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Bioconversion of Municipal (Organic) Solid Waste into Nutrient-rich Vermicompost by Earthworms (*Eudrilus eugeniae*, *Eisenia fetida* and *Perionyx excavatus*)

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ABSTRACT

Changes in the concentrations of major nutrients of vermicompost of Municipal Organic Solid Waste [MOSW] processed by three species of earthworms viz., *Eudrilus eugeniae*, *Eisenia fetida*, and *Perionyx excavatus* and its simple compost were assessed during different intervals. The bulk mass of MOSW was reduced up to 65, 55 and 40% by vermicomposting mediated by *E. eugeniae*, *E. fetida* and *P. excavatus*, respectively, and up to 20% in the compost. The pH, electrical conductivity (EC), and concentrations of major nutrients – nitrogen, phosphorus, potassium, calcium and magnesium in the vermicompost and compost gradually increased while the organic carbon, C/N and C/P ratios decreased as the composting process progressed from 0 to 60 days ($P<0.05$). The vermicompost of all the earthworm species possessed significantly higher concentrations of nutrients than the compost and substrate ($P<0.05$). Moreover, among them, vermicompost of *E. eugeniae* acquired higher nutrients than that of *E. fetida*, *P. excavatus*, and compost ($P<0.05$). Thus, *E. eugeniae* may be chosen for vermicomposting of MOSW over the other two species of earthworms.

Keywords: C/N ratio, compost, earthworm species, major nutrients, vermiculture
Abbreviations: MOSW, municipal organic solid waste

INTRODUCTION

Municipal Solid Waste (MSW) is generated in enormous quantities, because of contemporary living style, and becomes a menace when it is dumped unscientifically in urban areas, particularly in developing countries like India. The organic component of the urban waste constitutes about 45-60% of the total waste and can be used as a potential resource by recycling and reusing in the form of high quality compost. Vermicomposting is a suitable, hygienic and cost effective technique practiced for organic waste management, and is the process of devouring, digestion and excretion of any organic waste by earthworms, in which complex organic fractions of organic solid waste are broken down into good quality compost (EPA 1980). During the process, the nutrients locked up in the organic waste are transformed to simple and absorbable forms such as nitrate or ammonium nitrogen, exchangeable phosphorus, soluble potassium, calcium and magnesium in worm's gut (Lee 1985; Atiyeh *et al*. 2002) with significant reduction in the C/N ratio (Bansal and Kapoor 2000; Kaushik and Garg 2003). The end product, vermicompost is rich in plant nutrients and plant growth promoting hormone like substances (Dash and Senapati 1985, 1986; Edwards 2004; Reddy and Okhura 2004; Arancon *et al.* 2005; Dash and Dash 2008), and possessed higher level of nitrogen and phosphorus, and more soluble potassium, magnesium compared to the substrate and normal compost (Singh and Sharma 2002; Gupta *et al.* 2007). Its nutrient contents depend on that of the organic matter on which the earthworms feed (Kale 1995). It improves the soil productivity favoring higher yield (Reddy and Okhura 2004; Padmavathiamma *et al*. 2008).

Studies comparing the potential of different local and exotic species of earthworms in vermicomposting of Municipal Organic Solid Waste (MOSW) are few. Kaviraj and Sharma (2003) reported on the municipal solid waste management using the exotic *Eisenia fetida* and the local species of earthworm *Lampito mauritii*. The present investigation was carried out for management of urban waste converting into vermicompost using three epigeic species of earthworm, two of them being exotic, *viz.*, *Eudrilus eugeniae* (Kinberg) and *E. fetida* (Savigny) and the other one being local, *Perionyx excavatus* (Perrier). This study compared the nutrient status of vermicomposts of the MOSW processed by the three earthworm species in relation to that of simple compost and the substrate, in order to find out the efficient species of earthworm in nutrient conversion, which can be used in management of urban organic solid waste.

MATERIALS AND METHODS

Sample collection and processing

Municipal solid waste was collected from one of the major garbage dumping sites of Puducherry, namely *Karuvadikuppam* and characterized into biodegradable and non-biodegradable waste. Biodegradable portion of waste was segregated for the experiment, which comprised of yard waste followed by paper waste, food waste and others constituting fabric materials. It was then air dried for 48 hours and pre-composted for three weeks before putting into vermicomposting and composting process. Pre-composting, a pre-processed and pre-treated practice, was carried out by placing raw MOSW on a plastic sheet in a heap turning it with the help of a shovel once a week. In the pre-composting process, the microbial activity increased the temperature of the heap during its mesophilic and thermophilic phases followed by a cooling phase with a decrease in temperature (Nair *et al.* 2006). As increased temperature is lethal for earthworms, they were introduced during the cooling phase of pre-compost. When the temperature of the pre-composted substrate diminished to 25°C, adult earthworms with well defined clitella belonging to the three species *viz.*, *E. eugeniae*, *E. fetida* and *P. excavatus* were introduced on the pre-com-

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Table 1 Weight and different physical characteristics of vermicompost of three earthworm species in relation to that of compost and substrate, i.e., MOSW (mean ±SD, n = 3).

Parameters	0 days (Substrate)	60 days			
		Vermicompost			Compost
		E. eugeniae	*E. fetida*	*P. excavatus*	
Weight (kg)	5.0 ± 0.05	1.75 ± 0.01	2.25 ± 0.005	3.0 ± 0.071	4.0 ± 0.9
Temperature (°C)	31.3 ± 0.283	25.0 ± 0.632	25.2 ± 0.753	26.0 ± 0.018	26.8 ± 0.408
Moisture Content (%)	45.32 ± 0.015	60.0 ± 2.041	59.16 ± 2.041	55.83 ± 2.041	51.66 ± 2.582
pH	6.53 ± 0.058	7.11 ± 0.075	7.3 ± 0.063	6.86 ± 0.052	6.78 ± 0.075
Electric Conductivity (EC) (mhos/cm)	268.1 ± 0.4	789.2 ± 1.277	671.6 ± 0.5	592.7 ± 0.1	519.2 ± 0.1

posted material, which were collected from a local vermiculture unit at Lake Estate (Auorbindo Ashram, Puducherry, India).

Experimental design

Five kg of pre-compost substrate mixed with cow dung in a 3: 1 ratio was placed into each of the five earthen pots in the present study. There were totally four sets of earthen pots, each set containing six replicates. Three species of earthworms, each of 50 adult individuals, were introduced on the top of the pre-composted substrate separately in each of the three sets of pots keeping the fourth set for composting without any earthworm species. All pots were kept under an open shed with the average temperature of 25-26°C, with the pot-top covered by jute cloth and wire mesh to prevent the entry of predators like centipedes, moles, shrews, etc. The average moisture content (50-60%) was maintained by sprinkling 50 ml of water once every two days. The bottom of each pot with a small hole was filled with tiny pebbles to a height of 5 cm to provide drainage; however, utmost care was taken in sprinkling water so that there was no drainage or leaching. This experiment was carried out for a total period of 60 days. The harvesting of vermicompost and compost, total biomass of earthworms, individual body weight, and total numbers of juveniles and adults, cocoons, and mortality rate were done and assessed after 60 days, at the end of the experiment. The initial and final weights (wet) of the earthworms were obtained by weighing with an electronic mono-pan balance before and after the experiment, respectively. The average number of cocoons, juveniles and adults were enumerated using a magnifying glass at the end of the experiment. The average cocoon production rate (per day) was calculated by enumerating the cocoons per 15 days of composting process.

Physico-chemical analyses

The bulk dry mass of vermocompost and compost were calculated gravimetrically after air drying the samples for 48 hrs. The homogenized sub-samples of the substrate material (on the basis of 100 g dry weight) were collected at 0, 15, 30, 45 and 60 days from each pot and compound samples were made, which were analyzed for organic carbon (OC) and major nutrients – total nitrogen (N), available phosphorus (P), exchangeable potassium (K), calcium (Ca) and magnesium (Mg). The temperature (°C), moisture content (%), pH and electrical conductivity (EC) of the substrate were recorded during the vermicomposting and composting processes. Temperature was noted daily using a mercury bulb thermometer and moisture content was measured gravimetrically. The pH and EC of samples were recorded by a digital pH meter and conductivity meter (Multi-Parameter PCSTestr^{TM} 35, Oakton- Eutech Instruments), respectively. The OC of the samples was measured by Walkley-Black method (Walkley and Black 1934); the N was estimated by the Kjeldahl method (Jackson 1982), and the P and K contents of the samples were analyzed by a calorimetric method (Anderson and Ingram 1993) and a flame photometric method (Simard 1993), respectively. The Ca and Mg contents of the samples were also analyzed using an atomic absorption spectrophotometer (GBC make) (Jackson 1973). The C: N ratio was calculated from the measured values of C and N.

Statistical analysis

Two-way analysis of variance (ANOVA) was computed using SPSS (v. 10) to test the level of significance i.e., P value, in differences between the vermicomposts produced by the three species earthworms and compost samples with respect to nutrient parameters.

RESULTS

Changes in physical characteristics of MOSW during vermicomposting and composting process

The reduction in bulk dry mass of the substrate - MOSW, the range of temperature, moisture content, pH and EC of the substrate, compost and vermicompost are presented in **Table 1**. A marked reduction in the mass of MOSW was recorded in the vermicompost processed by *E. eugeniae* (65%), followed by that of *E. fetida* (55%) and *P. excavatus* (40%) compared to that of compost (20%). It clearly showed the marked stabilization of MOSW due to vermicomposting process and was higher in the former vermicompost compared to that of other two and the compost. The physical characteristics of all the samples of vermicomposts, compost and the substrate during this study period presented in **Table 1** showed that the temperature was lower by 20% in the vermicompost processed by *E. eugeniae*, by 19% in that of *E. fetida*, by 16% in that of *P. excavatus* and only by 14% in compost than that of initial substrate, i.e., MOSW. The moisture content varied in vermicompost of *E. eugeniae* (54.5%) compared to that of *E. fetida* (48.2%), *P. excavatus* (45.2%) and compost (14.0%) than the initial substrate material. The pH increased in vermicompost of *E. eugeniae* (8.9%) and that of *E. fetida* (11.8%), *P. excavatus* (5.0%) and compost (3.8%) compared to that of initial substrate material. A marked increase of EC was noted in vermicompost processed by *E. eugeniae* (194.4%), *E. fetida* (150.5%), *P. excavatus* (121.1%) and in compost (93.7%) than that of the initial material at the end of composting process.

Growth parameters of earthworms during vermicomposting of MOSW

Different growth parameters of three earthworm species presented in **Table 2** depicted that the net individual weight gain was lower in *E. eugeniae* than that of *E. fetida* and was higher in *P. excavatus*, which followed the marked gain of total earthworm biomass in the three species at the end of the experiment. The rate of cocoon production was higher in *P. excavatus* than *E. eugeniae* and *E. fetida*. Number of worms produced per cocoon was 28.9 and was 71.0% more in *E. fetida* than that of *E. eugeniae* and *P. excavatus*, respectively. Number of cocoons and juveniles collected at the end of the experiment were higher in *P. excavatus* than that of *E. eugeniae* and *E. fetida.* Adult earthworm number was higher in *P. excavatus* than that of *E. fetida* and *E. eugeniae* by 16.1 and 34.8%, respectively. The mortality rate of the earthworms was very negligible during the vermicomposting process.

Comparison of nutrients in MOSW and its vermicompost and compost

The nutrient contents, in the present study, showed significant temporal variation ($P<0.01$) (**Table 3**). Though the per-

Table 2 Earthworms' productivity during vermicomposting process (mean ±SD, n = 3)

Parameter	*E. eugeniae*	*E. fetida*	*P. excavatus*
Individual length (cm):			
Initial	15 ± 0.02	8 ± 0.01	4 ± 0.02
Final	17 ± 0.05	9.5 ± 0.03	6.9 ± 0.04
Individual weight (g):			
Initial	3.5 ± 0.02	0.67 ± 0.01	0.31 ± 0.02
Final	7.8 ± 0.03	1.51 ± 0.05	0.96 ± 0.06
Total biomass (g):			
Initial	175 ± 0.06	33.5 ± 0.05	15.5 ± 0.05
Final	1716.3 ± 0.005	483.1 ± 0.09	385.9 ± 0.06
Cocoon production rate	0.51 ± 0.006	0.5 ± 0.003	2.7 ± 0.001
Number of worm per cocoon	2.7 ± 0.09	3.8 ± 0.01	1.1 ± 0.03
Number of cocoons at the end	36 ± 0.05	30 ± 0.05	181 ± 0.001
Number of juveniles at the end	52 ± 0.03	76 ± 0.04	115 ± 0.005
Number of adults at the end	210 ± 0.4	270 ± 0.2	322 ± 0.1
Mortality rate	0.03 ± 0.002	0.05 ± 0.004	0.1 ± 0.01

Table 3 ANOVA of different nutrients of vermicomposts produced by three species of earthworms and compost (Treatments) of Municipal (Organic) Solid Waste across different time intervals

Source of variation	*df*	*SS*	*MS*	*F*	*P-value*
OC					
Time intervals	3	426.9963	142.3321	345.655	1.31E-09
Treatments	3	705.4327	235.1442	571.0503	1.39E-10
Error	9	3.705975	0.411775		
N					
Time intervals	3	0.25805	0.086017	77.415	9.53E-07
Treatments	3	1.49925	0.49975	449.775	4.05E-10
Error	9	0.01	0.001111		
C/N Ratio					
Time intervals	3	3084.635	1028.212	22.14528	0.000172
Treatments	3	480.0285	160.0095	3.44623	0.065044
Error	9	417.8727	46.4303		
P					
Time intervals	3	0.201069	0.067023	84.88391	6.4E-07
Treatments	3	0.198069	0.066023	83.61741	6.83E-07
Error	9	0.007106	0.00079		
C/P Ratio					
Time intervals	3	7582.808	2527.603	281.3774	3.28E-09
Treatments	3	60.32528	20.10843	2.238507	0.153027
Error	9	80.84667	8.982964		
K					
Time intervals	3	0.280875	0.093625	149.8	5.34E-08
Treatments	3	0.202475	0.067492	107.9867	2.25E-07
Error	9	0.005625	0.000625		
Ca					
Time intervals	3	19.98565	6.661883	1903.395	6.29E-13
Treatments	3	2.89965	0.96655	276.1571	3.56E-09
Error	9	0.0315	0.0035		
Mg					
Time intervals	3	0.295119	0.098373	1349.114	2.95E-12
Treatments	3	0.251169	0.083723	1148.2	6.08E-12
Error	9	0.000656	7.29E-05		

centage of OC decreased, that of N, P, K, Ca and Mg increased gradually in all three vermicomposts and in the sole compost as the composting progressed from 15 to 60 days. The initial substrate, MOSW, was characterized by 68.42% OC, 0.24% N, 0.19% P, 0.12% K, 0.23% Ca and 0.09% Mg, and the C/N ratio of the substrate was 285.1, which was reduced further to 158.2 after precomposting of the substrate. Its vermicompost produced by *E. eugeniae* after 60 days of processing compared to the substrate, showed a 508.3, 378.9, 583.3, 1782.6 and 844.4% increase in N, P, K, Ca and Mg, respectively; and it decreased by 57.1% in OC; that of *E. fetida* increased by 350.0, 284.2, 466.7, 1604.3 and 688.9%, respectively and decreased by 68.0% in OC. The N, P, K, Ca and Mg contents in vermicompost produced by *P. excavatus* increased by 266.7, 236.8, 375, 1469.6 and 589.0%, respectively and the OC decreased by 74.2%, at 60 days of processing. In compost, the increase was relatively less – 154.2, 173.7, 283.3, 1313.04 and 466.7% in N, P, K, Ca and Mg, respectively and its decrease in OC was 81.8% compared to that of MOSW after 60 days of composting process. The C/N ratio reduction was 93.0, 92.9, 93.0 and 92.8% while the C/P ratio reduction was respectively 91.05, 91.67, 92.35 and 93.36% in the vermicompost produced by *E. eugeniae*, *E. fetida*, *P.excavatus* and in sole compost, respectively than that of the substrate (**Figs. 1, 2**).

Compared to the substrate at 0 days of processing, the OC decreased by 34.04% at 15 days, 43.1% at 30 days and 50.5% at 45 days in *E. eugeniae* vermicompost; 48.4% at 15 days, 54.8% at 30 days and 63.0% at 45 days in *E. fetida* vermicompost; 55.1% at 15 days, 61.7% at 30 days and 67.9% at 45 days *P. excavatus* vermicompost. In contrast, the decrease in the OC of compost was 63.1% at 15 days, 69.9% at 30 days and 76.2% at 45 days of the vermicomposting and composting processes (**Fig. 1A**). The N content of substrate at 0 days of processing increased by 383.3, 433.3 and 462.5% in the *E. eugeniae* vermicompost; 175.0, 225.0 and 300.0% in the *E. fetida* vermicompost; 116.7,

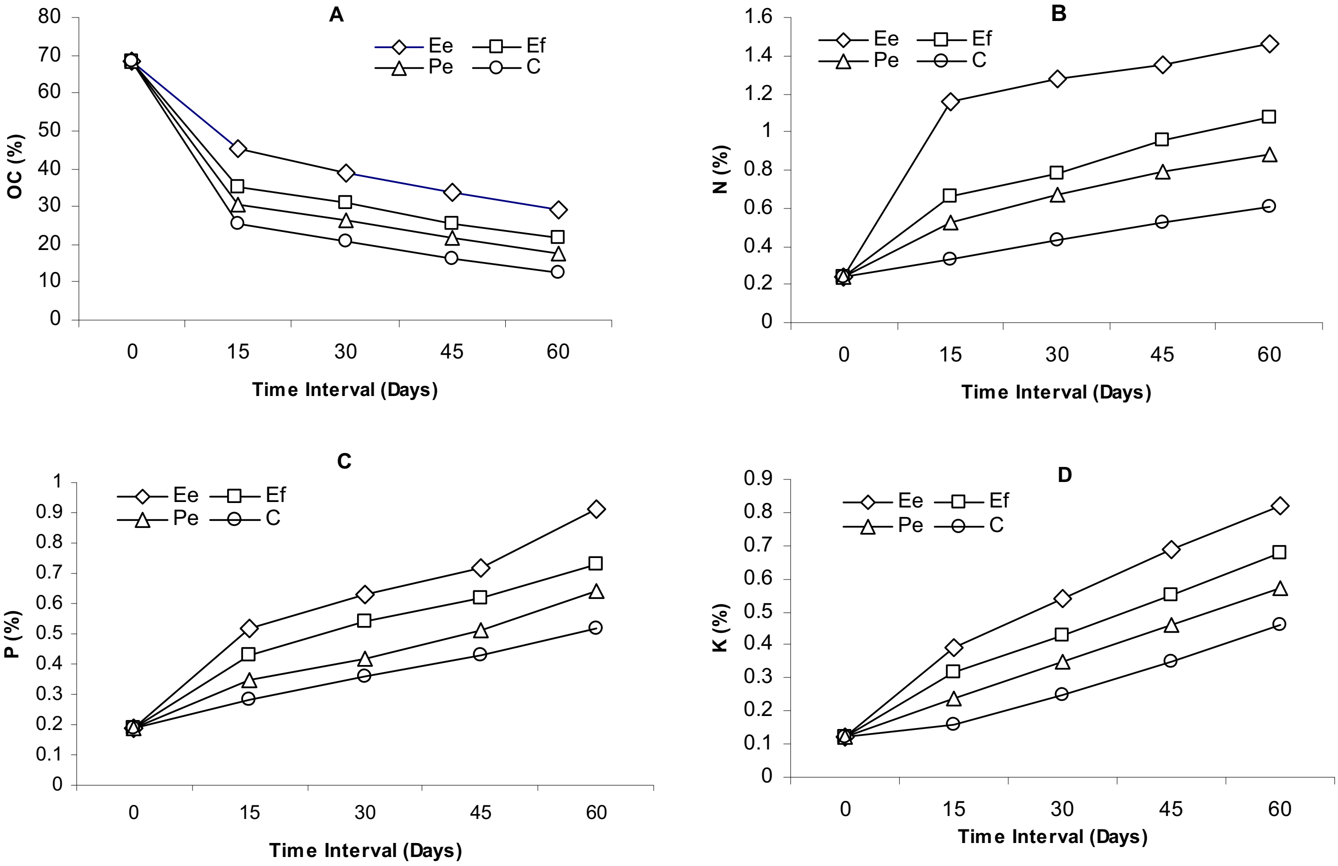

Fig. 1 Major nutrients (%) of vermicompost (VC) of three different species of earthworms - *Eudrilus eugeniae* (Ee), *Eisenia fetida* (Ef), *Perionyx excavatus* (Pe) and Compost (C) at different intervals: 15, 30, 45 and 60 days. (**A**) OC, (**B**) N, (**C**) P, (**D**) K.

179.2 and 229.2% in the *P. excavatus* vermicompost; and 37.5, 79.2 and 116.7% in the sole compost at 15, 30 and 45 days of processing, respectively (**Fig. 1B**). Similarly, the P content of *E. eugeniae* vermicompost increased by 173.7% at 15 days, 231.6% at 30 days and 278.9% at 45 days, while that of *E. fetida* increased by 126.3% at 15 days, 184.2% at 30 days and 226.3% at 45 days, and that of *P. excavatus* it was 84.2% at 15 days,121.0% at 30 days and 168.4% at 45 days of vermicomposting process; in compost it was 47.4% at 15 days, 89.5% at 30 days and 126.3% at 45 days of composting compared to that of substrate at 0 days of processing (**Fig. 1C**). The K content also increased at 15, 30 and 45 days of processing compared to the substrate (0 days) by 225.0, 350.0 and 475.0% in *E. eugeniae* vermicompost, 166.7, 258.3 and 358.3% in *E. fetida* vermicompost, 100.0, 191.7 and 283.3% in *P. excavatus* vermicompost and 33.3, 108.3 and 191.7% in compost, respectively (**Fig. 1D**).

The Ca content of substrate at 0 days of processing increased at 15, 30 and 45 days of processing by 486.9, 882.6 and 1386.9% in *E. eugeniae* vermicompost; 326.1, 647.8 and 1139.1% in *E. fetida* vermicompost; 191.3, 504.4 and 1004.3% in *P. excavatus* vermicompost; and 47.8, 339.1 and 821.7% in compost, respectively (**Fig. 2A**). The Mg content increased by 433.3, 555.6 and 700.0% in *E. eugeniae* vermicompost; 311.1, 411.1 and 544.4% in *E. fetida* vermicompost; 166.7, 277.8 and 422.2% in *P. excavatus* vermicompost and 66.7, 188.9 and 322.2% in compost at 15, 30 and 45 days of processing, respectively (**Fig. 2B**).

Interestingly, the C/N ratio in all the samples of vermicomposts and compost declined to 20: 1 at the end of the experiment, i.e., after 60 days of processing. The decrease was 86.3% at 15 days, 89.3% at 30 days and 91.2% at 45 days in vermicompost produced by *E. eugeniae*; 81.2% at 15 days, 86.1% at 30 days and 90.7% at 45 days in *E. fetida* vermicompost; 79.3% at 15 days, 86.3% at 30 days and 90.3% at 45 days in *P. excavatus* vermicompost; and 73.2% at 15 days, 83.2% at 30 days and 89.0% at 45 days in compost, respectively compared to the substrate at 0 days (**Fig. 2C**). The C/P ratios also decreased from the 0-day substrate by 75.9, 82.8 and 86.9% in *E. eugeniae* vermicompost, by 77.2, 84.1 and 88.7% in *E. fetida* vermicompost, by 75.6, 82.7 and 88.1% in *P. excavatus* vermicompost and by 75.0, 84.1 and 89.5% in compost at 15, 30 and 45 days of processing, respectively (**Fig. 2D**).

Inoculation of different species of earthworms in the pre-composted organic solid waste caused significant changes in its chemical composition across different time intervals as vermicomposting process progressed. All the nutrients were significantly higher in vermicompost than that of compost and were in the ranking order of vermicompost produced by *E. eugeniae* > that of *E. fetida* > that of *P. excavatus* > that of sole compost ($P<0.01$) (**Table 3**). After 60 days of processing, the increase in OC, N, P, K, Ca and Mg was 57.6, 58.2, 42.9, 43.9, 24.9 and 40% in vermicompost produced by *E. eugeniae*; 43.3, 43.5, 28.8, 32.3, 17.09 and 28.17% in that produced by *E. fetida*; and 29.5, 30.7, 18.7, 19.3, 10.0 and 17.7% in that produced by *P. excavatus* than that of sole compost, respectively.

DISCUSSION

Changes in physical characteristics of MOSW during vermicomposting and composting processes

The physical conditions during the present study were found to be conducive to earthworm activity during the vermicomposting process (Lee 1985; Dominguez *et al.* 2000). It was found that vermicomposting process reduced the bulk (dry) mass of MOSW and stabilized it considerably. The decreasing trend of temperature with the progress of composting process was probably due to regular sprinkling of water. Besides, inoculation of the substrate with fresh

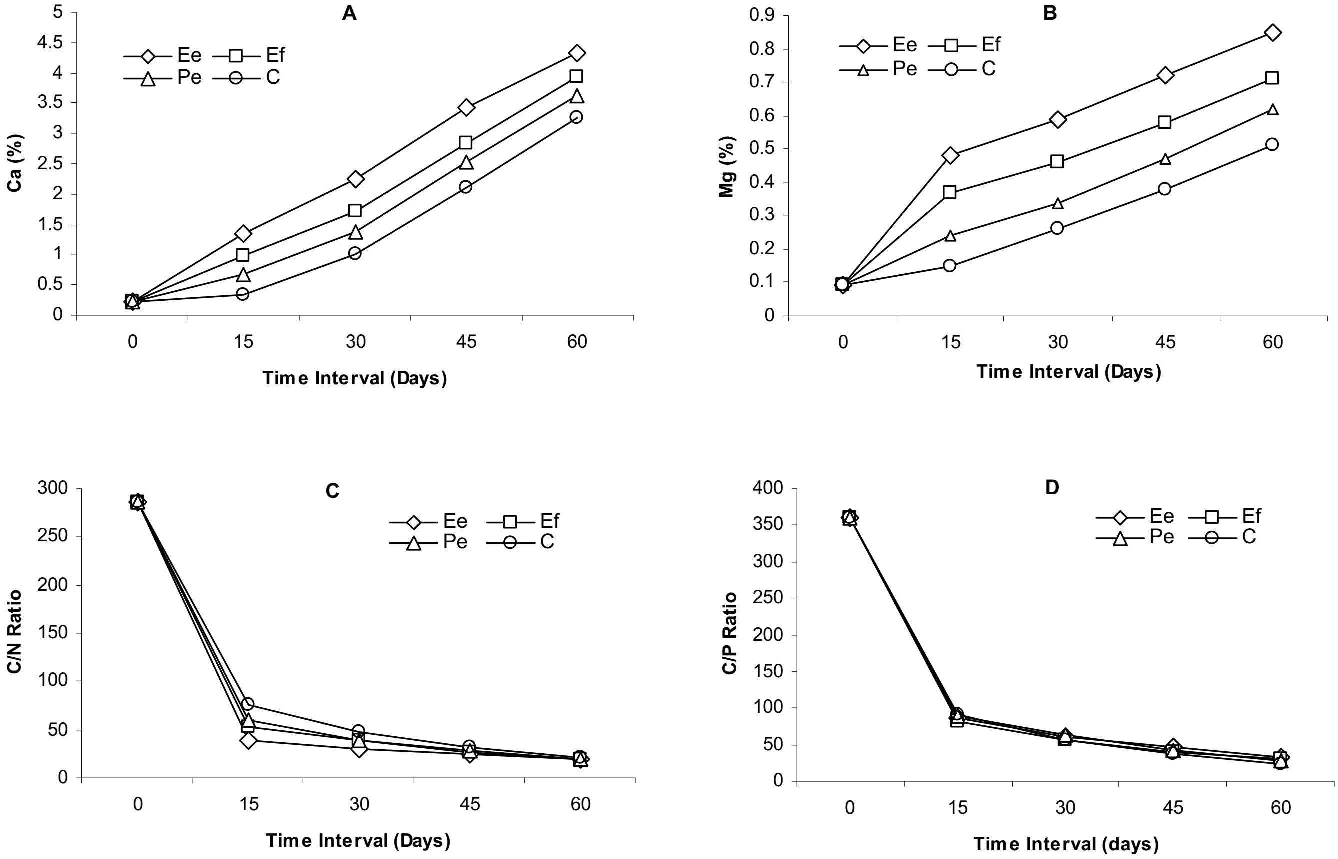

Fig. 2 Major nutrients (%) of vermicompost (VC) of three different species of earthworms - *Eudrilus eugeniae* (Ee), *Eisenia fetida* (Ef), *Perionyx excavatus* (Pe) and compost (C) at different intervals: 15, 30, 45 and 60 days. (**A**) Ca, (**B**) Mg, (**C**) C/N ratio, (**D**) C/P ratio.

cow dung improved the feed quality of the earthworms, may be by adding beneficial micro-organisms to the process (Pramanik *et al.* 2007). The increase in pH during the process was probably due to the degradation of short-chained fatty acids and ammonification of organic N (Tognetti *et al.* 2005). In consistence to the present findings, the increase in pH of the harvested vermicompost and compost was recorded by earlier workers (Tripathi and Bhardwaj 2004; Loh *et al.* 2005), which was attributed to higher mineralization. The gradual increase of EC with the progress of the vermicomposting process was also reported by earlier workers (Kaviraj and Sharma 2003), which may be because of the release of minerals such as exchangeable Ca, Mg, K and P in the available forms into the vermicompost due to mineralization of organic matter (Tognetti *et al.* 2005).

Growth parameters of earthworms during vermicomposting of MOSW

The increase in body weight of all three earthworm species was noted during vermicomposting process, which could be due to the substrate quality (Reinecke *et al*. 1992; Edwards *et al*. 1998; Suthar 2007a, 2007b). Cocoon production rate (number of cocoons per day) was higher in *P. excavatus*, compared to other species. More numbers of cocoons, juveniles and adults collected from the vermicompost processed by *P. excavatus*, was probably because its indigenous nature being adaptable to the abiotic environmental conditions extremely well compared to other exotic species.

Comparison of nutrients in MOSW and its vermicompost and compost

Vermicompost is known to possess higher concentrations of major nutrients than the organic substrate on which the earthworms feed (Edwards 2004). The increase in the nutrients - N, P, K, Ca and Mg contents and decrease in OC, C/N ratio and C/P ratio of the vermicompost, are in consistence with the findings of earlier investigations (Garg *et al.* 2006; Suthar 2007b). These findings reflected that the three species of earthworms showed rapid metabolism and higher mineralization of MOSW while passing through their gut compared to that of the simple compost (Albanell *et al.* 1988). Comparing different vermicompost and compost, it was found that vermicompost of *E. eugeniae* possessed significantly higher concentrations of these major nutrients compared to that of *E. fetida*, *P. excavatus* and that of compost ($P<0.05$), and were ranked in the order of *E. eugeniae* > *E. fetida* > *P. excavatus* > compost. It indicated that the efficiency of bioconversion of the organic waste into vermicompost was relatively higher in case of *E. eugeniae.* These findings are in agreement with those of Padmavathiamma *et al.* (2008) that *E. eugeniae* as an efficient species of earthworm for converting the organic wastes to nutritious compost. The nutrient contents of simple compost were found many times lower than that of vermicompost of the three species of earthworms ($P<0.05$). In consistence, Tognetti *et al.* (2005) reported that the vermicompost of municipal organic waste was richer in organic matter, total N and available nutrients compared to that traditional compost, and they attributed the same to the release of the nutrients due to earthworm grazing upon microflora during the process.

The reduction of OC during vermicomposting process has been reported by earlier studies (Kale *et al.* 1982; Garg and Kaushik 2005; Tognetti *et al.* 2005; Suthar 2007a). It was probably due to digestion of MOSW by enzymatic action in the worms gut. The earthworms utilized the organic matter as food and released carbon in the form of carbon dioxide during respiration (Elvira *et al*. 1998). Microbial respiration also contributed to the carbon loss. However, the difference between the carbon loss of the vermicompost processed by *E. eugeniae*, *E. fetida* and *P. excavatus*, could be due to the species-specific differences in their mineralization efficiency.

Relative increase in N in waste material during vermicomposting process was due to enhanced N mineralization and increased rates of conversion of ammonium-N into nitrate (Atiyeh *et al.* 2000; Suthar and Singh 2008). The secretion of mucus, body fluid, enzymes, ammonium and other nitrogenous materials in the earthworms' excreta and the increased rates of mineralization of organic N most probably enhanced the level of N (Suthar 2007a). However, the final content of N of vermicompost is dependent on the initial content of N present in the substrate (Kaviraj and Sharma 2003). The increasing trend of N in the vermicompost of the three species of earthworms in the present study corroborated the findings of earlier researchers (Bouche *et al.* 1997; Balamurugan *et al.* 1999). The observed difference could be attributed directly to the feeding preferences of individual earthworm species and indirectly to mutualistic relationship between ingested microorganisms and intestinal mucus which might be species-specific (Suthar and Singh 2008).

The C/N ratios of vermicompost of three earthworm species were about 20: 1 at 60 days of processing. Such ratios make nutrients easily available to plants. Plants cannot assimilate mineral N unless the C/N ratio is of about or lesser than 20: 1. N will be in utilizable form by plants if the ratio is usually less than 20: 1. In the present study, the decreasing trend of the C/N ratio in vermicompost and that of simple compost reflected the organic waste mineralization during the progress of vermicomposting and composting processes (Gajalakshmi *et al*. 2005; Suthar and Singh 2008). Such a decrease is attributable to the feeding of MOSW by earthworms, which reflected the remarkable reduction in C and significant increase in the total N in the vermicompost (Dash and Senapati 1986; Suthar 2007a).

The P was higher in the vermicompost harvested at the end of the experiment compared to that of initial substrate (Kaushik and Garg 2003; Manna *et al.* 2003; Suthar 2007a). The magnitude of transformation of P from the organic to inorganic state was due to P solubilising acids such as carbonic acid, nitric acid and sulphuric acid secreted by the micro-organisms present in the worm's gut and thereby changing to available forms (Padmavathiamma *et al.* 2008). The vermicompost increased P availability by P solublisation through phosphatases of earthworms' gut (Suthar and Singh 2008). This was supported by increased trend of EC showing enhancement of exchangeable soluble salts in vermicompost of all the three earthworm species. The increase in K of the vermicompost with the progress of the vermicomposting process in relation to the simple compost and substrate was probably due to the influence of gut microorganisms by producing microbial acids solublising the insoluble K (Kaviraj and Sharma 2003). In consistence to the present findings, higher K concentration in the vermicompost was also reported by earlier researchers (Delgado *et al.* 1995; Suthar and Singh 2008).

CONCLUSIONS

The present study clearly indicated that biodegradable portion of MSW can be utilized as resource when it converted into vermicompost containing high contents of nutrients – N, P, K, Ca and Mg compared to that of the substrate, i.e., MSW as well as the sole compost. The nutrient rich vermicompost can be applicable in enhancing productivity and soil fertility for sustainable agriculture development. The vermicompost possessed higher nutrient resources as the composting process progressed, and that produced by *E. eugeniae* contained higher nutrients compared to that of *E. fetida* and *P. excavatus* and thus, can be better species for use in bioconverting the urban solid waste into nutrient rich compost.

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REFERENCES

Albanell E, Plaixats, Carbrero T (1988) Chemical changes during vermicomposting (*Eisenia fetida*) of sheep manure mixed with cotton industrial wastes. *Biology and Fertility of Soils* **6**, 266-269

Anderson JM, Ingram JSI (1993) *Tropical Soil Biology and Fertility: A Hand Book of Methods*, CAB International, UK, 221 pp

Arancon NQ, Edwards CA, Bierman P, Metzger JD, Lucht C (2005) Effects of vermicomposts produced from cattle manure, food waste and paper waste on the growth and yield of peppers in the field. *Pedobiologia* **49**, 297-306

Atiyeh RM, Lee S, Edwards CA, Subler S, Metzger JD (2000) Earthworm processed organic wastes as components of horticulture potting media for growing marigolds and vegetable seedlings. *Compost Science and Utilization* **8**, 215-223

Atiyeh RM, Lee S, Edwards CA, Arancon NQ, Metzger JD (2002) The influence of humic acids derived from organic wastes on plant growth. *Bioresource Technology* **84**, 7-14

Balamurugan V, Gobi M, Vijayalakshmi G (1999) Comparative studies on degradation of pres mud using cellulolytic fungi and exotic species of earthworms with a note on its gut microflora. *Asian Journal of Microbiology, Biotechnology and Environmental Sciences* **1**, 131-134

Bansal S, Kapoor KK (2000) Vermicomposting of crop residues and cattle dung with *Eisenia foetida*. *Bioresource Technology* **73**, 95-98

Bouche M, Al-addan F, Cortez J, Hammed R, Heidet JC, Ferriere G, Mazend D, Samih M (1997) Role of earthworms in the nitrogen cycle: A falsifiable assessment. *Soil Biology and Biochemistry* **29**, 375-380

Dash MC, Senapati BK (1985) Vermitechnology potentiality of Indian Earthworms for vermicomposting and vermifeed. In: Mishra HK, Kapur K (Eds) *Proceedings of National Seminar on Current Trends in Soil Biology*, Haryana Agriculture University, Hissar, India, pp 61-69

Dash MC, Senapati BK (1986) Vermitechnology, an option for organic wastes management in India. In: Dash MC, Senapati BK, Mishra PC (Eds) *Verms and Vermicomposting*, Sambalpur University, Sambalpur, Orissa, India, pp 157-172

Dash MC, Dash SP (2008) Conservation and sustainable management of belowground biodiversity: A review on the functional role of soil fauna in Indian ecosystems with particular reference to earthworms. *International Journal of Ecology and Environmental Sciences* **34**, 223-243

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

Dominguez J, Edwards CA, Webster M (2000) Vermicomposting of sewage sludge effect of bulking materials on growth and reproduction of the earthworm *E. andri*. *Pedobiologia* **44**, 24-32

Edwards CA, Dominguez J, Neuhauser EF (1998) Growth and reproduction of *Perionyx excavatus* (Perr.) (Megascolecidae) as factors in organic waste management. *Biology and Fertility of Soils* **27**, 155-161

Edwards CA (2004) *Earthworm Ecology* (2nd Ed), CRC Press LLC, Boca Raton, Fl, USA, 448 pp

Elvira C, Sampedro L, Benítez E, Nogales R (1998) Vermicomposting of sludges from paper mill and dairy industries with *Eisenia andrei*: a pilot-scale study. *Bioresource Technology* **63**, 205-211

EPA (1980) *Compendium of Solid Waste Management by Vermicomposting*, US Environmental Protection Agency, Ohio, 45 pp

Gajalakshmi S, Ramasamy EV, Abbasi SA (2005) Composting–vermicomposting of leaf litter ensuing from the trees of mango (*Mangifera indica*). *Bioresource Technology* **96**, 1057-1061

Garg VK, Kaushik P (2005) Vermistabilization of textile mill sludge spiked with poultry droppings by epigeic earthworm *Eisenia fetida*. *Bioresource Technology* **96**, 1063-1071

Garg P, Gupta A, Satya S (2006) Vermicomposting of different types of waste using *Eisenia foetida*: A comparative study. *Bioresource Technology* **97**, 391-395

Gupta R, Mutiyara PK, Rawata NK, Saini MS, Garg VK (2007) Development of a water hyacinth based vermireactor using an epigeic earthworm *Eisenia foetida*. *Bioresource Technology* **98**, 2605-2610

Jackson ML (1973) *Soil Chemical Analysis* (1st Ed), Prentice Hall of India Private Limited, New Delhi, pp 111-204

Kale RD (1995) Vermicomposting has a bright scope. *Indian Silk* **34**, 6-9

Kale RD, Bano K, Krishnamoorthy RV (1982) Potential of *Perionyx excavatus* for utilizing organic wastes. *Pedobiologia* **23**, 419-425

Kaushik P, Garg VK (2003) Vermicomposting of mixed solid textile mill sludge and cow dung with the epigeic earthworm *Eisenia foetida*. *Bioresource Technology* **90**, 311-316

Kaviraj, Sharma S (2003) Municipal solid waste management through vermicomposting employing exotic and local species of earthworms. *Bioresource Technology* **90**, 169-173

Lee KE (1985) *Earthworms: Their Ecology and Relationships with Soils and Land Use*, Academic Press, London, 411 pp

Loh TC, Lee YC, Liang JB, Tan D (2005) Vermicomposting of cattle and goat manures by *Eisenia foetida* and their growth and reproduction performance.

Bioresource Technology **96**, 111-114
Manna MC, Jha S, Ghosh PK, Acharya CL (2003) Comparative efficacy of three epigeic earthworms under different deciduous forest litters decomposition. *Bioresource Technology* **88**, 197-206
Nair J, Sekiozoic V, Anda M (2006) Effect of pre-composting on vermicomposting of kitchen waste. *Bioresource Technology* **97**, 2091-2095
Padmavathiamma PK, Lib LY, Kumaric UR (2008) An experimental study of vermi-biowaste composting for agricultural soil improvement. *Bioresource Technology* **99**, 1672-1681
Pramanik P, Ghosh GK, Ghosal PK, Banik P (2007) Changes in organic – C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. *Bioresource Technology* **98**, 2485-2494
Reddy MV, Okhura (2004) Vermicomposting of rice-straw and its effects on sorghum growth. *Tropical Ecology* **45**, 327-331
Reinecke AJ, Viljoen SA, Saayman RJ (1992) The suitability of *Eudrilus eugeniae*, *Perionyx excavatus* and *Eisenia fetida* (Oligochaeta) for vermincomposting in southern Africa in terms of their temperature requirements. *Soil Biology and Biochemistry* **24**, 1295-1307
Simard RR (1993) Ammonium acetate extractable elements. In: Martin R, Carter S (Eds) *Soil Sampling and Methods of Analysis*, Lewis Publisher, Florida, USA, pp 39-43
Singh A, Sharma S (2002) Composting of a crop residue through treatment with microorganisms and subsequent vermicomposting. *Bioresource Technology* **85**, 107-111
Suthar S (2007a) Vermicomposting potential of *Perionyx sansibaricus* (Perrier) in different waste materials. *Bioresource Technology* **98**, 1231-1237
Suthar S (2007b) Nutrient changes and biodynamics of epigeic earthworm *Perionyx excavatus* (Perrier) during recycling of some agriculture wastes. *Bioresource Technology* **98**, 1608-1614
Suthar S, Singh S (2008) Vermicomposting of domestic waste by using two epigeic earthworms (*Perionyx excavatus* and *Perionyx sansibaricus*). *International Journal of Environmental Science and Technology* **5**, 99-106
Tripathi G, Bhardwaj P (2004) Decomposition of kitchen waste amended with cow manure using an epigeic species (*Eisenia fetida*) and an anecic species (*Lampito mauritii*). *Bioresource Technology* **92**, 215-218
Tognetti C, Mazzarino MJ, Laos F (2005) Improving the quality of municipal organic waste compost. *Bioresource Technology* **98**, 1067-1076
Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter and prepared modification of the chronic acid titration method. *Soil Science* **34**, 29-38