Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in

JEB

Journal of Environmental Biology

ISSN: 0254-8704
CODEN: JEBIDP

Vermicomposting of paper mill solid waste using epigeic earthworm *Eudrilus eugeniae*

S. Ponmani[1]*, C. Udayasoorian[2], R.M. Jayabalakrishnan[2] and K. Vinoth Kumar[2]

[1]Dryland Agricultural Research Station, Tamil Nadu Agricultural University, Chettinad-630 102, India

[2]Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore-641 003, India

*Corresponding Author E-mail: ponmaniphd@gmail.com

Publication Info

Paper received:
10 July 2012

Revised received:
15 June 2013

Revised received:
18 August 2013

Accepted:
12 September 2013

Abstract

A 90 day study was conducted to evaluate the efficiency of an exotic earthworm species (*Eudrilus eugeniae*) for decomposition of different types of organic substrates (mixed liquor suspended solids, cow dung and leaf litter) into valuable vermicompost. Mixed liquor suspended solids (MLSS) and leaf litter (LL) were mixed with cow dung (CD) in eight different ratios with three replicates for each treatment. All vermibeds expressed a significant decrease in pH, organic carbon, C:N ratio and an increase in total nitrogen, phosphorus and potash. Overall, earthworms could maximize decomposition and mineralization efficiency in bedding with lower proportions of MLSS. Maximum value for earth worm zoo mass and higher concentration of nutrient content was observed in CD + MLSS + LL in 1:1:2 ratios. Earthworm mortality tended to increase with increasing proportion of MLSS and maximum mortality in *E. eugeniae* was recorded for MLSS treatment alone. Results indicate that vermicomposting might be useful for managing the energy and nutrient of MLSS on a low-input basis. Products of this process can be used for sustainable land restoration practices.

Key words

Cow dung, *Eudrilus eugeniae*, Leaf litter, Paper mill MLSS, Vermicomposting

Introduction

The acute energy crisis and environmental degradation due to the growth of industries has become a serious global problem. Industries produce huge quantities of liquid, gaseous or solid wastes, these waste products contribute to environmental pollution. The conventional disposal system for waste consists of open dumping or land filling of waste material. This practice is not sustainable due to leaching of certain toxic chemicals and metals from dumped wastes (Abu- Rukah and Al- Kofahi, 2001). Contamination of groundwater, soil, as well as food resources are some of the problems which have resulted from land filling practices of dumped waste materials (Fatta *et al.,* 1999). There is a need for hsafe technology to manage these noxious industrial wastes; the technologies must be ecologically sound, economically viable and socially acceptable.

Vermicomposting, through earthworms, is an ecobio technological process that transforms energy rich and complex organic substances in to a stabilized vermicomposts (Bentiez *et al.*, 2000). Vermicomposting is stabilization of organic material, involving the joint action of earthworms and micro organisms. Although microbes are responsible for biochemical degradation of organic matter, earthworms are important derivers of the process, conditioning the substrate and altering the biological activity (Aira *et al.*, 2002). During vermicomposting, nutrients are released and converted into soluble and available forms for plants (Ndegwa and Thompson, 2001). Vermicomposting, through different species of earthworm has been studied (Edwards *et al.*, 1998). The epigeic earthworm were utilized for organic waste management (Suthar, 2006; Garg and Kaushik, 2005; Benitez *et al.*, 2005). Epigeic forms of earthworms can hasten the composting process to a significant extent with production of better availability of vermicomposts (Ndegwa and Thomson, 2001). The epigeic earthworm, *E. foetida* is a suitable species for management of waste and is utilized successfully in vermicomposting (Chaudhari and Battacharjee, 2002).

In light of the above, the present study deals with the suitability of composting earthworm species *i.e. E. eugeniae* for recycling paper mill MLSS mixed with bulking agents (CD and LL) in different ratios and to produce value-added product (vermicompost) which can be used for sustainable land restoration practices.

Materials and Methods

Preparation of vermibeds : In this experiment, samples of raw materials *viz.,* mixed liquor suspended solid (MLSS), leaf litter (LL) and cow dung (CD) were collected from Tamil Nadu Newsprint and Papers Limited (TNPL). The LL consisted mainly of mango and eucalyptus leaf. The LL were dried, chopped, sieved (<2 mm) and amended with CD and MLSS in different ratios in order to produce eight feed mixtures. The substrate and mixed substrate material served as bedding as well as feed for the earthworms. One treatment composed of pure CD (T_1); another treatment composed of MLSS (T_2). The following mixed substrates (bedding) were prepared: (i) CD + MLSS in 1:3 ratios (T_3); (ii) CD + MLSS in 1:1 ratios (T_4); (iii) CD + MLSS in 3:1 ratios (T_5); (iv) CD + MLSS + LL in 0:1:3 ratios (T_6); (v) CD + MLSS + LL in 1:1:2 ratios (T_7); and (vi) CD + MLSS + LL in 1:2:1 ratios (T_8). The experiment was laid out in a Randomized Block Design and the experimental beddings were prepared in triplicate for each treatment. All beddings were kept 2 months prior to experimentation for thermal stabilization, initiation of microbial degradation and softening of waste. About, 750 g of twenty two week old clitellated earthworms were collected from the stock culture and released into different beds containing 150 kg of substrate material. The moisture level of the substrates was maintained around 70 to 75 % throughout the study period by periodic sprinkling of adequate quantity of tap water.

Sampling and analysis : The samples were collected at different stages of the vermicomposting experiment *viz.,* 30, 60 and 90 days after initiation. The collected samples were sieved in 2 mm sieve for physico- chemical analysis. The pH was measured using a digital pH meter (Systronic made) in 1/10 (w/v) aqueous solution (deionized water). Organic carbon was determined by partial oxidation method (Walkley and Black, 1934). Total Kjeldahl nitrogen and total phosphorus was measured following the method of Jackson (1975). Total potassium was determined by flame photometer (Bansal and Kapoor, 2000). Earthworms produced during the experiment were separated from the substrate material by hand sorting, after which the worms were washed in tap water to remove adhering material from their body, and subsequently weighed on a live weight basis.

Statistical analysis : Two way analysis of variance (ANOVA) was applied to determine any significant ($P<0.05$) difference among the parameters observed in vermicompost bed (Sokal and Rohlf, 1973). The treatment differences that are not significant were noted as non significant (NS).

Results and Discussion

The pH of MLSS (7.67), CD (7.78) and LL (7.62) were neutral in nature. The organic carbon content of MLSS was 14.8 %, 25.5 % in CD and 22.3 % in LL. MLSS had a narrow C: N ratio of 23.1. The CD and LL had a wider C:N ratio of 30.4 and 28.6, respectively. The CD was comparatively higher in nitrogen content (0.84 %) than LL (0.78 %) and MLSS (0.64 %). MLSS had the highest P and K content of 0.72 and 1.29 %, respectively. The lowest nutrient content of phosphorus (0.57 %) and potassium (0.62 %) was recorded in CD.

The pH was lower than the initial values in all treatments.

Table 1 : Changes in pH and Organic Carbon during vermicomposting process of paper mill MLSS

Treatments	pH					Organic carbon (%)				
		Sampling period (days)					Sampling period (days)			
	Initial	30	60	90	Mean	Initial	30	60	90	Mean
T_1	7.33	7.29	7.25	7.23	7.28	26.2	25.1	24.2	22.4	24.5
T_2	7.62	7.59	7.46	7.38	7.51	25.8	22.7	22.0	19.8	22.6
T_3	7.45	7.42	7.31	7.28	7.37	27.3	24.8	23.7	21.6	24.4
T_4	7.42	7.39	7.32	7.30	7.36	27.6	25.0	24.3	22.1	24.8
T_5	7.24	7.22	7.20	7.17	7.20	28.0	26.3	25.0	22.8	25.5
T_6	7.49	7.48	7.38	7.31	7.42	26.9	24.2	24.0	22.0	24.3
T_7	7.26	7.24	7.22	7.20	7.23	27.8	25.2	24.9	22.6	25.1
T_8	7.25	7.23	7.21	7.18	7.22	29.1	27.1	26.5	23.8	26.6
Mean	7.38	7.36	7.29	7.25	7.32	27.3	25.1	24.3	22.1	24.7
		SEd		(P<0.05)			SEd		(P<0.05)	
T		0.09		0.18			0.10		0.20	
D		0.06		NS			0.07		0.14	
T x D		0.18		NS			0.20		0.40	

Treatments : T_1- CD; T_2- MLSS; T_3- CD + MLSS (1:3); T_4- CD + MLSS (1:1); T_5- CD + MLSS (3:1); T_6- CD+ LL + MLSS (0:1:3); T_7- CD+ LL + MLSS (1:1:2); T_8- CD+ LL + MLSS (1:2:1); SE-Standard Error; NS- Non Significant; T- Treatments; D-Days

Comparatively, the vermicomposting process caused more reduction in pH than the normal composting process (the control). The maximum reduction in pH (as compared to initial values) was in CD + MLSS (3:1) and the minimum reduction was in MLSS alone (Table 1). The pH shift toward acidic condition was attributed to mineralization of nitrogen and phosphorus into nitrates / nitrites and orthro-phosphates; bioconversion of organic materials in to intermediate species of organic acids (Ndegwa and Thompson, 2000). Production of CO_2 and organic acid by microbial decomposition during vermicomposting lowers the pH of substrate (Garg and Kaushik, 2004).

At 30^{th}, 60^{th} and 90^{th} day of vermicomposting process, significantly higher organic carbon content (27.1, 26.5 and 23.8 %) was noticed in CD+ LL +MLSS (1:2:1) whereas MLSS alone recorded the lowest organic carbon content of 22.7, 22.0 and 19.8 %, respectively. The interaction treatments and days were significantly different from each other. The organic carbon in all vermibeds declined (27 to 22 %) drastically compared to their initial levels (Table 1). Garg and Kaushik (2003) reported 20-45 % loss of organic carbon in the form of CO_2 from different industrial sludge during vermicomposting. The vermicomposting process refers to feeding of earthworm on organic matter and microbial degradation. Earthworms modify the substrate condition which consequently promotes carbon loss from the substrate through microbial respiration in the form of CO_2 and even through mineralization of organic matter. Elvira *et al*. (1998) stated that large fraction of organic matter in the initial substrate was as loss as CO_2 between 20 and 43% as total organic carbon by the end of vermicomposting. Elvira *et al*. (1998) and Suthar (2008a) reported that body fluid and excreta secreted by earthworm (e.g. mucus, high concentration of organic matter, ammonium and urea) promote microbial growth in vermicomposting.

The increase in total nitrogen content was significantly higher in vermicomposted material than control (MLSS alone). At 30^{th} day of vermicomposting process, the highest total nitrogen content of 1.13 % was recorded in CD+ leaf litter +MLSS (1:1:2), which was on par with CD+ LL +MLSS (1:2:1). During 60 and 90^{th} day of vermicomposting process, significantly higher total nitrogen content (1.20 and 1.42 %) was recorded in CD+ LL+ MLSS (1:1:2), which was on par with CD + MLSS + LL (1:2:1) and CD+ LL+MLSS (0:1:3). The lowest total nitrogen content of 0.68, 1.05 and 1.10 % was observed in MLSS alone at all the stages of vermicomposting process. The interaction effect of treatments and days was significantly different from each other. Total nitrogen was significantly higher in the end products of experimentations than their initial levels (Table 2). The enhancement of nitrogen in vermicompost was probably due to mineralization of the organic matter containing proteins (Garg and Kaushik, 2005) and conversion of ammonium-nitrogen into nitrate (Suthar and Singh, 2008). In general, the final content of nitrogen in the vermicompost is dependent on initial nitrogen present in the waste and the extent of decomposition (Kaviraj and Sharma, 2003). This finding was supported by the observation of Bhattacharya and Chattopadhyay (2004) where nitrogen availability was found to be more during the process of vermicomposting in combination with cow dung.

C : N ratio is one of the most widely used indices for maturity of organic wastes, decreased with time in all the treatment due to decomposition (Table 2). The least C:N ratio of 22.3, 20.8 and 15.9 was observed in CD+ LL+ MLSS (1:1:2) followed by CD +LL+ MLSS (0:1:3) and the highest C:N ratio of 35.4, 22.6 and 19.0 was registered in CD alone at 30^{th}, 60^{th} and 90^{th} day of vermicomposting process, respectively. The interaction was significantly different from each other. The

Table 2 : Changes in total nitrogen and C: N ratio during vermicomposting process of paper mill MLSS

Treatments	**Total nitrogen (%)**					**C: N ratio**				
		Sampling period (days)					**Sampling period (days)**			
	Initial	**30**	**60**	**90**	**Mean**	**Initial**	**30**	**60**	**90**	**Mean**
T_1	0.68	0.71	1.07	1.18	0.91	38.5	35.4	22.6	19.0	28.9
T_2	0.65	0.68	1.05	1.10	0.87	39.7	33.4	21.1	18.0	28.0
T_3	0.70	0.96	1.10	1.29	1.01	39.0	25.8	21.5	16.7	25.8
T_4	0.74	0.99	1.11	1.30	1.04	37.3	25.3	21.9	17.0	25.4
T_5	0.76	1.02	1.13	1.33	1.06	36.8	25.8	22.1	17.1	25.5
T_6	0.78	1.05	1.14	1.36	1.08	34.5	23.0	21.0	16.2	23.7
T_7	0.83	1.13	1.20	1.42	1.15	33.5	22.3	20.8	15.9	23.1
T_8	0.81	1.10	1.19	1.41	1.13	35.9	24.6	22.3	16.9	24.9
Mean	0.74	0.96	1.12	1.30	1.03	36.9	26.9	21.7	17.1	25.7
		SEd		(P<0.05)			SEd		(P<0.05)	
T		0.03		0.06			0.84		1.68	
D		0.02		0.04			0.59		1.18	
T x D		0.06		0.12			1.68		3.35	

Treatments : T_1- CD; T_2- MLSS; T_3- CD + MLSS (1:3); T_4- CD + MLSS (1:1); T_5- CD + MLSS (3:1); T_6- CD+ LL + MLSS (0:1:3); T_7- CD+ LL + MLSS (1:1:2); T_8- CD+ LL + MLSS (1:2:1); SE- Standard Error; NS- Non Significant; T- Treatments; D-Days lowering of C:N ratio was probably achieved by the combustion of carbon substances during respiration and the incorporation of plant derived organic material and transit of organic matter through the gut of earthworms. Suthar (2008b) reported that C : N ratio of substrate material reflects the organic waste mineralization and stabilization during the process of decomposition. The loss of carbon as CO_2 through microbial respiration and addion of nitrogenous excretory material between C : N ratio of the substrate. C: N ratio is one of the most widely used indicators of vermicompost maturation, decreases sharply during vermicomposting process (Kale, 1998).

During 30[th] day of vermicomposting process, the highest total phosphorus content of 0.99 % was recorded in CD+ LL +MLSS (1:1:2) followed by CD+ MLSS (3:1). At 60[th] day of vermicomposting process, significantly higher total phosphorus content (1.02 %) was observed in CD+ LL+ MLSS (1:1:2), which was at par with CD+MLSS (3:1). At 90[th] day of vermicomposting process, higher total phosphorus content of 1.20 % was recorded in CD+ LL+ MLSS (1:1:2) and it was at par with CD+MLSS (3:1)] and CD + MLSS + LL (1:2:1). The interactive effect of treatments and days were non significant. In all the three stages of vermicomposting process, CD alone recorded the lowest total phosphorus content (0.68, 0.79 and 0.94 %). This might be due to initial substrate of CD was recorded lowest phosphorus content than other substrates *viz.,* LL and MLSS. Total phosphorus was greater in the final vermicompost than in the initial vermibed mixture (Table 3). The enhanced phosphorus level in vermicompost suggests phosphorous mineralization during the process. The worms during the process of vermicomposting converted the insoluble phosphorus into soluble forms with the help of phosphorus solubilizing microorganisms through phosphatases present in the gut, making it more available to plants (Padmavathiamma *et al.,* 2008).

Total potassium concentration was slightly increased in vermicomposts of all the combination of wastes than in the initial feed mixture (Table 3). At 30[th], 60[th] and 90[th] day of vermicomposting process, significantly the highest total potassium content of 0.69, 1.13 and 1.41 % was recorded in CD+ LL+ MLSS (1:1:2), which was at par with CD+MLSS (3:1). The interactive effect of treatments and days were significantly different from each other. Invariably, CD alone recorded the lowest total potassium content (0.53, 0.77 and 1.01 %) at all the stages of vermicomposting process.

As in the case of phosphorus, potassium concentration was low in the initial substrate of CD. Delgado *et al.* (1995) have reported a higher content of total potassium in the new sewage sludge vermicompost. Benitez *et al.* (1999) studied that the leacheates collected during the vermicomposting process had higher potassium concentrations. Kaviraj and Sharma (2003) observed that the level of total potassium increased by 10 % by *Eisenia foetida* and 5% by *L. maturitii* during vermicomposting. Shutar (2007) suggested that earthworm processed waste material contained high concentration of exchangeable potassium, due to enhanced microbial activity during the vermicomposting process, which consequently enhanced the rate of mineralization.

Significantly higher earthworm zoo mass of 1283 g C^{-1} was recorded in CD+ LL+ MLSS (1:1:2). The lowest content of earthworm zoo mass of 871 g C^{-1} was observed in MLSS alone (Fig 1). The MLSS alone was not able to support earthworm growth, however the mixture could be a suitable technique for its utilization as food source in vermicomposting. Reduction in earth

Table 3 : Changes in total phosphorus and total potassium during vermicomposting process of paper mill MLSS

Treatments	Total phosphorus (%)					Total potassium (%)				
		Sampling period (days)					Sampling period (days)			
	Initial	30	60	90	Mean	Initial	30	60	90	Mean
T_1	0.63	0.68	0.79	0.94	0.76	0.51	0.53	0.77	1.01	0.71
T_2	0.82	0.88	0.90	1.08	0.92	0.59	0.60	0.88	1.10	0.79
T_3	0.79	0.81	0.84	1.05	0.87	0.54	0.57	0.79	1.08	0.75
T_4	0.82	0.86	0.88	1.06	0.91	0.56	0.59	0.81	1.09	0.76
T_5	0.89	0.92	0.98	1.15	0.99	0.63	0.66	1.11	1.38	0.95
T_6	0.74	0.77	0.83	1.01	0.84	0.53	0.55	0.78	1.07	0.73
T_7	0.90	0.99	1.02	1.20	1.03	0.64	0.69	1.13	1.41	0.97
T_8	0.88	0.90	0.95	1.09	0.96	0.61	0.63	0.90	1.20	0.84
Mean	0.81	0.85	0.90	1.07	0.91	0.58	0.60	0.90	1.17	0.81
		SEd		($P<0.05$)			SEd		($P<0.05$)	
T		0.03		0.06			0.02		0.04	
D		0.02		0.04			0.03		0.05	
T x D		0.06		NS			0.05		0.10	

Treatments : T_1- CD; T_2- MLSS; T_3- CD + MLSS (1:3); T_4- CD + MLSS (1:1); T_5- CD + MLSS (3:1); T_6- CD+ LL + MLSS (0:1:3); T_7- CD+ LL + MLSS (1:1:2); T_8- CD+ LL + MLSS (1:2:1); SE Standard error deviation; NS-Non Significant; T- Treatments; D-Days

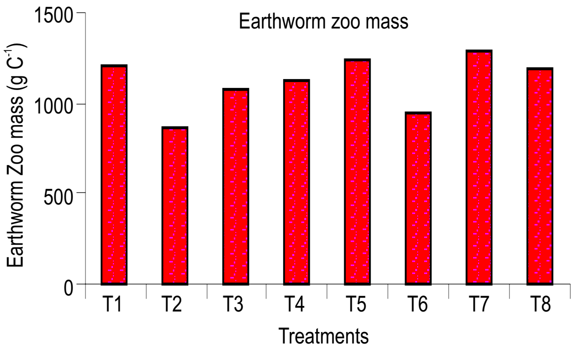

Fig. 1 : Earthworm population at the end of the vermicompost

Treatments : T_1- CD; T_2- MLSS; T_3- CD + MLSS (1:3); T_4- CD + MLSS (1:1); T_5- CD + MLSS (3:1); T_6- CD+ LL + MLSS (0:1:3); T_7- CD+ LL + MLSS (1:1:2); T_8- CD+ LL + MLSS (1:2:1); g C^{-1}- gram per compost

worm population in majority of the mixtures suggests that MLSS proportions play an important role in breakdown and in environmental changes. Reduction of earth worm population was not due to lack of food but degradation process probably resulting in changes of the environmental characteristics, the polysaccharides breakdown could modify the structure of the substrate so the water retention capacity decreases and this fact would decrease the earth worm population. This is in line with the findings of Garg and Kaushik (2005), who reported that the increasing proportion of solid textile mill sludge in the feed mixtures decreased the growth. This indicated that a greater percentage of paperboard sludge in the feed mixture delayed sexual maturity and reproduction of earth worms. Earthworms fed with 100 % paper sludge were reported to have less active and the lowest yield when compared with cow dung mixed treatments. Therefore, the sludge was suggested to be mixed with nitrogen rich sources (Elvira *et al.,* 1998).

The study thus suggests that the final vermicompost was rich in nitrogen, phosphorus, potassium and their C:N ratio was below 20 which indicate their agronomic importance. A considerable amount of worm biomass was also produced in different treatments. This study revealed that vermicomposting technology could be efficiently used to combat the problem of industrial solid waste management.

Acknowledgment

The authors wish to thank the Tamil Nadu Newsprint and Papers Limited (TNPL) for providing financial support to this study.

References

Abu- Rukah, Y. and O. Al- Kofahi: The assessment of the effect of landfill leachate on ground-water quality-A case study. El-Akader landfill site-North Jordan. *Arid Environ.,* **49,** 615-630 (2001).

Aira, M., F. Monoroy, J. Dominguez and S. Mato: How earthworm density affects microbial biomass and activity in pig manure. *Eur. J. Soil Biol.,* **38**, 7-10 (2002).

Bansal, S. and K.K. Kapoor: Vermicomposting of crop residues and cattle dung with *Eisenia foetida. Biores. Technol.,* **73**, 95-98 (2000).

Benitez, E., R. Nogales, C. Elvira, G. Masciandaro and B. Ceccanti: Enzyme activity as indicators of the stabilization of sewage sludge composting with *Eisenia foetida*. *Biores. Technol.,* **67**, 297-303 (1999).

Benitez, E., R. Nogales, G. Masciandro and B. Ceccanthi: Isolation by isoelectric focusing of humic urease complex from earthworm *Eisenia foetida* processed sewage sludge. *Biol. Fert. Soil.,* **31**, 489-493 (2000).

Benitez, E., H. Sianz and R. Nogales: Hydrolytic enzyme activities of extracted humic substances during the vermicomposting lignocelulosic olives waste. *Biores. Technol.,* **96**, 785-790 (2005).

Bhattacharya, S.S. and G.N. Chattopadhyay: Transformation of nitrogen during vermicomposting of flyash. *Waste Manage. Res.,* **22,** 488-491 (2004).

Chaudhari, P.S. and G. Bhattacharjee: Capacity of various experimental diets to support biomass and reproduction of *Perionyx excavates. Biores. Technol.,* **82**, 147-150 (2002).

Delgado, M., M. Bigeriego, I. Walter and R. Calbo: Use of California red worm sewage sludge transformation. *Turrialba.,* **45**, 33-41 (1995).

Edwards, C.A., J. Dominguez and E.F. Neuhauser: Growth and reproduction of *Perionyx excavates* (Perrier) (Megascolicideae) as factor inorganic waste management. *Biol. Fert. Soils.,* **27**, 155-161 (1998).

Elvira, C.A., L. Sampedro, E. Benitez and R. Nogales: Vermicomposting of sludges from paper mill and dairy industries with *Eisenia Andrei*: A pilot scale study. *Biores. Technol.,* **63**, 205-211 (1998).

Fatta, D., A. Papadopoulos and M. Loizidou: A study on the landfill leachate and its impact on the groundwater quality of the greater area. Environ. *Geochem. Health*, **21,** 175-190 (1999).

Garg, V.K. and P. Kaushik: Vermicomposting of solid textile will sludge and cow dung with the epigeic earthworm *Eisenia foetida. Biores. Technol.,* **90**, 311-316 (2003).

Garg, V.K. and P. Kaushik: Dynamics of biological and chemical parameter during vermicomposting of solid textile mill sludge mixed with cow dung and agricultural residues. *Biores. Technol.,* **94**, 203-209 (2004).

Garg, V. K. and P. Kaushik: Vermistabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*. *Biores. Technol.,* **96,** 1063-1071 (2005).

Jackson, M. L: Soil Chemical Analysis. New Delhi, Pranctice Hall of India (1975).

Kale, R.D: Earthworm nature's gift for utilization of organic wastes. In: Earthworms Ecology (Ed.: C.A. Edwards). Soil and waste conversion society. Ankeny Lowa St. Lucie Press, New York. pp. 335- 373 (1998).

Kaviraj, M. and S. Sharma: Municipal solid wastes management through vermicomposting employing exotic and local species of earthworm. *Biores. Technol.,* **90**, 169-173 (2003).

Ndegwa, P.M. and S.A. Thompson: Effect of stocking density and feeding rate vermicomposting of biosolids. *Biores. Technol.,* **71**, 5-12 (2000).

Ndegwa, P.M. and S.A. Thompson: Integrating composting and vermicomposting the treatment and bioconversion of biosolids. *Biores. Technol.,* **76**, 107-112 (2001).

Padmavathiamma, K., Y. Loretta Li and R. Usha Kumari: An experimental study of vermi-biowaste composting for agricultural soil improvement. *Biores. Technol.,* **99,** 1672-1681 (2008).
Sokal, R. and J. Rohlf: Introduction of biostatistics. W. H. Freeman & C. San Francisco (1973).
Suthar, S.: Potential utilization of Guar gum industrial wastes in vermicomposts productions. *Biores. Technol.,* **97**, 2474-2477 (2006).
Suthar, S.: Nutrients changes and biodynamic of epigeic earthworms *Perionyx excavatus* during recycling of some agricultural wastes. *Biores. Technol.,* **98**, 1608-1614 (2007).
Suthar, S.: Microbial and decomposition efficiencies of monoculture and polyculture vermireactors based on epigeic and anecic earthworms. *World J. Microbiol. Biotechnol.,* **24**, 1471– 1479 (2008a).
Suthar, S: Bioconversion of post harvest crop residues and cattle shed manure into value added products using earthworm *Eudrilus eugeniae* (King berg). *Ecological Engineering,* **32**, 206-214 (2008b).
Suthar, S. and S. Singh: Vermicomposting of domestic waste by using two epigeic earthworms (*Perionyx excavatus* and *Perionyx sansibaricus*). *Intl J. Enviro. Sci. Technol.,* **5,** 99-106 (2008).
Walkley, A. and I. A. Black: An examination of the Degtjareff method for determining soil organic matter and prepared modification of the chronic acid titration method. *Soil Sci.,* **34,** 29 – 38 (1934).