg) + water lettuce (0.75 kg; 3:1), iii) cowdung (2.25 kg) + poultry litter (0.75 kg; 3:1), and iv) cowdung (2.25 kg) + rice straw (0.75 kg; 3:1)

Twenty-four charis were divided into 3 sets (each set containing 8 treatment combinations) representing 3 replications.

Experimental Details

Initially, 50 g of earthworms of each earthworm species (*Eiseniae fetida* and *Eudrilus eugeniae* 177.14 ± 6.23 and 155.47 ± 5.97 in number, respectively) were released into each chari containing 3 kg of feeding materials according

to different treatments. During the 60 days of the vermicomposting period, each chari was monitored regularly and moisture was maintained properly (60–80%). The appearance of black and deep brown granules on the top of feeding materials was interpreted as an indication of the harvesting stage of vermicompost. Data on the biomass of earthworms, number of earthworms, and production of vermicompost were recorded. Initial feeding materials and produced vermicompost were chemically analyzed to estimate pH, organic carbon, total N, available P, exchangeable K, and available S following standard methods (Table 1).

Statistical Analysis

Data on different parameters were statistically analyzed using the computer-based statistical program R software in accordance with the basic principles outlined by Gomez and Gomez (1984). Significant effects of treatments were determined by analysis of variance (ANOVA) and treatment means were compared at 1% and 5% levels of significance by Duncan's new multiple range test.

Table 1 Analytical methods for chemical analyses of vermicompost

Elements/ parameters	Analytical methods
pH	A glass-electrode pH meter was used to measure pH keeping the vermicompost-to-water ratio at 1:2.5 (McLean, 1982).
Organic carbon	The soil organic carbon was oxidized with 1 N potassium dichromate and the amount of organic carbon in the aliquot was evaluated by titration with 0.5 N ferrous sulphate solution, as described by Nelson and Sommers (1996). Multiplying the organic carbon percenetage by the van Bemmelen factor of 1.73, the organic matter percenetage was calculated (Piper, 1950).
Total N	The micro-Kjeldahl method was used to determine the total nitrogen content of vermicompost (Bremner and Mulvaney, 1982). In the presence of a catalyst mixture (K_2SO_4:$CuSO_4$.$5H_2O$:Se = 10:1:0.1), the sample was digested with conc. H_2SO_4. The digest's nitrogen content was determined by distilling it with 10 N NaOH and then titrating the distillate trapped in an H_3BO_3 indicator solution with 0.01 N H_2SO_4.
Available P	P, K, and S content were determined by digesting the sample with a di-acid mixture (HNO_3-$HClO_4$) (Fang, 1991). Using the molybdovanadate solution yellow color technique, the concentration of P in the digest was measured colorimetrically (Yoshida *et al*., 1976).
Exchangeable K	A flame photometer was used to determine the amount of K in the digest (Yoshida *et al*., 1976).
Available S	The concentration of S in the digest was evaluated by employing $BaCl_2$ to develop turbidity (Chapman and Pratt, 1964).

RESULTS AND DISCUSSION

Earthworm Biomass

Earthworm biomass was found to be significantly higher in *E. eugeniae* at 58.01 ± 2.80 g chari^{-1} than in *E. fetida* at 55.59 ± 3.15 g chari^{-1} (Table 2). Significantly, *E. eugeniae* had a higher increase in earthworm biomass (16.02%) as compared to initial biomass. It was possibly due to *E. eugeniae*'s larger body weight. *E. eugeniae* thrive relatively well in most organic wastes and increases total biomass much faster than *E. fetida* (Edwards, 1988). Feeding materials had a significant role in earthworm biomass. The highest biomass of earthworms (61.94 ± 3.05 g chari^{-1}) was observed in cowdung as a feeding material, followed by cowdung + poultry litter (58.84 ± 2.26 g chari^{-1}). The lowest earthworm biomass of 44.25 ± 2.76 g chari^{-1} was produced in cowdung + water lettuce. The interactions between earthworm species and feeding materials did not play any significant role in the biomass of earthworms. Significantly, cowdung responded to the highest (20.87 ± 1.35%) change in biomass among the feeding materials. It could be because cowdung is palatable as feeding material. Moreover, the biochemical quality of the substrate materials influences earthworm growth and reproduction (Vodounnou *et al*., 2016). Cowdung + water lettuce resulted in a decrease in earthworm biomass (-11.50 ± 1.42%). The interactions between earthworm species and feeding materials did not play any significant role in the change in earthworm biomass.

Number of Earthworms Chari^{-1}

The number of earthworms varied significantly depending on earthworm species and feeding materials (Table 2). After 60 days of inoculation, *E. fetida* had a higher number of earthworms (215.08 ± 6.34 chari^{-1}) and *E. eugeniae* had a lower number (185.17 ± 5.13 chari^{-1}). Cowdung contained the most earthworms (243.00 ± 6.30 chari^{-1}) followed by cowdung + poultry litter (218.67 ± 6.03 chari^{-1}). Almost all types of animal dung are highly appealing and nutritious food sources for earthworms, with cowdung playing an important role in the worm diet (Curry and Schmidt, 2007). Meanwhile, cowdung + water lettuce had the lowest number of earthworms (144.33 ± 5.63 chari^{-1}). The lowest biomass and number of earthworms in the mixture of cowdung and water lettuce could be attributed due to the presence of higher pH and K in the initial feeding materials, which was less conducive to earthworm growth and could result in mortality. The interactions between earthworm species and feeding materials have no significant role in the number of earthworms chari^{-1}.

Vermicompost Productivity and Production Efficiency

Between two earthworm species, *E. fetida* (1.41 ± 0.11 kg chari^{-1}) produced significantly higher vermicompost than *E. eugeniae* (1.34 ± 0.09 kg chari^{-1}). The feeding materials had a significant effect on vermicompost productivity (Table 2). Cowdung showed the highest vermicompost productivity (1.52 ± 0.10 kg chari^{-1}) while cowdung + water lettuce responded to the lowest vermicompost productivity (1.09 ± 0.12 kg chari^{-1}). Cowdung as a feeding source may have easily metabolizable organic matter and a low concentration of growth inhibitors, promoting worm growth in the substrate and resulting in a higher compost yield (Joshi *et al*., 2015). The interaction between earthworm species and feeding materials had no significant role in vermicompost productivity.

The efficiency of vermicompost production varied significantly according to earthworm species and feeding materials (Table 2). The interaction between earthworm species and feeding materials had no significant effect on the efficiency of vermicompost production. *E. fetida* had higher vermicompost production efficiency (47.66 ± 3.09%) than *E. eugeniae* (44.66 ± 2.04%). On the other hand, cowdung as a feeding material, showed the highest vermicompost production efficiency (50.66 ± 2.67% of supplied cowdung), whereas cowdung + water lettuce showed the lowest vermicompost production efficiency (36.33 ± 3.07%). Cowdung can increase the stability of the material when converted into vermicompost, which is used as a feed for both microbes and earthworms (Kaur *et al*., 2010). The use of *E. eugeniae* resulted in a 71% conversion ratio of paddy straw to vermicompost (Viji and Neelanarayanan, 2013).

Table 2 Effects of earthworm species, feeding materials and their interactions on earthworm biomass, number, and vermicompost production

Treatments	Biomass of earthworm (g chari^{-1})	Change in earthworm biomass (%)	Number of earthworms chari^{-1}	Vermicompost productivity (kg chari^{-1})	Vermicompost production efficiency (%)
Earthworm species					
E. fetida	55.59 ± 3.15^{b}	11.19 ± 1.30^{b}	215.08 ± 6.34^{a}	1.41 ± 0.11^{a}	47.66 ± 3.09^{a}
E. eugeniae	58.01 ± 2.80^{a}	16.02 ± 1.45^{a}	185.17 ± 5.13^{b}	1.34 ± 0.09^{b}	44.66 ± 2.04^{b}
LS (P-value)	0.01	0.01	0.01	0.01	0.01
Feeding materials					
CD	61.94 ± 3.05^{a}	20.87 ± 1.35^{a}	243.00 ± 6.30^{a}	1.52 ± 0.10^{a}	50.66 ± 2.67^{a}
CDWL	44.25 ± 2.76^{d}	-11.50 ± 1.42^{d}	144.33 ± 5.63^{d}	1.09 ± 0.12^{d}	36.33 ± 3.07^{d}
CDPL	58.84 ± 2.26^{b}	17.68 ± 1.22^{b}	218.67 ± 6.03^{b}	1.33 ± 0.08^{b}	44.33 ± 2.73^{b}
CDRS	55.16 ± 3.02^{c}	10.33 ± 1.57^{c}	194.50 ± 5.55^{c}	1.18 ± 0.11^{c}	39.33 ± 2.82^{c}
LS (P-value)	0.01	0.01	0.01	0.01	0.01
Earthworm species × Feeding materials					
E. fetida × CD	62.81 ± 3.00	25.62 ± 1.34	262.00 ± 6.23	1.57 ± 0.09	52.33 ± 2.69
E. fetida × CDWL	43.36 ± 3.04	-13.28 ± 1.23	156.33 ± 66.31	1.11 ± 0.12	37.00 ± 3.06
E. fetida × CDPL	57.92 ± 2.72	15.84 ± 1.37	238.33 ± 5.83	1.40 ± 0.10	46.66 ± 2.47
E. fetida × CDRS	55.64 ± 2.69	11.28 ± 1.40	203.67 ± 5.64	1.18 ± 0.11	39.33 ± 2.56
E. eugeniae × CD	65.06 ± 2.92	30.12 ± 1.32	224.00 ± 6.03	1.47 ± 0.08	49.00 ± 2.60
E. eugeniae × CDWL	45.50 ± 2.61	-9.98 ± 1.27	132.33 ± 5.78	1.06 ± 0.09	35.33 ± 2.76
E. eugeniae × CDPL	59.42 ± 2.52	19.51 ± 1.30	199.00 ± 6.21	1.27 ± 0.11	42.33 ± 3.06
E. eugeniae × CDRS	55.28 ± 3.01	10.56 ± 1.35	185.33 ± 6.08	1.19 ± 0.10	39.66 ± 2.46
LS (P-value)	NS	NS	NS	NS	NS
CV (%)	6.42	40.52	8.72	5.36	5.36

Note: Means following dissimilar letter in a column are significantly different at 1% and 5% level of significance. NS = not significant, LS = level of significance, CV = coefficient of variation, CD = cowdung, CDWL = cowdung + water lettuce (3:1), CDPL = cowdung + poultry litter (3:1), CDRS = cowdung + rice straw (3:1)

Relationship between Temperature and Vermicompost Productivity

The maximum temperature ranged from 28.3 to 31.8°C while the minimum temperature ranged from 25.1 to 27.1°C. The average temperature ranged from 27 to 30.2°C. Irrespective of feeding materials, there were non-significant positive relationships between average (Figure 1A), maximum (Figure 1B), and minimum (Figure 1C) temperatures with vermicompost productivity. The highest relationship between temperature and vermicompost productivity was found for average temperature. It was possibly due to the temperature range of 20–30°C which was more favorable for earthworm growth, reproduction, and metabolic activity (Dominguez *et al*., 2001; Shagoti *et al*., 2001).

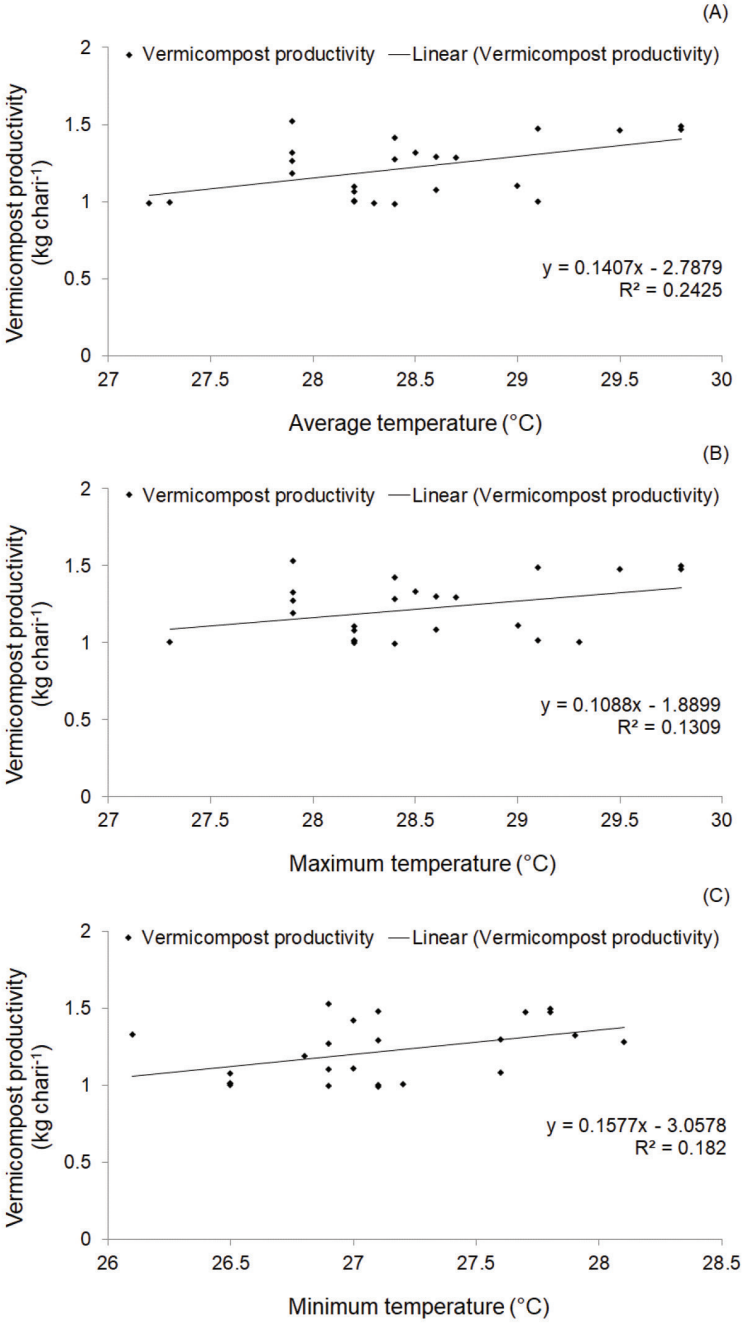

Figure 1 Relationship between average temperature (A), maximum temperature (B) and minimum temperature (C) with vermicompost productivity

Quality of Vermicompost

The chemical compositions of 4 feeding materials at initial stage are presented in Table 3.

pH

the pH of vermicomposts varied significantly due to earthworm species, feeding materials, and their interactions in the study (Table 4). Higher pH (7.11 ± 0.10) was observed for *E. fetida* while lower pH was noticed for *E. eugeniae* (6.59 ± 0.09). Due to the effect of feeding materials, the highest value of pH recorded for cowdung + water lettuce (7.41 ± 0.03) while the lowest value was found for cowdung (6.00 ± 0.12) feeding material. The interactions of earthworm species and feeding materials also affected the highest pH value (7.47 ± 0.25) by the interaction of *E. fetida* × CDWL followed by the interaction of *E. eugeniae* × CDWL (7.39 ± 0.20). This higher pH might be due to the higher pH in the respective feeding material. The lowest pH value (6.06 ± 0.15) was found in the interaction of *E. eugeniae* × CD. The pH values were lower in vermicomposts than in the initial feeding materials (Table 3). The decrease in pH during vermicomposting might be due to the decomposition of organic matter, the emissions of CO_2, and the presence of NH^{4+}-N ions (Pareek *et al*., 2016; Villar *et al*., 2016; Wang *et al*., 2016). A dissimilar trend was obtained by Singh *et al*. (2005) where pH increased from 4.3 to 8.2.

Table 3 Chemical characteristics in initial feeding materials

Treatments	pH	Organic carbon (%)	Total N (%)	C:N ratio	Available P (%)	Exchangeable K (%)	Available S (%)
CD	6.40 ± 0.12	9.50 ± 0.18	1.46 ± 0.11	6.50:1	0.27 ± 0.21	0.93 ± 0.17	0.29 ± 0.23
CDWL	7.60 ± 0.03	11.88 ± 0.12	1.38 ± 0.13	8.60:1	0.28 ± 0.16	1.16 ± 0.11	0.38 ± 0.18
CDPL	6.70 ± 0.11	11.68 ± 0.10	1.22 ± 0.18	9.57:1	0.31 ± 0.14	0.86 ± 0.21	0.45 ± 0.26
CDRS	7.10 ± 0.08	12.87 ± 0.15	1.29 ± 0.12	9.97:1	0.30 ± 0.09	0.90 ± 0.19	0.36 ± 0.20

Note: CD = cowdung, CDWL = cowdung + water lettuce (3:1), CDPL = cowdung + poultry litter (3:1), CDRS = cowdung + rice straw (3:1)

Organic carbon

Earthworm species had no significant role in organic carbon content in vermicompost. Different feeding materials used in the study significantly influenced the organic carbon content of vermicompost (Table 4). The highest organic carbon content was observed for cowdung + rice straw (14.32 ± 0.15%) feeding materials while the lowest content was observed for cowdung + poultry liter (12.59 ± 0.10%) as feeding materials. The interaction between earthworm species and feeding materials did not significantly affect organic carbon content of vermicompost where it varied from 12.48 ± 0.43 to 15.67 ± 0.33%. Similar results for organic carbon were also found by Maheswari and Priya (2018; 9.8–13.4%), Jaybhaye and Bhalerao (2016; 17.38%), and Ramnarain *et al*. (2019; 18.53%). The earthworm species as well as the interaction between earthworm species and feeding materials did not affect the organic carbon content of vermicompost at all.

Total nitrogen (N)

Earthworm species had no significant role in the total N content of vermicompost. The feeding materials used in the experiment significantly affected the nitrogen content of vermicomposts where the highest content (1.57 ± 0.11%) was found for using cowdung and the lowest (1.36 ± 0.12%) was for cowdung + rice straw as feeding materials (Table 4). The interaction between earthworm species and feeding materials did not affect the N content of vermicompost. The total N content of vermicompost was higher than the initial feeding materials (Table 3). This could be attributed to the rapid nitrification of ammonium ions into nitrates (Dominguez, 2004).

According to Benitez *et al*. (1999), earthworm decomposition accelerates the N mineralization process and thus alters the N profile of the substrate. Total N content in vermicomposts could range from 0.1 to 4% or higher (S *et al*., 2016).

Available phosphorus (P)

Earthworm species and feeding materials had significant role in available P content of vermicompost (Table 4). The highest available P content was observed with *E. eugeniae* (0.33 ± 0.11%) where the lowest was found with *E. fetida* (0.29 ± 0.08%). Due to effect of feeding materials, the highest available P content was measured for cowdung + poultry litter (0.38 ± 0.14%) while the lowest one was found in cowdung (0.29 ± 0.21%) as feeding materials. The interactions between earthworm species and feeding materials had no significant role in the available P content of vermicomposts where it ranged from 0.28 ± 0.13 to 0.34 ± 0.09%. Vermicompost had also higher available P content than the initial feeding materials (Table 3). The enhanced P level in vermicompost was possibly due to phosphorous mineralization and phosphorylation of organic content present in the feeding materials during the vermicomposting process (Dass *et al*., 2008). Gut enzymes of earthworms, such as acid phosphatases and alkaline phosphatases, aid in the conversion of some phosphorus to more available forms during the vermicomposting process (Le Bayon and Binet, 2006). According to Kale (1995), available P in vermicomposts ranges from 0.1 to 0.3%.

Table 4 Chemical characteristics of vermicompost

Treatment	pH	Organic carbon (%)	Total N (%)	Available P (%)	Exchangeable K (%)	Available S (%)
Earthworm species						
E. fetida	7.11 ± 0.10^{a}	13.36 ± 0.16	1.53 ± 0.12	0.29 ± 0.08^{b}	1.08 ± 0.15	0.35 ± 0.19
E. eugeniae	6.59 ± 0.09^{b}	13.03 ± 0.13	1.49 ± 0.10	0.33 ± 0.11^{a}	1.05 ± 0.12	0.32 ± 0.21
LS (P-value)	0.01	NS	NS	0.01	NS	NS
Feeding materials						
CD	6.00 ± 0.12^{b}	13.19 ± 0.18^{b}	1.57 ± 0.11^{a}	0.29 ± 0.21^{c}	0.92 ± 0.17^{b}	0.28 ± 0.23^{c}
CDWL	7.41 ± 0.03^{a}	13.38 ± 0.12^{b}	1.47 ± 0.13^{b}	0.34 ± 0.16^{b}	1.19 ± 0.11^{a}	0.30 ± 0.18^{b}
CDPL	6.93 ± 0.11^{b}	12.59 ± 0.10^{c}	1.44 ± 0.18^{b}	0.38 ± 0.14^{a}	0.95 ± 0.21^{b}	0.48 ± 0.26^{a}
CDRS	6.51 ± 0.08^{b}	14.32 ± 0.15^{a}	1.36 ± 0.12^{c}	0.32 ± 0.09^{b}	1.01 ± 0.19^{b}	0.37 ± 0.20^{b}
LS (P-value)	0.01	0.01	0.01	0.01	0.01	0.01
Earthworm species × Feeding materials						
E. fetida × CD	6.18 ± 0.15^{c}	13.03 ± 0.22	1.59 ± 0.30	0.28 ± 0.13	1.11 ± 0.14	0.29 ± 0.31
E. fetida × CDWL	7.47 ± 0.25^{a}	13.47 ± 0.38	1.44 ± 0.30	0.29 ± 0.18	1.27 ± 0.23	0.41 ± 0.22
E. fetida × CDPL	6.42 ± 0.15^{b}	12.48 ± 0.43	1.41 ± 0.06	0.33 ± 0.13	0.94 ± 0.20	0.49 ± 0.17
E. fetida × CDRS	6.69 ± 0.35^{b}	13.57 ± 0.34	1.39 ± 0.06	0.31 ± 0.15	0.97 ± 0.12	0.38 ± 0.32
E. eugeniae × CD	6.06 ± 0.15^{c}	14.16 ± 0.25	1.54 ± 0.06	0.29 ± 0.11	1.08 ± 0.16	0.30 ± 0.09
E. eugeniae × CDWL	7.39 ± 0.20^{a}	13.37 ± 0.17	1.45 ± 0.03	0.31 ± 0.09	1.21 ± 0.15	0.39 ± 0.38
E. eugeniae × CDPL	6.60 ± 0.40^{b}	13.27 ± 0.37	1.32 ± 0.05	0.34 ± 0.09	0.92 ± 0.07	0.48 ± 0.12
E. eugeniae ×CDRS	6.61 ± 0.25^{b}	15.67 ± 0.33	1.43 ± 0.02	0.32 ± 0.08	1.07 ± 0.12	0.39 ± 0.21
LS (P-value)	0.01	NS	NS	NS	NS	NS
CV (%)	4.21	6.48	12.11	14.11	16.18	5.41

Note: Means following dissimilar letter in a column are significantly different at 1% and 5% level of significance. NS = not significant, LS = level of significance, CV = coefficient of variation, CD = cowdung, CDWL = cowdung + water lettuce (3:1), CDPL = cowdung + poultry litter (3:1), CDRS = cowdung + rice straw (3:1)

Exchangeable potassium (K)

Exchangeable K contents of vermicompost did not vary significantly by the earthworm species and they were 1.05 ± 0.12% for *E. eugeniae* and 1.08 ± 0.15% for *E. fetida* (Table 4). On the other hand, the exchangeable K content was significantly influenced by the use of different feeding materials. The highest exchangeable K content was recorded for cowdung + water lettuce (1.19 ± 0.11%). The other three feeding materials had no statistically siginificant difference in exchangeable K content of vermicomposts. The interactions between earthworm species and feeding materials did not play any significant role in the exchangeable K content of vermicomposts which ranged from 0.92 ± 0.07 to 1.27 ± 0.23%. The K values ranging from 0.54 to 1.72% have been reported in previous studies which are closer to the result of the current study (Kitturmath *et al*., 2007; Giraddi, 2011; Waseem *et al*., 2013). The rate of mineralization increases as a result of increased microbial activity during the vermicomposting process, influencing vermicompost to have a higher concentration of exchangeable K (Suthar, 2007).

Available sulphur (S)

Feeding materials had a significant role in available S content (Table 4). The highest available S content was recorded for cowdung + poultry litter (0.48 ± 0.26%) while the lowest content was found in cowdung (0.28 ± 0.23%). The interactions between earthworm species and feeding materials did not play any significant role in the available S content of vermicomposts which ranged from 0.29 ± 0.31 to 0.49 ± 0.17%. The vermicomposts had a higher available S content than the initial feeding materials (Table 3). It could be attributed to the various biochemical reactions that took place in the earthworms' gut.

CONCLUSION

The results of the study showed that *E. fetida* had higher vermicompost productivity, vermicomposting efficiency, and number of earthworm chari^{-1} over *E. eugeniae*. The biomass of earthworms was produced higher in *E. eugeniae.* Among feeding materials, cowdung alone showed the best performance in the case of biomass and number of earthworms as well as vermicompost productivity. The nutrients concentration of N, P, K, and S showed higher in vermicompost over initial feeding materials

ACKNOWLEDGEMENTS

The authors are very grateful to Sylhet Agricultural University Research System (SAURES) for the financial support under the project entitled "Life Cycle Evaluation and Composting Efficiency of Two Earthworms Species (*Eisenia fetida* and *Eudrilus eugeniae*)". The corresponding author expresses her thankful acknowledgement to the authority of the National Science and Technology (NST) of Bangladesh for providing fellowship.

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