Dynamic Soil, Dynamic Plant ©2010 Global Science Books

Influence of Soil Characteristics on Biomass Growth and Reproduction of Earthworm *Eisenia fetida*

Kunwar D. Yadav[1*] • Vinod Tare[2] • M. Mansoor Ahammed[1]

[1] Civil Engineering Department, SV National Institute of Technology, Surat 395 007, India
[2] Department of Civil Engineering, Indian Institute of Technology, Kanpur 208 016, India

Corresponding author: * kdjhansi@yahoo.com

ABSTRACT

It is known that in vermicomposting soil layer in bedding of the reactor helps in earthworm biomass growth and reproduction but growth is influenced by soil characteristics such as texture, pH, and water holding capacity. The present study was conducted to asses the influence of soils on earthworm biomass growth and reproduction during the vermicomposting of source separated human faeces. The study was conducted by using the earthworm species *Eisenia fetida* with agriculture, saline and sandy soils. The study utilized reactors with SVFV combination (soil, vermicompost, faeces and vermicompost - bottom to top layers). All sets of reactors were examined monthly for four months for growth of earthworms and offspring production. The results of the study indicated that biomass growth of earthworms and offspring production were in the order: sandy soil > agricultural soil > saline soil. The multiplication of earthworm was 3.8-5.5–fold within 4 months. Vermicomposting helped to improve the soil characteristics such as carbon and nitrogen content, pH and conductivity.

Keywords: human faeces, soil, vermicomposting, earthworm, *E. fetida*

INTRODUCTION

Vermicomposting is emerging as a most appropriate alternative to conventional aerobic composting. This process is not only rapid, easily controllable, cost effective, energy saving, and zero waste process, but also accomplishes most efficient recycling of organics and nutrients (Eastman *et al.* 2001). Earthworms normally prefer to perform most of their activities in the soil and hence are referred to as soil animals. The earthworms also play a major role in changing the soil structure by improving aeration and drainage capabilities (Edwards 1998), promote the cycling of carbon and enhance the soil fertility or productivity (Lee and Foster 1991; Edwards and Bohlen 1996). Although these benefits may vary depending upon the soil types (Ocades 1993), changes in the structure of soil were mainly due to earthworm activities and production of casts (Scullion and Malik 2000).

The potential of using earthworm species such as *E. fetida* (also known as brandling, red wiggler or manure worm), *E. andrei* (red tiger) and *Lumbricus rubellus* (red worms) in the digestion of a wide variety of organic matter such as animal excreta, sewage sludge, human faeces, crop residual and agricultural wastes, and raw organic wastes in small and large-scale projects has been reported by many researchers (Kaushik and Garg 2004; Loh *et al*. 2005; Reddy *el al*. 2005; Garg *et al*. 2006; Monroy *et al*. 2006; Shalabi 2006; Yadav and Tare 2006; Suthar 2008; Khwairakpam and Bhargava 2009a; Yadav *et al*. 2010).

In the culture reactor successive layers of blast, stone, sand, soil and mulch are generally provided for maximum biomass growth and reproduction (Satvat 2006). It is reported that (1) earthworms require the grit and soil particle for grinding the food inside the gizzard (2) soil layer helps in controlling the temperature and maintaining the moisture and (3) different types of soil would affect the life cycle of *E. fetida* due to differences in the physico-chemical characteristics (Satvat and Tare 2004; Satvat 2006).

The objective of the present study was to assess the influence of soil characteristics on biomass growth and reproduction of *E. fetida* during the vermicomposting of source-separated human faeces. Soils with three different characteristics, agriculture, saline, sandy soils were used in the present study. Parameters like carbon and nitrogen content, pH and conductivity were also monitored at the end of experimental study which lasted 4 months.

MATERIALS AND METHODS

Earthworms (*Eisenia fetida*)

Earthworm species *E. fetida* supplied by "Baif", a Non-Governmental Organization (NGO) working in Gonda district, Uttar Pradesh, India was used in the present study. The NGO maintained the worm culture by feeding a mixture of partially degraded animal dung and plant residues such as leaves. The worm culture was subsequently developed in the laboratory in specially made rectangular brick reactors of size 2000 × 1000 × 2000 mm. Proper drainage was provided by keeping successive layers of blast, stones and sand to avoid any water logging conditions. The reactors were covered with paddy sheds in hut shape. Separate cultures that fed on partially degraded animal dung and human faeces were maintained by keeping optimum moisture levels.

Soil

Agricultural soil collected from an agricultural field from the village Barasirohi near Indian Institute of Technology (IIT), Kanpur, saline soil collected from barren land on Sivali Road, IIT, Kanpur, and sandy soil from the banks of river Ganga near IIT, Kanpur, were used in the study. Top 10 cm layer of soils was scrapped and objectionable materials like stones, weeds and grass in the soils were removed manually. It was thoroughly mixed before used in different experiments. Some relevant characteristics of the different soils used are presented in **Table 1**.

Bulking material

Bulking material is needed for enrichment of the diversity of microbial population and enzymatic activities in addition to improving the physical environment for the sustenance in the reac-

Received: 28 March, 2010. Accepted: 23 August, 2010.

Original Research Paper

Table 1 Characteristics of the soils used.

Parameter	Agriculture	Saline	Sandy
pH	8.0	10.8	7.5
Electrical Conductivity, µmho/cm	294	511	39.4
Water Holding Capacity, %	32	25	22
Carbon, %	1.448	0.550	0.582
Nitrogen, %	0.090	0.003	0.003
% Sand (0.05-0.50 mm)	40	40	90
% Silt (0.002-0.05 mm)	30	30	10
% Clay (<0.002 mm)	30	30	0

Table 2 Characteristics of human faeces.

Parameter	Value*
Moisture content, %	80 ± 5
pH	5.3 ± 0.2
Electrical Conductivity, µmho/cm	600 ± 150
Volatile Solids, %	82 ± 5
Total Carbon-C, %	42 ± 2.5
Nitrogen (N), %	4.0 ± 0.4
Phosphorous as P_2O_5, %	1.1 ± 0.2
Potassium as K_2O, %	2.8 ± 0.17

* Values indicate mean ± standard deviation based on 48 samples

tors. In the present study fresh and mature vermicompost was used as bulking material. It was collected from stock culture reactors. Partially degraded animal dung and human faeces were added to the reactors as feed to the earthworm species *E. fetida* to produce vermicompost.

Human faeces

In the present study human faeces were collected from a non-flush, drop and store type of toilet from a village Mandhana near IIT, Kanpur. The toilet was designed to have separate seats for defecation and anal cleaning. Faeces were collected daily from 4-5 houses and thoroughly mixed before used for analysis, maintenance of earthworm stock, feeding in different experiments. The composition of human faeces is presented in **Table 2**.

Methodology

The study was conducted with SVFV combination (soil, vermicompost, faeces and vermicompost - bottom to top layers) (**Fig. 1**). This combination was decided based on the study conducted by Yadav *et al.* (2010). The study was conducted in open backyard of the Environmental Engineering Laboratory of IIT Kanpur, India in brick reactors of dimension 300 × 300 × 600 mm at ambient temperature (10-30°C). The top surface of the reactors was covered with thick jute sheet. Forty five mature earthworms having approximately same body weight (0.30-0.32 g) were introduced in all the reactors after one week of starting the reactors. Earthworm gut correction was not applied and so there was the possibility of cocoons inside the gut of earthworms. Experiments were conducted in duplicate. 750 g of precomposted faeces were loaded at 15 days interval. Precomposting of faeces was done in presence of bulking materials for one week in sandwich model (that is, faeces layer in between bulking material layers). All reactors were examined after 1, 2, 3 and 4 months for survival and growth of earthworms by counting the number of cocoons and hatchlings. Total weight of mature earthworms was estimated and the mean individual weight of the earthworms was calculated based on the number of earthworms present in each reactor. The activity of earthworm in soil layer was observed by burrows in soil, burrows filled with cast and presence of earthworms in soil layer. The change in total carbon and nitrogen content was also measured in top 10 cm soil layer at the end of 4 months.

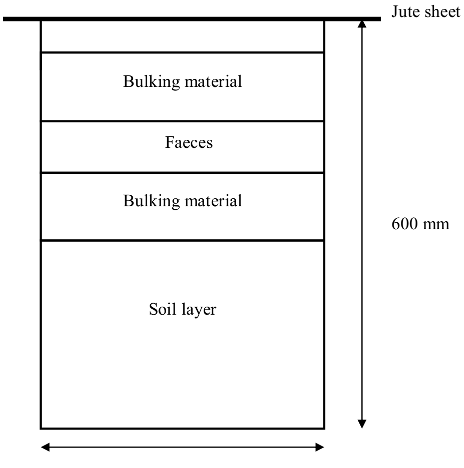

Fig. 1 Schematic diagram of reactor used for this study.

Chemical analysis

For determination of pH and electrical conductivity of faeces, soil and compost, 1:10 suspension with de-ionized water was made. The water holding capacity was determined by submerging the material for 24 hrs in water and draining the excess water for 30 min. Moisture content was determined upon drying the samples to constant weight at 70 ± 2°C for 24-72 hrs by using hot air oven. Volatile solids were obtained by burning the dried samples at 550 ± 5°C. The analysis of pH, electrical conductivity, water holding capacity, moisture content, phosphorous, potassium and organic matter was done by methods as given in USDA and USCC (2002). The total carbon and nitrogen was determined by using Elemental Analyzer (Model: CE440, Leeman Labs Inc., USA) on dried samples.

Statistical analysis

Statistical analyses of the experimental data were performed using Microsoft Excel 2007. Mean and standard deviation were used for analysis of soil characteristics data.

RESULTS

Biomass growth and offspring production

Table 3 presents the biomass growth rate of different soils. In different soils, biomass growth rate varied in the range of 37.9-106.6 mg/g/day. The mean individual weight of earthworms introduced in the reactors varied between 0.31 ± 0.01 g. After one month, the mean individual weight increased to 0.46, 0.55 and 0.49 g in agriculture, saline and sandy soil, respectively. The mean individual weight of earthworm remained the same in second month except in saline soil but after third month it started decreasing. At the end of the experiment, that is after 4 months, the mean individual weight varied in the narrow range of 0.31-0.34 g irrespective of soil characteristics (**Table 4**). Multiplication of earthworms started after second month and 2.9-, 2.3- and 3.1-fold increase were observed after three months in agri-

Table 3 Influence of soil on total biomass growth rate.

Soil	Reactor	Total biomass growth rate, mg/g/day			
		Month			
		1	2	3	4
Agriculture	Reactor 1	89.19	40.75	74.25	80.24
	Reactor 2	81.37	37.66	84.27	124.56
	Mean	83.84	37.88	79.14	83.33
Saline	Reactor 1	105.83	50.26	60.80	69.34
	Reactor 2	81.44	46.00	53.52	59.23
	Mean	93.09	46.36	58.44	65.32
Sandy	Reactor 1	94.42	56.30	89.31	89.07
	Reactor 2	116.42	65.05	98.57	115.07
	Mean	106.59	60.28	95.73	103.03

Temperature: (10-25ºC); Relative Humidity: 50-70%; Reactor Surface Area: 0.09 m^2
Earthworm Introduced: (number: 45; individual weight: 0.30-0.32 g); Duration: 4 months

Table 4 Influence of soil on earthworm number and individual weight.

Soil	Reactor	Mature earthworm									
		Number					Individual weight (g)				
		Month					Month				
		0	1	2	3	4	0	1	2	3	4
Agriculture	Reactor 1	45	44	45	125	211	0.31	0.44	0.42	0.39	0.32
	Reactor 2	45	45	43	132	238	0.34	0.48	0.47	0.46	0.35
	Mean	45	45	44	129	225	0.33	0.46	0.45	0.43	0.34
Saline	Reactor 1	45	45	45	110	168	0.32	0.56	0.48	0.35	0.30
	Reactor 2	45	43	45	96	150	0.35	0.55	0.49	0.39	0.34
	Mean	45	44	45	103	159	0.33	0.55	0.48	0.37	0.32
Sandy	Reactor 1	45	44	43	145	241	0.34	0.47	0.5	0.38	0.29
	Reactor 2	45	43	45	135	259	0.31	0.51	0.52	0.42	0.33
	Mean	45	44	44	140	250	0.32	0.49	0.51	0.40	0.31

Temperature: (10-25ºC); Relative Humidity: 50-70%; Reactor Surface Area: 0.09 m^2
Earthworm Introduced: (number: 45; individual weight: 0.30-0.32 g)

Table 5 Influence of soil on offspring production.

Soil	Reactor	Cocoons/worm/month				Hatchlings/worm/month			
		Month				Month			
		1	2	3	4	1	2	3	4
Agriculture	Reactor 1	4.4	3.0	2.3	1.1	3.1	3.8	4.3	4.9
	Reactor 2	3.8	3.2	1.9	1.4	3.0	4.2	4.4	4.3
	Mean	4.1	3.1	2.1	1.3	3.0	4.0	4.3	4.6
Saline	Reactor 1	2.2	2.1	1.9	1.6	1.8	2.5	3.0	3.4
	Reactor 2	2.1	2.1	1.7	1.2	1.4	2.8	3.1	3.5
	Mean	2.1	2.1	1.8	1.4	1.6	2.4	3.1	3.4
Sandy	Reactor 1	4.8	4.6	1.6	1.4	3.2	4.1	5.2	6.2
	Reactor 2	4.2	4.2	1.3	1.8	3.8	4.0	4.5	6.6
	Mean	4.5	4.4	1.5	1.6	3.5	4.0	4.9	6.4

Temperature: (10-25ºC); Relative Humidity: 50-70%; Reactor Surface Area: 0.09 m^2
Earthworm Introduced: (number: 45; individual weight: 0.30-0.32 g)

culture, saline and sandy soil, respectively, and further increased to 5.0-, 3.5- and 5.7-fold after four months.

The cocoon production was observed within a week and hatchlings production after two weeks in all reactors. The maximum offspring production was observed in the sandy soil. In first month the cocoon production was 4.1, 2.1 and 4.5 cocoons/worm/month in agriculture, saline and sandy soil, respectively and started decreasing as the time progressed, and it was 1.3, 1.4 and 1.6 cocoons/worm/month. The hatchling production was 3.0, 1.6 and 3.5 hatchlings/worm/month in agriculture, saline and sandy soil, respectively for the first month (**Table 5**); the hatchling production increased with time and it was 4.6, 3.4 and 6.4 hatchlings/worm/month after four months.

Changes in characteristics of soils during the vermicomposting process

The activity of earthworms in soil layer was observed from second month and the movement increased as time progressed in all soils, but earthworms movement was high in sandy soil compared to other soils. After four months, total number of earthworms in soil layer alone accounted for 34.7, 12.6 and 76.7% in agriculture, saline and sandy soil, respectively.

The changes in the carbon content and nitrogen content were monitored up to 10 cm depth of soil layer. Agriculture soil showed 1.8-fold increase in the carbon content while maximum change of 6.4-fold increase was observed in sandy soil. Similar pattern was observed for nitrogen content (2.6-fold in agriculture and 76.6-fold in sandy soil). In percentage term the carbon content in the different soil increased from 1.5 to 2.7%, 0.55 to 1.6%, and 0.58 to 3.7% in agriculture, saline soil and sandy soil, respectively (**Fig. 2**). Similarly nitrogen content also increased from 0.09 to 0.23%, 0.003 to 0.10%, and 0.003 to 0.23% in agriculture, saline soil and sandy soil, respectively (**Fig. 2**).

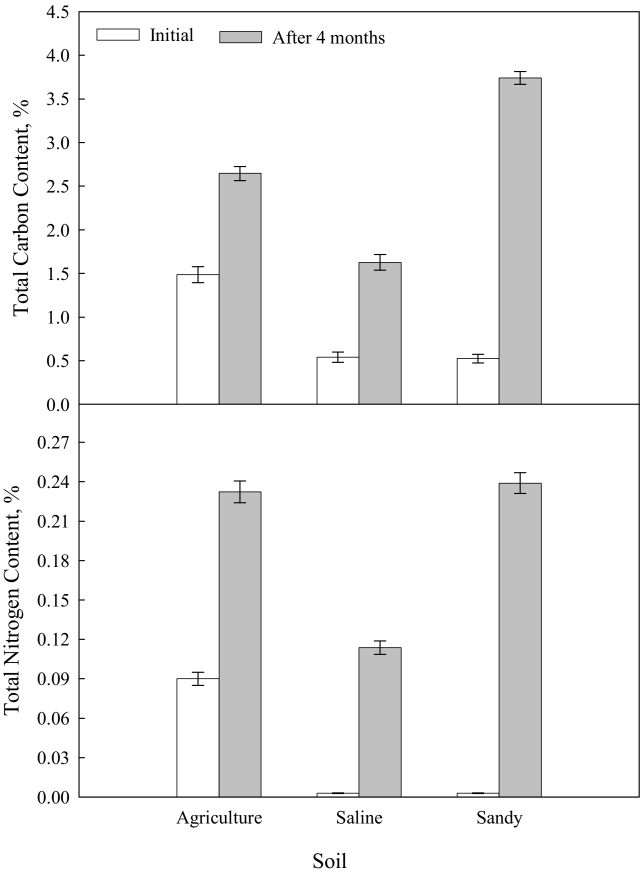

Fig. 2 Changes in carbon and nitrogen content in different soil after 4 months of vermicomposting. Temperature: 10-25ºC; relative humidity: 50-70%; reactor surface area: 0.09 m^2 numbers of samples are 4 for each soil.

DISCUSSION

In the present study precomposted faeces were added in the reactors. It was realized precomposting of faeces helped (i) to eliminate anaerobic conditions, at least at the exterior of the feed, (ii) to reduce the concentration of mortality causing substances, and (iii) to make the feed acceptable to the earthworms. Yadav *et al.* (2010) reported that application of vermicompost as bulking material in sandwich model helped to reduce the odour and volatile fatty acids concentration and to maintain the pH. Gunadi *et al.* (2002) and Garg *et al.* (2005, 2006) also reported that precomposting of waste was essential to avoid death of earthworms and to enhance the survivability of earthworms.

The biomass growth was high in first month compared to second month and it was due to high mean individual weight compared to its initial value. The biomass growth in the present study was 13.13-16.57 mg/g/day after one month while Garg *et al.* (2005) reported a value of 13.7-26.2 mg/worm/day within 6 weeks. Khwairakpam and Bhargava (2009a, 2009b) reported that biomass growth rate was 8.8 to 11.1 mg/g/day with sewage sludge and filter mud as feed while a lower growth rate of 3.98 mg/g/day was reported by Suthar (2009) with vegetable solid waste as feed. The highest biomass growth in the present study was found in sandy soil possibly due to presence of inorganic particle. The total biomass growth in all soils increased with time due to sufficient availability of food and favorable environmental conditions in the reactors. Neuhauser *et al*. (1980) and Jefferies and Audsley (1988) also reported increasing trend for *E. fetida* with time in animal waste. Satvat and Tare (2004) reported that soil layer positively influenced the survival of earthworms as it helped to maintain moisture in the vermicomposting and feed layer. Study by Yadav *et al.* (2010) on source separated human faeces showed that soil layer in bedding of the reactor helped in enhancing biomass growth and reproduction.

The mean individual weight of earthworms was high in saline soil compared to other soils in the first month due to high salinity and pH of this soil. It was observed that when earthworms were introduced in saline soil, they absorb more water for their survivability. It was also observed that earthworm from saline soil reactors when taken out for counting and weighing started losing their weight due to release of this absorbed water. The individual weight of mature earthworm varied between 0.31 to 0.52 g during the study period in all soils except saline soil during first month. Gunadi *et al.* (2002) with separated cattle solids and Monroy *et al.* (2006) with cow dung also reported individual weight of *E. fetida* in the range 0.30 to 0.55 g.

The cocoon production was more in first and second months compared to third and fourth month due to availability of sufficient space in the reactor as enough feed was available in all reactors. The cocoon and hatchling production was in order: sandy soil > agriculture soil > saline soil. In the present study, the cocoon production ranged from 1.1 to 4.8 cocoons/worm/month. Gunadi *et al.* (2002) reported that it ranged from 1.6 to 2.7 cocoons/worm/month in separated cattle solids. Monroy *et al.* (2006) reported that changes in the cocoon density were related to density of mature worms. Garg *et al.* (2005) reported 5.7-13.2 cocoons/worm/month in different animal wastes. It was observed that production of hatchlings depended upon the hatching of cocoons and survivability of hatchling. It was also observed that cocoons needed less moisture compared to hatchlings for their survivability.

In the present study the changes in carbon and nitrogen content in different soil layers were observed from second month onwards. It was also observed that for the first two months the earthworm movement was found mostly in feed layer. As the number of earthworms increased, the movement of earthworm in soil layer increased. The movement of earthworms in soil layer and releasing of cast enhanced the carbon and nitrogen content in the soil and also changed the other physical and chemical properties of the soil. Scullion and Malik (2000) reported that organic matter had greater efficiency in stabilizing aggregates where earthworms were abundant.

Vermicomposting helped to improve characteristics of saline soil. pH of the saline soil decreased to 7.2 from 10.8 while conductivity decreased to 315 from 511 μmho/cm. Though compared to other soils, earthworms in saline soil were less, this was sufficient to improve the saline soil properties like pH and conductivity.

CONCLUDING REMARKS

The study showed that characteristics of soil layer affect the biomass growth and reproduction of earthworms during vermicomposting. The earthworm biomass growth and offspring production were in the order: sandy soil > agricultural soil > saline soil. During the vermicomposting, movements of earthworms in soil helped to improve the properties of soil. Increased carbon and nitrogen content was observed in all soils, and for saline soil decrease in pH to neutral value and reduced conductivity were observed.

REFERENCES

Eastman BR, Kane PN, Edwards CA, Trytek L, Gunadi B, Stermer AL, Mobley JR (2001) The effectiveness of vermiculture in human pathogen reduction for USEPA biosolids stabilization. *Compost Science and Utilization* **9 (1)**, 38-49

Edwards CA, Bohlen PJ (1996) *Biology and Ecology of Earthworms*, Chapman and Hall, London, 426 pp

Edwards CA (1998) The use of earthworms in the breakdown and management of organic wastes. In: Edwards CA (Ed) *Earthworm Ecology*, CRC Press, The Netherlands, pp 327-354

Garg VK, Kaushik P, Dilbaghi N (2006) Vermiconversion of wastewater sludge from textile mill mixed with anaerobically digested biogas plant slurry employing *Eisenia fetida. Ecotoxicology and Environmental Safety* **65 (3)**, 412-419

Garg VK, Chand S, Chhillar A, Yadav A (2005) Growth and reproduction of *Eisenia fetida* in various animal wastes during vermicomposting. *Applied Ecology and Environmental Research* **3 (2)**, 51-59

Gunadi B, Blount C, Edwards CA (2002) The growth and fecundity of *Eisenia fetida* (Savigny) in cattle solids pre-composted for different periods. *Pedobiologia* **46**, 15-23

Jefferies IR, Audsley E (1988) A population model for the earthworm Eisenia fetida. In: Edwards CA, Neuhauser EF (Eds) *Earthworms in Waste and Environmental Management*, SPB Academic Publishing, The Hague, pp 119-134

Khwairakpam M, Bhargava R (2009a) Vermitechnology for sewage sludge recycling. *Journal of Hazardous Materials* **161**, 948-954

Khwairakpam M, Bhargava R (2009b) Bioconversion of filter mud using vermicomposting employing two exotic and one local earthworm species. *Bioresource Technology* **100 (23)**, 5846-5852

Kaushik P, Garg VK (2004) Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with cow dung and agricultural residue. *Bioresource Technology* **94**, 203-209

Lee KE, Foster RC (1991) Soil fauna and soil structure. *Australian Journal of Soil Research* **29**, 745-776

Loh TC, Lee YC, Liang JB, Tan D (2005) Vermicomposting of cattle and goat manures by *Eisenia fetida* and their growth and reproduction performance. *Bioresource Technology* **96**, 111-114

Monroy F, Aira M, Domínguez J, Velando A (2006) Seasonal population dynamics of *Eisenia fetida* (Savigny, 1826) (Oligochaeta, Lumbricidae) in the field. *Comptes Rendus Biologies* **329 (11)**, 912-915

Neuhauser EF, Hartenstein R, Kaplan DL (1980) Growth of the earthworm *Eisenia fetida* in relation to population density and food rationing. *Oikos* **35 (1)**, 93-98

Oades JM (1993) The role of biology in formation, stabilization and degradation of soil structure. *Geoderma* **56**, 337-400

Reddy KK, Yadav KD, Tare V (2005) Conversion of fecal matter to humus using earthworm spices *Eisenia fetida. 9th International Ecosan Conference*, 25-26 November, 2005, Mumbai, India, pp 55-59

Satvat PS (2006) Analysis and applications of vermicomposting employing *Eisenia fetida.* PhD thesis, Indian Institute of Technology, Kanpur, pp 2-252

Satvat PS, Tare V (2004) *In-situ* vermicomposting for reclaiming saline soils. *19th International Conference on Solid Waste Management and Technology*, Philadelphia, USA

Scullion J, Malik A (2000) Earthworm activity affecting organic matter, aggregation and microbial activity in soils restored after opencast mining for coal. *Soil Biology and Biochemistry* **32**, 119-126

Shalabi M (2006) Vermicomposting of fecal matter as a component of source control sanitation. Ph.D Thesis, Hamburg University of Technology, Germany, pp 43-82

Suthar S (2008) Bioconversion of post harvest crop residue and cattle shed manure into value-added products using earthworm *Eudrilus eugeniae* Kinberg. *Ecological Engineering* **32 (3)**, 206-214

Suthar S (2009) Vermicomposting of vegetable-market solid waste using *Eisenia fetida*: Impact of bulking material on earthworm growth and decomposition rate. *Ecological Engineering* **35 (5)**, 914-920

USDA, USCC (2002) *Test Methods for the Examination of Composting and Compost*, pp 301-414

Yadav KD, Tare V (2006) An approach for conversion of dry toilet waste to vermicompost. *Second International Dry Toilet Conference (DT 2006)*, 16-19 August, 2006, Tampere, Finland, 73p

Yadav KD, Tare V, Ahammed MM (2010) Vermicomposting of source-separated human faeces for nutrient recycling. *Waste Management* **30 (1)**, 50-56