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RESEARCH ARTICLE

Vermiremediation of dyeing sludge from textile mill with the help of exotic earthworm *Eisenia fetida* Savigny

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Abstract The aim of present study was for the vermiremediation of dyeing sludge from textile mill into nutrient-rich vermicompost using earthworm *Eisenia fetida*. The dyeing sludge was mixed with cattle dung in different ratios, i.e., 0:100 (D_0), 25:75 (D_{25}), 50:50 (D_{50}), 75:25 (D_{75}), and 100:0 (D_{100}) with earthworms, and 0:100 (S_0), 25:75 (S_{25}), 50:50 (S_{50}), 75:25 (S_{75}), and 100:0 (S_{100}) without earthworms. Minimum mortality and maximum population build-up were observed in a 25:75 mixture. Nitrogen, phosphorus, sodium, and pH increased from the initial to the final products with earthworms, while electrical conductivity, C/N ratio, organic carbon, and potassium declined in all the feed mixtures. Vermicomposting with *E. fetida* was better for composting to change this sludge into nutrient-rich manure.

Keywords Vermicomposting · *Eisenia fetida* · Dyeing sludge · Earthworm · Textile mill

Introduction

India has a large network of textile industries of varying capacity. The solid wastes produced from textile industries are considered as one of the most polluting wastes, and their proper disposal and management is a burden to the industries. Solid wastes are largely contaminated by different chemical products (Yadav and Garg 2011). On an industrial scale, the sludge of dyeing and printing operations is managed through destructive methods like land filling practices and incineration. Textile mill sludge has a variable composition and normally contains high organic matter, nitrogen, phosphorus, potassium, and micronutrients contents (Balan and Monteiro 2001). Although various physical, chemical, and microbiological methods of disposal of organic waste are currently in use, these methods are time consuming, dangerous, and involve high costs. Therefore, there is a dire need to find out cost-effective and safe alternative method of shorter duration particularly suited to Indian conditions. In this regard, vermicomposting has been considered to be a viable, cost-effective, and rapid technique for the efficient management of the organic solid wastes (Hand et al. 1988; Raymond et al. 1988; Harris et al. 1990; Logsdson 1994). During vermicomposting process, the important plant nutrients such as NPK and calcium present in the feed material are converted through microbial action into forms that are much more soluble and available to plants than those in the parent substrate (Ndegwa and Thompson 2001), while the worms themselves provide a protein source for animal feed (Sabina 1978; Hartenstein 1981). However, the processing time and quality of the end product vary according to the composition of the initial mixture being processed (Singh et al. 2010). In the present work, dyeing sludge was mixed with cattle dung with and without earthworms in ratios of 0:100, 25:75, 50:50, 75:25, and 100:0 to evaluate the role of organic material (cattle dung) in enhancing rate of degradation and quality of the end product. Efficiency of *Eisenia fetida* for recovering nutrients was evaluated by comparing physicochemical changes in the waste (without worms) and vermicompost (with worm) after bioconversion.

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Materials and methods

Dyeing sludge was procured from effluent treatment plant of a textile mill situated in Amritsar, Punjab, India. The collected waste was crushed into very fine particles so that it becomes easier for worms to consume. Young *E. fetida* were picked from the stock culture maintained in the vermicomposting unit of the Department of Botanical and Environmental Sciences, Guru Nanak Dev University, Amritsar, Punjab, India. Cattle dung was spread for 20 days for air drying, so that unwanted gases and heat were removed, which may cause harm to earthworms. The initial physicochemical characteristics of dyeing sludge and cattle dung are given in Table 1.

Plastic trays of volume 3,834 cc were filled with 1-kg mixtures containing different proportions of dyeing sludge and cattle dung in triplicates with worms (D) and without worms (S) as 0:100 (D_0, S_0), 25:75 (D_{25}, S_{25}), 50:50 (D_{50}, S_{50}), 75:25 (D_{75}, S_{75}), and 100:0 (D_{100}, S_{100}) on dry weight basis. The trays were covered with a jute mat, and mixtures were turned over manually every 24 h for 15 days in order to eliminate the volatile toxic gases. After 15 days, 20 young nonclitellated *E. fetida* (3.0 g) were released in the trays. The moisture content was maintained at 60–70 % throughout the study period by periodic sprinkling of adequate quantity of water. Earthworms, cocoons, and hatchlings were sorted and counted manually and then put back in the trays after sampling. At the end of the experiment, the worms, cocoons, and hatchlings were removed. The vermicompost was sieved, air-dried, and stored in plastic bags for physicochemical analysis.

Table 1 Initial physicochemical properties of dyeing sludge and cattle dung

Physicochemical parameters	Dyeing sludge	Cattle dung
pH	7.55±0.02	8.22±0.05
EC (mS/cm)	2.39±0.20	3.52±0.05
TKN[a]	0.26±0.11	1.00±0.05
TAP[a]	0.36±1.19	1.25±1.18
TK[a]	10.18±1.73	4.71±0.21
Na[a]	3.25±1.45	1.28±0.60
TOC[a]	6.96±0.79	47.56±0.24
C/N ratio	26.76±1.15	47.18±1.01
Cu[b]	14.06±0.25	2.04±0.07
Mn[b]	235.08±0.88	25.02±0.65
Fe[b]	1510.0±1.01	498.44±2.3
Zn[b]	37.57±0.37	7.55±0.98

[a] Weight in percent

[b] Weight in milligrams per kilogram

Physicochemical analysis

Total organic carbon (TOC) was measured after igniting the sample in a muffle furnace at 550 °C for 60 min by the method of Nelson and Sommers (1996). Electrical conductivity (EC) and pH were determined in double-distilled water suspension of each concentration in the ratio of 1:10 (*W*/*V*) using HM digital meter-COM-100 and Equip-tronics EQ-614-A, respectively. Micro-Kjeldhal method of Bremner and Mulvaney (1982) was used for measuring nitrogen after digesting the sample in digestion mixture (H_2SO_4+K_2SO_4/$CuSO_4$/SeO_2 in 10:4:1). The method of John (1970) was used for measuring total potassium (TK), sodium (TNa), and total available phosphorus (TAP) using Systronics flame photometer-128 and UV visible spectrophotometer, respectively, after digesting the samples in diacid mixture ($HClO_4$/HNO_3 in 4:1 ratio). Heavy metals were also measured by a Varian 20 model atomic absorption spectrophotometer in the digested samples.

Statistical analysis

One-way ANOVA was used to calculate the differences among various mixtures. Student's *t* test was used to evaluate differences between the initial and the final values of various physicochemical parameters. Statistical analysis was done with the help of SPSS computer software program.

Results and discussion

The physicochemical parameters of various mixtures with and without worms are given in (Tables 2 and 3). In the present study, a rise in pH was observed in the final products of vermicomposting. The maximum increase in pH with earthworms was in D_0 (8.51 %) and the minimum (0.92 %) in D_{100} feed mixture. The percent increase in pH was in the order of D_0>D_{25}>D_{50}>D_{75}>D_{100}. Feed mixtures without earthworms also showed a slight increase in pH. The maximum increase in pH was in S_0 (2.08 %) and minimum (0.78 %) in S_{100} feed mixture, but the increase was comparatively less than vermicomposting. The percent increase in pH was in order of S_0>S_{25}>S_{75}>S_{50}>S_{100}. Increase in pH during vermicomposting has been reported by Datar et al. (1997). The increase in pH during vermicomposting may be due to excess of organic nitrogen, which is not required by microbes and released later as ammonia. It gets dissolved in water and increases the pH of the vermicompost (Rynk et al. 1992). Humus is also reported to bind free cations in turn leading to an increase in the pH of the soil (Brady and Weil 2002). EC decreased significantly (p<0.05) from initial. The maximum decline was in D_{25} (45.0 %) and the minimum in D_{100} (8.69 %) feed mixtures. The percent decrease in EC was in the order of D_{25}>D_0>D_{50}>D_{75}>D_{100}. Feed mixtures without earthworms also showed a slight decrease in EC. The maximum decline was in S_{25} (21.42 %) and the minimum in S_{75} (4.0 %) feed mixtures. The percent decrease in EC was in the order of S_{25}>S_0>S_{50}>S_{100}>S_{75}. The electrical conductivity reflects the salinity of any material, and it is a good indicator of the applicability and utility of a compost or vermicompost for agricultural purposes. The increase in EC was due to the loss of organic matter and release of different mineral salts in available forms such as phosphate, ammonia, potassium, etc. (Kaviraj and Sharma 2003).

The combined action of earthworms and microorganisms may be responsible for TOC loss from the initial feed waste in the form of CO_2. Total organic content was lesser in all the final products than initial feed mixtures. Decline in TOC was maximum in D_{25} (29.16 %) feed mixture. The percent

Table 2 Initial and final nutrient content (mean±SE) and percent change over initial nutrient content of different proportions of dyeing sludge and cattle dung with earthworms

Physicochemical parameters		D_0	D_{25}	D_{50}	D_{75}	D_{100}
pH	Initial	8.22±0.05	7.44±0.03	7.31±0.02	7.23±0.10	7.55±0.02
	Final	8.92±0.09	7.89±0.05	7.66±0.06	7.49±0.02	7.62±0.03
	Percent change	8.51	6.04	4.78	3.59	0.92
EC (mS/cm)	Initial	3.52±0.05	3.13±0.02	2.84±0.15	2.66±0.11	2.39±0.20
	Final	2.82±0.03	1.73±0.01	2.34±0.05	2.26±0.09	2.19±1.0
	Percent change	−19.88	−44.72	−17.60	−15.03	−8.36
TKN[a]	Initial	1.00±0.05	1.26±0.33	0.61±0.81	0.56±0.13	0.26±0.11
	Final	2.40±1.20	1.80±0.57	1.06±0.57	0.75±0.88	0.40±0.57
	Percent change	140.0	42.85	73.77	33.92	53.84
TOC[a]	Initial	47.56±0.24	27.84±0.09	16.24±0.23	13.92 ±1.13	6.96±0.79
	Final	37.12±0.11	19.72±0.04	11.96±0.06	10.44±0.50	5.80±0.24
	Percent change	−21.95	−29.16	−26.35	−25.0	−16.66
C/N ratio	Initial	47.18 ±1.01	22.09 ±1.20	26.62±0.24	24.85±0.50	26.76 ±1.15
	Final	15.46±0.57	10.70±0.50	11.28±0.12	13.92±1.11	14.50±0.63
	Percent change	−67.23	−51.56	−57.62	−43.98	−45.81
TAP[a]	Initial	1.25±1.18	0.88 ±1.61	0.51±2.19	0.40±2.07	0.36±1.19
	Final	1.49±0.81	1.11±0.31	0.71±0.65	0.47±0.17	0.40±0.51
	Percent change	19.2	26.13	39.21	17.5	11.11
TK[a]	Initial	4.71±0.21	7.44±1.98	6.18±1.11	9.93±1.18	10.18±1.73
	Final	1.90±2.08	4.87±1.45	5.04±1.67	9.01±2.42	9.64±1.82
	Percent change	−59.66	−34.54	−18.44	−9.26	−5.30
TNa[a]	Initial	1.28±0.60	2.52±0.62	2.78±0.16	2.91±1.76	3.25±1.45
	Final	1.41±0.38	3.19±1.20	3.22±1.21	3.15±1.32	3.30±0.63
	Percent change	10.15	26.58	15.82	8.24	1.53
Zn[b]	Initial	7.55±0.98	20.05±1.30	26.03±0.87	30.0 5±0.65	37.57±0.37
	Final	11.54±0.37	25.0 4±0.21	29.0 3±0.09	34.06±0.50	38.79±0.23
	Percent change	52.84	24.88	11.52	13.34	3.24
Cu[b]	Initial	2.04±0.07	5.06±0.25	11.01±0.37	12.0 4±0.65	14.0 6±0.25
	Final	9.0 3±0.20	8.0 7±0.18	15.0 3±0.32	14.5 6±0.37	15.0 7±0.10
	Percent change	342.64	59.48	36.51	20.93	7.18
Fe[b]	Initial	498.44±2.3	1,200±3.51	1,380±2.32	1,460±1.60	1,510±1.01
	Final	590.04±1.5	1,360±1.30	1,456±1.67	1,570±0.98	1,600±0.87
	Percent change	18.37	13.33	5.50	7.53	5.96
Mn[b]	Initial	25.0 2±0.65	112.0 5±1.2	184.07±1.5	200.04±1.3	235.08±0.88
	Final	38.0 1±0.88	126.0 6±1.0	240.0 6±1.3	350.0 5±0.9	295.07±0.37
	Percent change	51.91	12.50	30.41	74.99	25.51

[a] Concentrations in percent

[b] Weight in milligrams per kilogram

decrease in TOC content was in the order of $D_{25}>D_{50}>D_{75}>D_0>D_{100}$. Feed mixtures without earthworms also showed slight decline in TOC. Decline in TOC was maximum in S_{75} (12.75 %) feed mixture. The loss of TOC was more in vermicomposting process as compared to the final products without earthworms. The percent decrease in TOC content was in the order of $S_{75}>S_{100}>S_{50}>S_0>S_{25}$. Dominguez and Edwards (2004) reported that earthworm fragments and homogenize the ingested material through muscular action of their foregut. It also adds mucus and enzymes to the ingested material and increases the surface area for microbial action. Microorganisms perform the biochemical degradation of waste material providing some extracellular enzymes within the worms's gut. This combined action of earthworm and microorganism brings about a carbon loss from substrates in the form of CO_2 (Tognetti et al. 2007;

Table 3 Initial and final nutrient content (mean±SE) and percent change over initial nutrient content of different proportions of dyeing sludge and cattle dung without earthworms

Physicochemical parameters		S_0	S_{25}	S_{50}	S_{75}	S_{100}
pH	Initial	8.22±0.05	7.44±0.03	7.31±0.02	7.23±0.10	7.55±0.02
	Final	8.40±0.10	7.59±0.12	7.37±0.01	7.30±0.11	7.61±0.11
	Percent change	2.18	2.01	0.82	0.96	0.79
EC (mS/cm)	Initial	3.52±0.05	3.13±0.02	2.84±0.15	2.66±0.11	2.39±0.20
	Final	3.22±0.02	2.50±0.01	2.64±0.05	2.56±0.01	2.29±0.02
	Percent change	−8.52	−20.12	−7.04	−3.75	−4.18
TKN[a]	Initial	1.00±0.05	1.26±0.33	0.61±0.81	0.56±0.13	0.26±0.11
	Final	1.03±0.24	1.44±0.13	0.68±0.50	0.63±0.40	0.30±0.30
	Percent change	3.0	14.28	11.47	12.50	15.38
TOC[a]	Initial	47.56±0.24	27.84±0.09	16.24±0.23	13.92±1.13	6.96±0.79
	Final	45.40±1.01	26.96±0.02	15.20±0.30	12.30±0.11	6.35±0.98
	Percent change	−4.54	−3.16	−6.40	−11.63	−8.76
C/N ratio	Initial	47.18±1.01	22.09±1.20	26.62±0.24	24.85±0.50	26.76±1.15
	Final	44.30±1.62	18.40±0.70	22.01±0.19	19.29±0.36	21.50±0.05
	Percent change	−6.10	−16.70	−17.31	−22.37	−19.65
TAP[a]	Initial	1.25±1.18	0.88±1.61	0.51±2.19	0.40±2.07	0.36±1.19
	Final	0.92±0.30	0.80±0.11	0.42±0.17	0.33±0.05	0.28±0.02
	Percent change	−26.40	−9.09	−17.64	−17.50	−22.22
TK[a]	Initial	4.71±0.21	7.44±1.98	6.18±1.11	9.93±1.18	10.18±1.73
	Final	4.01±1.20	6.95±0.92	5.80±0.52	9.71±0.98	10.01±0.80
	Percent change	−14.86	−6.58	−6.14	−2.21	−1.66
TNa[a]	Initial	1.28±0.60	2.52±0.62	2.78±0.16	2.91±1.76	3.25±1.45
	Final	0.71±0.20	2.42±0.08	2.70±0.10	2.88±0.09	3.12±0.56
	Percent change	−44.53	−3.96	−2.87	−1.03	−4.0
Zn[b]	Initial	7.55±0.98	20.05±1.30	26.03±0.87	30.05±0.65	37.57±0.37
	Final	9.85±0.37	23.10±0.88	27.30±0.11	37.55±0.23	40.07±0.11
	Percent change	30.46	15.21	4.87	24.95	6.65
Cu[b]	Initial	2.04±0.07	5.06±0.25	11.01±0.37	12.04±0.65	14.06±0.25
	Final	8.04±0.23	7.06±0.45	13.51±0.17	13.04 ±0.37	14.50±0.05
	Percent change	294.11	39.52	22.70	8.30	3.12
Fe[b]	Initial	498.44±2.3	1,200±3.51	1,380±2.32	1,460±1.60	1,510±1.01
	Final	620.04±1.6	1,310±2.20	1,400±1.05	1,490±0.55	1,550±0.37
	Percent change	24.39	9.16	1.44	2.05	2.64
Mn[b]	Initial	25.0 2±0.65	112.05±1.2	184.07±1.5	200.04±1.3	235.08±0.88
	Final	13.02±1.77	101.05±1.5	151.07±1.8	180.04±1.6	220.09±1.1
	Percent change	−47.96	−9.81	−17.92	−9.99	−6.37

[a] Concentrations in percent

[b] Weight in milligrams per kilogram

Hait and Tare 2011; Singh and Suthar 2012). According to Viel et al. (1987), losses in organic carbon might be responsible for nitrogen addition. Earthworms also have a great impact on nitrogen mineralization so that mineral nitrogen was retained in the nitrate form (Atiyeh et al. 2000).

Total Kjeldhal nitrogen (TKN) increased significantly with time in the final products of vermicomposting. The maximum increase in TKN was in D_0 (138.09 %), and the minimum in D_{75} (33.92 %) feed mixture. The percent increase in TKN was in the order of $D_0>D_{50}>D_{100}>D_{25}>D_{75}$. However, feed mixtures without earthworms showed nonsignificant increase in nitrogen content. The maximum increase in TKN was in S_{25} (13.54 %) and the minimum in S_0 (1.17 %) feed mixture. The percent increase in TKN was in the order of $S_{25}>S_{100}>S_{50}>S_{75}>S_0$. Addition of nitrogen in the form of mucus, nitrogenous excretory substances, growth-stimulating hormones, and enzymes from earthworms has been reported by Tripathi and Bhardwaj (2004). These nitrogen-rich substances were not originally present in the feed material and, hence, might have contributed to the additional nitrogen content. The C/N ratio, one of the most widely used indices for maturity of organic wastes, decreased with time for all the feed mixtures. In the present study, the decrease in C/N ratio during vermicomposting is brought about by a simultaneous decline in organic carbon and an increase in the content of nitrogen. Decline in C/N ratio was more in D_0 (67.23 %) feed mixture. The percent decrease in C/N ratio was in the order of $D_0>D_{50}>D_{25}>D_{100}>D_{75}$. Slight decline in C/N ratio was also observed in feed mixtures without earthworms. Decrease in C/N ratio was more in S_{75} (22.64 %) feed mixture. The percent decrease in C/N ratio was in the order of $S_{75}>S_{100}>S_{50}>S_{25}>S_0$.

The increase in TAP content was observed in different feed mixtures and was significantly different ($p<0.01$). The maximum increase in TAP was noticed in D_{50} (39.21 %) feed mixture with earthworms. The percent increase in TAP was in the order of $D_{50}>D_{25}>D_0>D_{75}>D_{100}$. On the other hand, decrease in the TAP was observed in feed mixtures without earthworms. Maximum decrease in the TAP was in S_0 (26.15 %) and minimum in S_{25} (8.64 %). The percentage decrease in TAP was in the order of $S_0>S_{100}>S_{75}>S_{50}>S_{25}$. Alexander (1983) suggested that nitrification of ammonium salts increased the phosphorus, which might be the cause for the increase in phosphorus content of the vermicompost in the present study. Furthermore, Satchell and Martin (1984) observed that worm gut enzymes had stimulating effect on phosphate-solubilizing microbes as phosphorus increase in the excreta of the worms ultimately increased phosphorus in vermicompost. TK decreased significantly ($p<0.05$) from initial in different feed mixtures with earthworms. The maximum percentage decline in potassium content in the products of vermicomposting was in D_0 (59.66 %) and minimum in D_{100} (5.30 %). The percent decrease in TK was in the order of $D_0>D_{25}>D_{50}>D_{75}>D_{100}$. The slight decrease in TK was also seen in feed mixtures without earthworms. The maximum percentage decline in potassium content was in S_0 (15.78 %) and the minimum in S_{100} (1.72 %). The percent decrease in TK was in the order of $S_0>S_{25}>S_{50}>S_{75}>S_{100}$. Total potassium concentration in the initial substrate had decreased significantly by the end of the vermicomposting period. This may be due to the use of potassium by earthworm during metabolic activity (Singh et al. 2010; Vig et al. 2011). Orozco et al. (1996) also attributed the decline in potassium to leaching during vermicomposting. Sodium increases significantly ($p<0.05$) from initial in different feed mixtures with earthworms. Maximum increase in Na was in D_{25} (26.58 %) and minimum in D_{100} (1.53 %). The percent increase in sodium was in the order of $D_{25}>D_{50}>D_0>D_{75}>D_{100}$. On the other hand, a decrease in the sodium was observed in feed mixtures without earthworms. Maximum decrease in Na was in S_0 (−43.84 %) and minimum in S_{75} (−0.99 %). The percent decrease in sodium was in the order of $S_0>S_{25}>S_{100}>S_{50}>S_{75}$. The above trend was also supported by Khawairakpam and Bhargava (2009) and Singh et al. (2010).

Heavy metals increases significantly from initial in different feed mixtures with earthworms. The maximum increase in Zn was in D_0 (50.0 %) and minimum in D_{100} (3.2 %) feed mixture. The percent increase in Zn was in the order of $D_0>D_{25}>D_{75}>D_{50}>D_{100}$. Feed mixtures without earthworms also showed increase in Zn. The maximum increase in Zn was in S_0 (30.66 %) feed mixture and minimum (5.0 %) in S_{50} feed mixture. The percent increase in Zn was in order of $S_0>S_{75}>S_{25}>S_{100}>S_{50}$. Copper increases significantly from initial in different feed mixtures with earthworms. Maximum increase in Cu was in D_0 (350.0 %) and minimum in D_{100} (7.14 %) feed mixture. The percent increase in Cu was in the order of $D_0>D_{25}>D_{50}>D_{75}>D_{100}$. Feed mixtures without earthworms also showed increase in Cu. The maximum increase in Cu was in the S_0 (300.0 %) feed mixture and minimum in 3.57 % in the S_{100} feed mixture. The percent increase in Cu was in

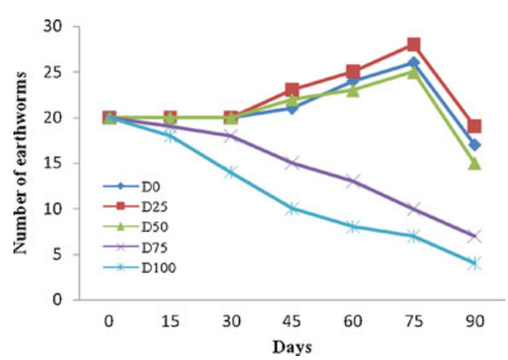

Fig. 1 Number of clitellated earthworms in various feed mixtures of dyeing sludge and cattle dung

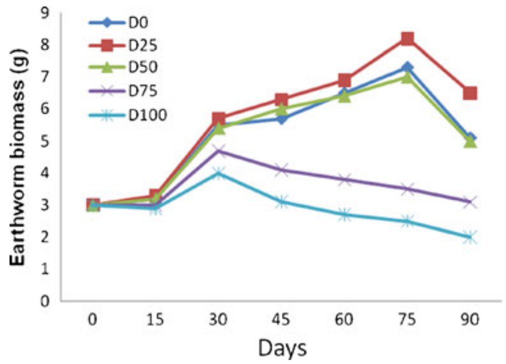

Fig. 2 Earthworms biomass (g) in various feed mixtures of dyeing sludge and cattle dung

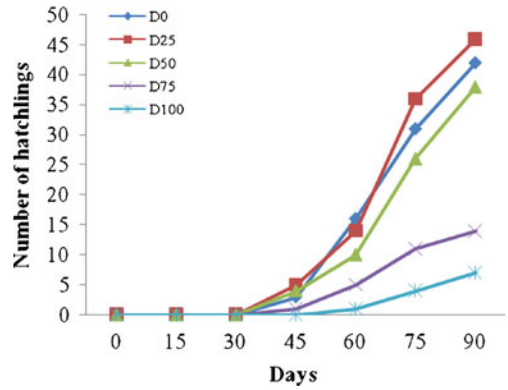

Fig. 4 Number of hatchlings in various feed mixtures of dyeing sludge and cattle dung

order of $S_0>S_{25}>S_{50}>S_{75}>S_{100}$. Iron increases significantly from initial in different feed mixtures with earthworms. Maximum increase in Fe was in D_0 (18.37 %) and minimum in D_{50} (5.50 %). The percent increase in Fe was in the order of $D_0>D_{25}>D_{75}>D_{100}>D_{50}$. Feed mixtures without earthworms also showed increase in Fe. The maximum increase in Fe was in the S_0 (24.39 %) feed mixture and minimum in 1.44 % in the S_{50} feed mixture. The percent increase in Fe was in the order of $S_0>S_{25}>S_{100}>S_{75}>S_{50}$. Manganese increases significantly from initial in different feed mixtures with earthworms. Maximum increase in Mn was in D_{75} (75.0 %) and minimum in D_{25} (12.5 %). The percent increase in Mn was in the order of $D_{75}>D_0>D_{50}>D_{100}>D_{25}$. On the other hand, a decrease in Mn was observed in feed mixtures without earthworms. The maximum decrease in the Mn was in S_0 (48.0 %) and the minimum in S_{100} (6.38 %). The percentage decrease in Mn was in the order of $S_0>S_{50}>S_{75}>S_{25}>S_{100}$. Heavy metals play an important role in metabolism but, beyond a certain limit, become toxic to organisms. Thus, influence of earthworms on bioavailability of four heavy metals (Zn, Cu, Fe, and Mn) was evaluated in the final product. The four heavy metals increased significantly over initial in all the feed mixtures except Mn, which decreases in the final products of without earthworms. Suthar et al. (2008) have also reported higher concentration of metals in earthworm casts collected from sewage soils and cultivated lands. The increase in the content of heavy metals in vermicompost may be due to a decline in the weight and volume of the final product as suggested by (Deolalikar et al. 2005). Yadav and Garg (2011) have reported an increase in heavy metal concentration in final vermicompost of poultry droppings and food industrial sludge. Although there was an increase in the contents of all the heavy metals, the contents are less than the international standards for compost, which indicates that the compost can be used in the fields without any ill effects on the soil (Singh et al. 2010).

Population build-up in the form of number of worms, cocoons, hatchlings, and biomass in the feed mixture by *E. fetida* was significantly different ($p<0.01$). The number of worms at different time intervals in various feed mixtures was also statistically different ($p<0.01$). The number of earthworms increased on the 45th day of experiment in D_0, D_{25}, and D_{50} feed mixtures. The maximum number of clittelated earthworms (28.0) was noticed in D_{25} on the 75th day of experiment followed by 26.0 in D_0 and 25.0 in D_{50} feed mixtures. In D_0, D_{25}, and D_{50} feed mixtures, the number started to decrease between the 75th and 90th day (Fig. 1). The survival, biomass production, and reproduction of earthworms are the best indicators to evaluate the vermicomposting process. The maximum earthworm biomass was in the D_{25} feed mixture on the 75th day of

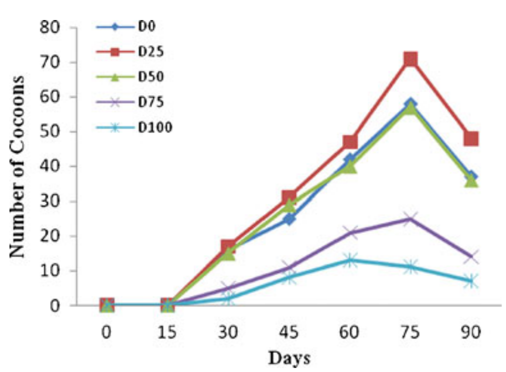

Fig. 3 Number of cocoons in various feed mixtures of dyeing sludge and cattle dung

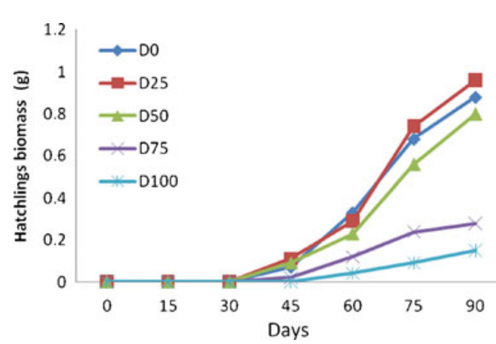

Fig. 5 Hatchlings biomass (g) in various feed mixtures of dyeing sludge and cattle dung

experiment and minimum in the D_{100} feed mixture (Fig. 2). The earthworm number decreased from the 15th day of experiment in higher concentration like D_{75} and D_{100} feed mixtures. Only 10.0 and 7.0 worms were present in the vermibed on the 75th day in D_{75} and D_{100} feed mixtures. The maximum mortality of earthworms were in the D_{100} (80 %) feed mixture and then in D_{75} (65 %) from initial value at the end of the experiment. It could be probably due to the nonpalatability and toxicity of sludge.

The number of cocoons with varying sludge concentrations was also significantly different ($p<0.01$). The formation of cocoon was observed on the 30th day of experiment in all the feed mixtures. The maximum number of cocoons was observed in D_{25} (71.0) on the 75th day and minimum in D_{100} (7.0) (Fig. 3). Cocoon production was relatively less in higher proportions like D_{50}, D_{75}, and D_{100} as compared to the lower proportion D_{25}. There was a significant difference ($p<0.01$) in the number of hatchlings with varying sludge concentrations. The first hatchlings were observed on the 45th day of experiment in D_0, D_{25}, D_{50}, and D_{75}, while D_{100} showed first hatchling on the 60th day of experiment. The maximum number of hatchlings were observed on the 90th day of experiment in D_{25} (46.0) followed by D_0 (42.0), D_{50} (38.0), D_{75} (14.0), and D_{100} (7.0) (Fig. 4). Maximum hatchling biomass was observed in D_{25} (0.96 g) on the 90th day of experiment and minimum in the D_{100} (0.15 g) feed mixture (Fig. 5).The results suggested that higher proportions of dyeing sludge were not suitable for cocoon production. Production of cocoons in different feed mixtures could be related to the biochemical quality of the feed, which was one of the important factors (Flack and Hartenstein 1984). The decrease in the number can be attributed to the exhaustion of food (Neuhauser et al. 1980). Suthar (2006) emphasized that, in addition to the biochemical properties of waste, the microbial biomass and decomposition activities during vermicomposting are also important in determining the worm biomass and cocoon production. Thus, it was inferred that the higher percentage of dyeing sludge in the feed mixtures significantly affected cocoon production. The studies revealed that the kind, palatability, and quality of food (in terms of their chemistry) directly affected the survival, growth rate, and reproduction (Ndegwa and Thompson 2000; Tripathi and Bhardwaj 2004; Gajalakshmi et al. 2005). Therefore, cattle dung acting as a complementary waste not only reduced the processing time but also improved its quality and converted the sludge into quality manure.

Conclusion

This work was undertaken to explore the use of vermicom posting technology in dyeing sludge waste management. The study showed that vermicompost produced from *E. fetida* possessed higher nutrient content, lower C/N ratio, and lower electrical conductivity as compared to feed mixtures without earthworms. Vermicomposting could be introduced as an effective technology to convert the dyeing sludge into a valuable product.

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