Hindawi Publishing Corporation
Applied and Environmental Soil Science
Volume 2010, Article ID 967526, 13 pages
doi:10.1155/2010/967526

Research Article

Nutrient Status of Vermicompost of Urban Green Waste Processed by Three Earthworm Species—*Eisenia fetida, Eudrilus eugeniae,* and *Perionyx excavatus*

Swati Pattnaik and M. Vikram Reddy

Department of Ecology and Environmental Sciences, Pondicherry University, Puducherry 605 014, India

Correspondence should be addressed to M. Vikram Reddy, venkateshsrinivas1@gmail.com

Received 1 July 2009; Accepted 21 September 2009

Academic Editor: M. Nurul Alam

Major nutrient status of vermicompost of vegetable market waste (MW) and floral waste (FW) processed by three species of earthworms namely, *Eudrilus eugeniae, Eisenia fetida*, and *Perionyx excavatus* and its simple compost were assessed across different periods in relation to their respective initiative substrates. Their physical parameters—temperature, moisture, pH, and electrical conductivity—were also recorded. The nutrients—nitrogen, phosphorus, potassium, calcium, and magnesium—increased in the vermicompost and compost while the organic carbon, C/N and C/P ratios decreased as the composting process progressed from 0 to 15, 30, 45, and 60 days. The nutrient statuses of vermicomposts of all earthworm species produced from both the wastes were more than that of the compost and that of their respective substrates. Moreover, the vermicompost produced by *E. eugeniae* possessed higher nutrient contents than that of *E. fetida, P. excavatus*, and compost. The MW showed higher nutrient contents than the FW. Thus, vermicomposting is the paramount approach of nutrient recovery of urban green waste.

1. Introduction

The urban green waste generally comprises of garden or park waste such as grass or flower cuttings and hedge trimmings, domestic and commercial food waste, and vegetable market waste, the later is generated in large quantities and accumulated in unhygienic way adjacent to vegetable markets emanating unbearable malodor due to lack of proper scientific disposal management particularly in developing countries like India. The vegetable market waste is the leftover and discarded rotten vegetables, fruits, and flowers in the market. This urban waste can be converted to a potential plantnutrient enriched resource—compost and vermicompost that can be utilized for sustainable land restoration practices [1]. Vermicomposting is a mesophilic process and is the process of ingestion, digestion, and absorption of organic waste carried out by earthworms followed by excretion of castings through the worm's metabolic system, during which their biological activities enhance the levels of plant-nutrients of organic waste [2]. Compost and vermicompost are the end products of aerobic composting process, the later with using earthworms. Vermicompost possessed higher and more soluble level of major nutrients—nitrogen, phosphorus, potassium, calcium and magnesium [3–5]—compared to the substrate or underlying soil, and normal compost. During the process, the nutrients locked up in the organic waste are changed to simple and more readily available and absorbable forms such as nitrate or ammonium nitrogen, exchangeable phosphorus and soluble potassium, calcium, magnesium in worm's gut [6, 7]. Vermicompost is often considered a supplement to fertilizers and it releases the major and minor nutrients slowly with significant reduction in C/N ratio, synchronizing with the requirement of plants [8].

The vegetable market waste (MW) as well as floral (*Peltophorum pterocarpum*) waste (FW) were collected and composted using three different earthworm species—*Eisenia fetida, Eudrilus eugeniae, and Perionyx excavatus* during the present study. These worms have been considered as key agents for organic waste management through the process

Table 1: Growth parameters of three earthworm species during the process of vermicomposting of MW and FW.

Earthworm growth parameters	*E. eugeniae*		*E. fetida*		*P. excavates*	
	MW	FW	MW	FW	MW	FW
Av. Individual length:						
Initial (cm)	15.0 ± 0.02	15.0 ± 0.02	8 ± 0.01	8 ± 0.01	4 ± 0.02	4 ± 0.02
Final (cm)	18.5 ± 0.04	19.4 ± 0.05	11.5 ± 0.05	12.3 ± 0.04	7.4 ± 0.06	8.9 ± 0.07
Av. Individual weight						
Initial (gm)	3.5 ± 0.02	3.5 ± 0.02	0.67 ± 0.01	0.67 ± 0.01	0.31 ± 0.02	0.31 ± 0.02
Final (gm)	10.5 ± 0.05	12.8 ± 0.1	2.42 ± 0.01	3.57 ± 0.02	1.94 ± 0.04	3.12 ± 0.03
Av. Total biomass						
Initial (gm)	175 ± 0.06	175 ± 0.06	33.5 ± 0.05	33.5 ± 0.05	15.5 ± 0.05	15.5 ± 0.05
Final (gm)	2724 ± 0.2	3975 ± 0.4	735.4 ± 0.06	1194.3 ± 0.0	682.6 ± 0.04	1142.7 ± 0.0
Av. Cocoon production rate	0.51 ± 0.006	0.51 ± 0.006	0.5 ± 0.003	0.5 ± 0.003	2.7 ± 0.001	2.7 ± 0.001
Av. Worm number per cocoon	2.7 ± 0.09	2.7 ± 0.09	3.8 ± 0.01	3.8 ± 0.01	1.1 ± 0.03	1.1 ± 0.03
Av. Cocoon number at the end	57 ± 0.3	76 ± 0.07	51 ± 0.05	74 ± 0.06	197 ± 0.05	218 ± 0.03
Av. Juvenile number at the end	78 ± 0.08	93 ± 0.06	95 ± 0.07	124 ± 0.05	143 ± 0.06	162 ± 0.06
Av. Adult number at the end	254 ± 0.04	310 ± 0.04	298 ± 0.08	331 ± 0.06	345 ± 0.04	362 ± 0.09
Av. Mortality rate	0.03 ± 0.002	0.05 ± 0.003	0.06 ± 0.004	0.08 ± 0.005	0.3 ± 0.02	0.6 ± 0.03

of vermicomposting [9–13]. The main aim of the present investigation was to know the extent to which vermicomposting and the normal composting of urban green waste may be combined in order to maximize the potentials of both the processes. Earlier, Graziano and Casalicchio [14] have proposed a combination of aerobic composting and vermicomposting to enhance the value of the final products. Frederickson and Knight [15] have showed that vermiculture and anaerobic systems can be combined to enhance organic matter stabilisation. The benefits of a combined system to process urban green waste could include effective sanitization and pathogen control due to an initial brief period of thermophilic composting, enhanced rates of stabilization, plus the production of earthworms and vermicompost [16]. Stabilization of green waste such as yard waste and vegetable waste through the process of composting and vermicomposting has been carried out earlier [16–18]. The present investigation attempted mainly to evaluate the nutrient status of different vermicomposts produced by the three earthworm species and that of compost of urban MW and FW in relation to the respective initial substrates, and also to obtain empirical information on the growth and productivity of the three species of earthworms cultured in the two substrates.

2. Materials and Methods

2.1. Methods of Waste Collection. The MW and FW samples each weighing about 125 kg were collected separately in random manner. The MW, both fresh and decomposed, was collected from the main vegetable market of Puducherry, which comprised of different leftover putrefied vegetables such as cabbage, tomato, potato, onion, carrot, turnip, brinjal, and leafy vegetables; the FW was obtained from the *P. pterocarpum* (Family-Fabaceae and Subfamily Caesalpinioideae), a widely appreciated shade tree and a reclamation plant with dense spreading crown, and planted along the roadsides in the Pondicherry University campus. These wastes were characterized by segregating and discarding the nonbiodegradable fraction, and the biodegradable component was used for the experiment. Five samples of each waste were taken for experimentation and analyses.

2.2. Sample Processing—Pre-Composting. The collected MW and FW were air dried separately spreading over a polythene sheet for 48 hours. The air dried samples were precomposted for three weeks before putting into vermicomposting and composting process. Pre-composting is the pre processed and pretreated practice of raw waste. The waste materials, in the pre-composting process were decomposed aerobically by the active role of bacteria due to which temperature raised up to 60°C. As such a high temperature was lethal for earthworm survival, the thermal stabilization was done prior to introduction of earthworms into the substrate. When the temperature of the pre-composted substrate diminished to 25°C, adult earthworms with well-defined clitella belonging to the three species namely, *E. eugeniae, E. fetida,* and *P. excavatus* were introduced on the pre-composted material filled in each set of earthen pots (The earthworms were collected from a local vermiculture unit at Lake Estate of Auorbindo Ashram, Puducherry, India).

2.3. Experimental Design. In each pot five kg of the substrate mixed with cow dung in 3 : 1 ratio were taken for vermicomposting and composting. A total of four sets of earthen pots each set comprising six replicates was taken for each waste, of which three sets were used for vermicomposting with each set using one species of earthworm and the forth set was used for normal composting that is, without using any earthworm. Three species of earthworms, each of fifty adult individuals, were introduced on the top of the pre-composted substrate in each of the three sets of pots keeping aside the fourth set for composting without earthworms. All the pots were covered on the top by jute cloth cover and wire mesh to prevent and protect the earthworms from the predators—centipedes, moles, and shrews. Small holes were drilled at the bottom of each pot which was filled with small stones up to a height of 5 cm for air circulation and good drainage. The processes of vermicomposting and composting were carried out for a period of 60 days. The temperature and moisture content were maintained by sprinkling adequate quantity of water at frequent intervals. The harvesting of vermicompost and compost, and total earthworm biomass, individual body weight, total numbers of juveniles, adults, and cocoons were carried out, and the mortality rates of the three earthworm species were calculated after 60 days, at the end of the experiment.

2.4. Physico-Chemical Analyses. The homogenized subsamples of each substrate material and their respective compost and vermicompost samples (on the basis of 100 g dry weight) were collected undestructively at 0 (i.e., substrate), 15, 30, 45, and 60 days from each replicate pot and compound samples were made, which were processed for analyses of organic carbon (OC) and major nutrients—total nitrogen (N), available phosphorus (P), exchangeable potassium (K), calcium (Ca), and magnesium (Mg). The temperature (°C), moisture (%), pH, and electrical conductivity (EC) were recorded for the substrate and during the vermicomposting and composting processes. Temperature was noted daily using a thermometer, and moisture content was measured gravimetrically. The pH and EC of samples were recorded by a digital pH meter and conductivity meter, respectively. The OC of the samples was measured by Walkey-Black method [19]; the N was estimated by the Kjeldahl method [20], and the P and K contents of the samples were analyzed by calorimetric method [21] and flame photometric method [22], respectively. The Ca and Mg contents of the samples were also analyzed using atomic absorption spectrophotometer (GBC make) [20]. The C : N ratio was calculated from the measured values of C and N.

2.5. Statistical Analysis. Two-way analysis of variance (ANOVA) was computed using SPSS (version No. 10) to test the level of significance of difference between the vermicomposts produced by the three species earthworms and compost samples with respect to nutrient parameters.

3. Result and Discussion

3.1. Growth and Productivity of Earthworms. The growth parameters of three earthworm species cultured in MW and FW showed that the length increased by 23.3% in *E. eugeniae,* 43.7% in *E. fetida,* and 85.0% in *P. excavatus* grown in MW, while it increased by 29.3% in *E. eugeniae,* 53.7% in *E. fetida,* and 122.5% in *P. excavatus* grown in FW, whereas the net individual weight gained by each of the three species was 200.0, 261.2, and 525.8% in MW and 265.7, 432.8, and 906.4% in FW respectively, at the end of the experiment (Table 1). The net individual weight gain and total biomass gain were higher in *P. excavatus* than that of *E. fetida,* and *E. Eugeniae*. The total biomass gain was found 1456.6 and 2171.4% by *E. eugeniae*, 2095.2 and 3465.1% by *E. fetida,* and 4303.9 and 7272.3% by *P. excavatus* in MW and FW respectively, at the end of the vermicomposting process. Cocoon production rate was higher in *P. excavatus* than that of *E. eugeniae* and *E. fetida*. The number of worms produced per cocoon was 28.9 and 71.0% higher in *E. fetida* than that of *E. eugeniae* and *P. excavatus,* respectively, while the number of cocoons collected at the end of the experiment was more in *P. excavatus* by 245.6% than that of *E. eugeniae* and 286.3% than that of *E. fetida* in MW; and by 186.8% and 194.6% than that of *E. eugeniae* and *E. fetida* in FW, respectively. The number of juveniles collected was 83.3% higher in *P. excavatus* than that of *E. eugeniae* and 50.5% than that of *E. fetida* in MW, whereas the increase was 74.2% in *E. eugeniae* and 30.6% in *E. fetida.* Adult earthworm number was higher in *P. excavatus* than that of *E eugeniae,* and *E. fetida* by 35.8 and 15.8% in MW, and 16.8 and 9.4% in FW, respectively. The production of cocoons, juveniles, and adults of all the three species was higher in FW than that of MW, which indicated the former waste material as a better substrate for the earthworms. The mortality rate of the *P. excavatus* was 900% higher than that of *E eugeniae* and 400% higher than that of *E. fetida* grown in MW, while it was higher by 1100 and 650% than *E eugeniae* and *E. fetida* grown in FW, respectively.

The mean individual length and live weight, mean growth rate of an individual (mg/day), individual and total biomass gain, reproduction rate (cocoon $worm^{-1}day^{-1}$), fecundity rate (worm cocoon $^{-1}$day–1), total cocoon, juveniles and adult numbers, and mortality rate in the present study varied across different treatments. The worms when introduced into wastes showed an increased growth rate and reproduction activities [1]. The increase in body weight of all three earthworm species was noted in both the substrates during vermicomposting process, which could be due to the substrate quality or could be related to fluctuating environmental conditions [23–25]. The readily available nutrients in MW and FW enhanced the feeding activity of the worms, showing their increase in biomass [1]. Interestingly, cocoon production rate was higher in *P. excavatus*, whereas the number of worms per cocoon was higher in *E. fetida* compared to other species. The indigenous species, *P. excavates,* exhibited better growth and reproduction performance compared to the other two exotic species [26]. The higher numbers of cocoons, juveniles, and adults collected from the vermicompost processed by *P. excavatus*, were probably because its indigenous nature being acclimatized to the abiotic environmental conditions extremely well compared to other species. The difference in worm mortality among the three species could be related to the species-specific composting behavior or to specific tolerance nature of earthworm according to the changing microenvironmental conditions in composting subsystem

Table 2: Weight and other different physical parameters of the substrates—MW and FW—and their respective compost and vermicompost of three earthworm species (Mean ± sd; $n = 3$).

Parameters	0 days		60 days							
			Vermicompost						Compost	
			E. eugeniae		*E. fetida*		*P. excavatus*			
	MW	FW	MW	FW	MW	FW	MW	FW	MW	FW
Weight (kg)	5.00 ± 0.005	5.00 ± 0.01	1.25 ± 0.03	0.85 ± 0.05	1.85 ± 0.04	1.65 ± 0.04	2.5 ± 0.03	2.2 ± 0.01	3.7 ± 0.009	3.5 ± 0.008
Temperature (0c)	29.8 ± 0.06	26.5 ± 0.05	24.1 ± 0.04	22.3 ± 0.03	24.2 ± 0.05	23.4 ± 0.03	24.4 ± 0.04	23.5 ± 0.05	24.7 ± 0.05	23.9 ± 0.02
Moisture content (%)	55.73 ± 0.08	34.62 ± 0.03	65.2 ± 0.03	60.8 ± 0.08	64.72 ± 0.03	59.67 ± 0.02	64.04 ± 0.01	58.68 ± 0.05	63.11 ± 0.04	57.49 ± 0.05
pH	6.31 ± 0.07	6.84 ± 0.04	7.12 ± 0.02	7.37 ± 0.02	7.08 ± 0.01	7.28 ± 0.03	6.95 ± 0.02	6.89 ± 0.04	6.87 ± 0.03	6.79 ± 0.04
Electric conductivity (mhos/cm)	495.5 ± 0.04	152.2 ± 0.02	3354.4± 0.02	532.5 ± 0.03	2716.7± 0.07	466.3 ± 0.03	1983.2± 0.06	415.7 ± 0.02	1789.3± 0..07	363.5 ± 0.01

[1]. Moreover, the growth rate difference between the three species was probably due to the species-specific growth patterns or could be related to the feed quality and preferences by individual species of earthworm [1].

3.2. Waste Stabilization. The reduction in bulk dry mass of both the substrates—MW and FW, the range of temperature, moisture content, pH, EC of the substrate, compost and vermicompost presented in Table 2. depicted that higher mass reduction of MW was recorded in the vermicompost processed by *E. eugeniae* (75%), followed by that of *E. fetida* (63%), *and P. excavatus* (50%) compared to that of compost (26%), whereas the mass reduction was higher 83% in vermicompost produced by *E. eugeniae,* 67% by that of *E. fetida*, 56% in that of *P. excavates,* and 30% in sole compost than that of FW. The marked stabilization of both the substrates due to vermicomposting process was higher in the vermicompost processed by *E. eugeniae* compared to that of other two and the compost. The FW and its vermicomposts and composts were found to be more stabilized than that of MW.

The pre-composting because of its thermophilic nature prior to vermicomposting helped in mass reduction and pathogen reduction [27]. It was found that the bulk (dry) mass reduction and stabilization of both the wastes during present study through vermicomposting process were significant [2, 27]; the vermicomposting may also be known as vermistabilization [28]. The cow dung used as the inoculant in the vermicomposting process enhanced the quality of feeding resource attracting the earthworms and accelerated the breakdown of wastes resulting in the reduction of C : N ratio by increasing certain nutrients [1, 29–31].

3.3. Physical State of MW and FW during Vermicomposting and Composting Processes. The physical characteristics recorded during the period of this study presented in Table 2 were conducive for vermicomposting process [6, 32]. The temperature ranged from 22.3 to 29.8°C and was lower by 19.1 and 15.8% in the vermicompost processed by *E. eugeniae,* by 18.8 and 11.7% in that of *E. fetida*, by 18.1 and 11.3% in that of *P. excavates,* and by 17.1 and 9.8% in compost than that of initial substrate of MW and FW, respectively. The moisture content of vermicompost of *E. eugeniae* varied by 17.0 and 75.6%, by 16.1 and 72.4% in that of *E. fetida,* by 14.9 and 69.5% in that of *P. excavates,* and by 13.2 and 66.1% in the compost than that of initial MW and FW, respectively. The pH ranged from 6.31 to 7.37 and increased by 12.8, 12.2, 10.1, and 8.9% than that of MW; and 7.7, 6.4, 2.1 and 0.7% than that of FW, in vermicompost of *E. eugeniae, E. fetida, P. excavatus,* and compost, respectively. The EC of vermicompost ranged from 152.2 to 3354.4 mhos/cm and increased EC noted in vermicompost processed by *E. eugeniae, E. fetida, P. excavatus* and in compost was 577.0, 448.3, 300.2, and 261.1% more than that of MW, and was 249.9, 206.4, 173.1, and 138.8% more than that of FW, respectively, at the end of composting process. Temperature, moisture content, and EC were more and pH was less in MW compared to that of FW.

3.4. Temperature. At the start of the experiment, the temperature of the substrate was high and then decreased gradually as the composting process progressed. The heat released by the oxidative action of intensive microbial activity on the organic matter resulted in the rise in temperature during the first mesophilic phase of composting process [33]. The temperature of the following thermophilic phase rose up above 40°C reaching about 60°C when most of the organic matter was degraded with the help of thermophilic bacteria and fungi, consequently depleting most of the oxygen. The thermophilic phase was followed by cooling phase, when compost maturation stage occurred and compost temperature dropped to that of the ambient [34]. Then, the decreasing trend of temperature with the progress of composting process occurred, which was probably due to the decreased bacterial activity. It may also be attributable to regular sprinkling of water.

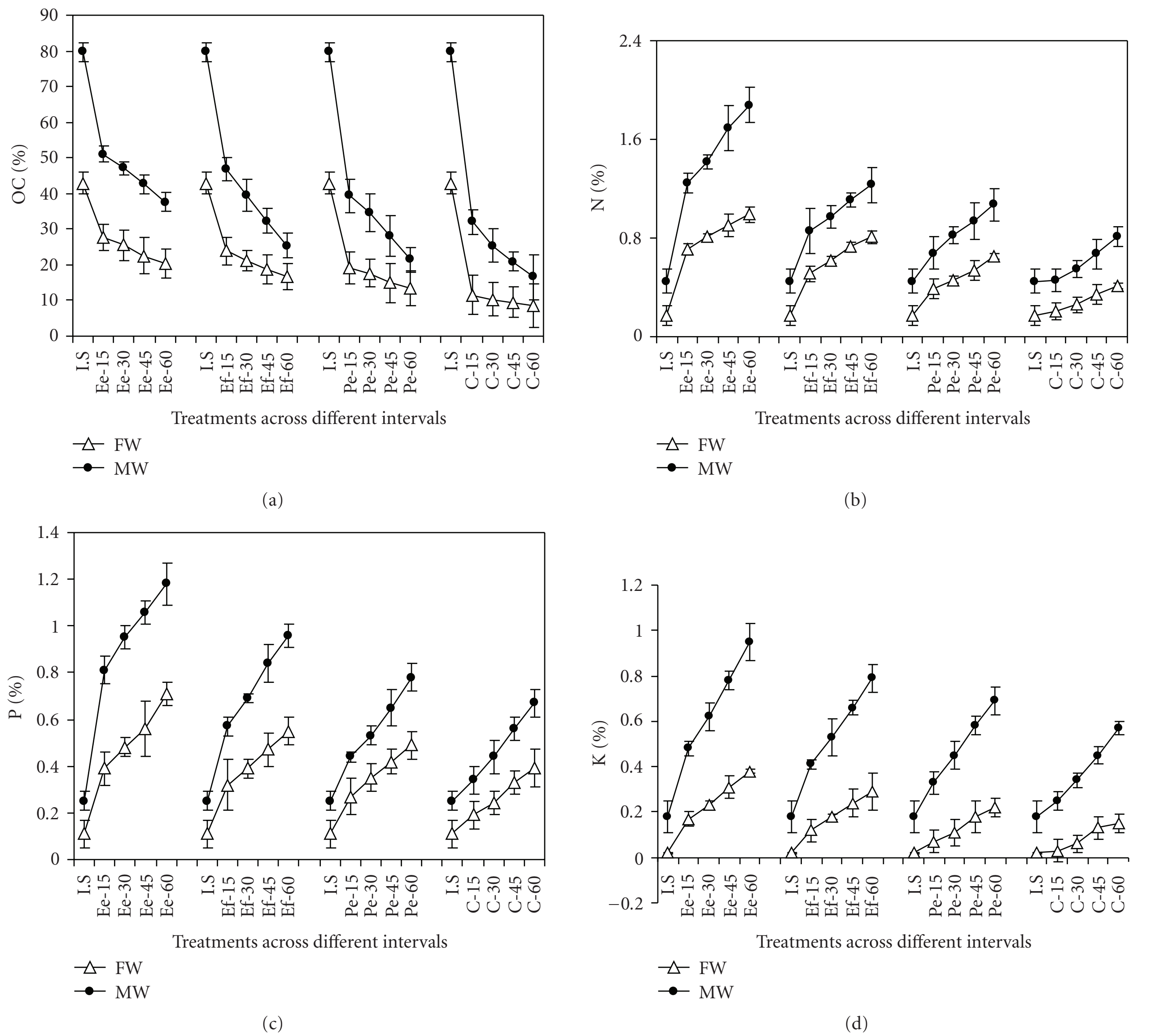

FIGURE 1: Major nutrients—OC, N, P, K (%) of vermicompost (VC) of three different species of earthworms—*Eudrilus eugeniae* (Ee) at 15 days (Ee-15), 30 days (Ee-30), 45 days (Ee-45), and 60 days (Ee-60); *Eisenia fetida* (Ef) at 15 days (Ef-15), 30 days (Ef-30), 45 days (Ef-45), and 60 days (Ef-60); *Perionyx excavatus* (Pe) at 15 days (Pe-15), 30 days (Pe-30), 45 days (Pe-45), and 60 days (Pe-60); and Compost (C) at 15 days (C-15), 30 days (C-30), 45 days (C-45), and 60 days (C-60) produced from FW and MW. (a) OC, (b) N, (c) P, (d) K.

3.5. Moisture Content. Moisture content ranged from 50–70% [35]. Edwards and Bater [36] reported that optimum moisture content for growth of earthworms—*E. fetida, E. eugeniae and P. excavatus*—was 85% in organic waste management. The rate of mineralization and decomposition becomes faster with the optimum moisture content [37]. According to Liang et al. [38], the moisture content of 60–70% was proved having maximal microbial activity, while 50% moisture content was the minimal requirement for rapid rise in microbial activity. Vermicompost samples during the present study showed higher moisture content than the compost and substrate, which may be due to their high absorption capacity, and may also be because of assimilation rate by microbial population indicating the higher rate of degradation of waste by earthworms. Relatively highest moisture content of vermicompost produced by *E. eugeniae* followed by that of *E. fetida* and *P. excavatus* implied greater palatability of the substrate by the species.

3.6. pH. It was neutral being around 7 and increased gradually from substrate to compost to vermicompost [35, 39]. The near-neutral pH of vermicompost may be attributed by the secretion of NH_4^+ ions that reduce the pool of H^+ ions [40] and the activity of calciferous glands in earthworms containing carbonic anhydrase that catalyzes the fixation of CO_2 as $CaCO_3$, thereby preventing the fall in pH [9]. The increased trend of pH in the vermicompost and compost samples is in consistence with the findings of Tripathi and

Table 3: ANOVA of different nutrients of vermicomposts produced by three species of earthworms and compost (Treatments) of Market Waste across different time intervals.

Source of Variation	SS	df	MS	F
OC				
Time Intervals	648.6706	3	216.2235	83.74185**
Treatments	923.0771	3	307.6924	119.1671**
Error	23.23823	9	2.582025	
N				
Time Intervals	0.431569	3	0.143856	38.0167**
Treatments	1.881169	3	0.627056	165.7113**
Error	0.034056	9	0.003784	
C/N Ratio				
Time Intervals	2834.197	3	944.7322	36.40393**
Treatments	301.5306	3	100.5102	3.87302**
Error	233.5624	9	25.95138	
P				
Time Intervals	0.286919	3	0.09564	418.6049**
Treatments	0.568369	3	0.189456	829.231**
Error	0.002056	9	0.000228	
C/P Ratio				
Time Intervals	6752.972	3	2250.991	39.35673**
Treatments	225.6022	3	75.20074	1.314823**
Error	514.751	9	57.19456	
K				
Time Intervals	0.32795	3	0.109317	141.5612**
Treatments	0.2005	3	0.066833	86.54676**
Error	0.00695	9	0.000772	
Ca				
Time Intervals	28.18897	3	9.396323	2027.679**
Treatments	8.064019	3	2.688006	580.0583**
Error	0.041706	9	0.004634	
Mg				
Time Intervals	0.30515	3	0.101717	1220.6**
Treatments	0.3242	3	0.108067	1296.8**
Error	0.00075	9	8.33E-05	

Level of significance: ** $P < .001$

Bhardwaj [41] and Loh et al. [42], which was due to higher mineralization, whereas the present findings are in contradiction to the findings of Suthar and Singh [1], Haimi and Huhta [40] and Ndegwa et al. [43] who reported lower pH. The increased pH during the process was probably due to the degradation of short-chained fatty acids and ammonification of organic N [44–46]. Fares et al. [47] found the increased pH at the end of the composting process, which was attributed to progressive utilization of organic acids and increase in mineral constituents of waste.

3.7. EC. The increased EC during the period of the composting and vermicomposting processes is in consistence with that of earlier workers [48, 49], which was probably due to the degradation of organic matter releasing minerals such as exchangeable Ca, Mg, K, and P in the available forms, that is, in the form of cations in the vermicompost and compost [44, 46].

3.8. Nutrients in MW and FW and Their Vermicompost and Compost. It was found that the N was 0.45% in MW and 0.17% in FW; P was 0.25% in MW and 0.11% in FW; K was 0.18% in MW and 0.02% in FW, Ca was 0.62% in MW and 0.07% in FW; Mg was 0.17% in MW and 0.04% in FW, while the content of OC was 79.6% in MW and 42.9% in FW (Figures 1 and 2).

The present study revealed that all vermicomposts prepared from their respective organic wastes possessed considerably higher levels of major nutrients—N, P, K, Ca, and Mg compared to that of the substrates [31, 50]. The increase in the nutrients and decrease in OC, C/N ratio and C/P ratios in the vermicompost, are in consistence

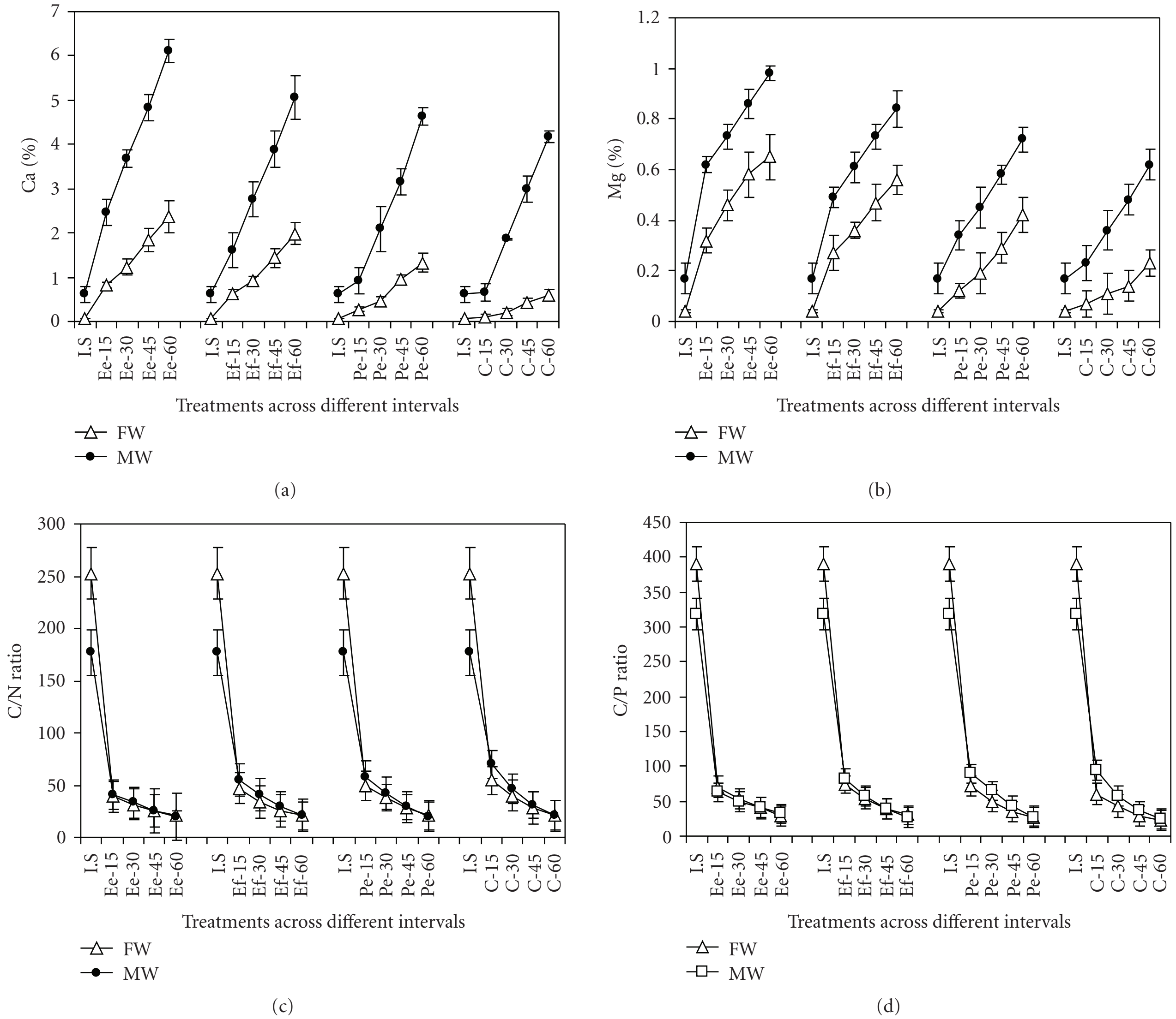

Figure 2: Major nutrients—Ca and Mg (%), C/N ratio and C/P ratio of vermicompost (VC) of three different species of earthworms—*Eudrilus eugeniae* (Ee) at 15 days (Ee-15), 30 days (Ee-30), 45 days (Ee-45), and 60 days (Ee-60); *Eisenia fetida* (Ef) at 15 days (Ef-15), 30 days (Ef-30), 45 days (Ef-45), and 60 days (Ef-60); *Perionyx excavatus* (Pe) at 15 days (Pe-15), 30 days (Pe-30), 45 days (Pe-45), and 60 days (Pe-60); and Compost (C) at 15 days (C-15), 30 days (C-30), 45 days (C-45), and 60 days (C-60) produced from FW and MW. (a) Ca, (b) Mg, (c) C/N ratio, (d) C/P ratio.

with the findings of earlier investigators [25, 26]. Moreover, comparing the nutrient contents of vermicompost with that of compost, vermicompost possessed significantly higher concentrations of nutrients than that of compost ($P < .05$), which was probably due to the coupled effect of earthworm activity as well as a shorter thermophilic phase [51, 52], making the plant-availability of most the nutrients higher in vermicomposting than that of composting process [3, 53, 54].

3.9. Temporal Variation in Nutrients. In the present study the percentage of OC decreased (Figure 1(a)) and that of N increased (Figure 1(b)), while the percentage of P (Figure 1(c)) and K (Figure 1(d)), and that of Ca (Figure 2(a)) and Mg (Figure 2(b)) also increased gradually in all the three vermicomposts and in the sole compost as the composting process progressed from 15 days to 60 days. Interestingly, the C/N ratio (Figure 2(c)) and C/P ratio (Figure 2(d)) in all the samples of vermicomposts and compost declined at the end of the experiment (i.e., after 60 days of processing). The nutrient contents showed significant temporal variation in vermicompost and compost of both the substrates, that is, MW (Table 3) and FW (Table 4) ($P < .001$).

The vermicompost of MW produced by *E. eugeniae* showed 177.8, 224.0, 166.7, 296.7, and 264.7% increase after 15 days of processing and 317.8, 372.0, 427.8, 887.1, and 476.5% increase after 60 days of processing in N, P, K, Ca, and Mg compared to that of the substrate, respectively, whereas it decreased by 35.9 and 52.8% after 15 and 60 days,

Table 4: ANOVA of different nutrients of vermicomposts produced by three species of earthworms and compost (Treatments) of Floral Waste across different time intervals.

Source of Variation	SS	df	MS	F
OC				
Time Intervals	76.11592	3	25.37197	28.39579**
Treatments	426.3413	3	142.1138	159.0508**
Error	8.041606	9	0.893512	
N				
Time Intervals	0.151425	3	0.050475	118.7647**
Treatments	0.649525	3	0.216508	509.4314**
Error	0.003825	9	0.000425	
C/N Ratio				
Time Intervals	1629.242	3	543.0806	67.49946**
Treatments	103.9289	3	34.64297	4.305774**
Error	72.41133	9	8.045703	
P				
Time Intervals	0.130719	3	0.043573	78.33333**
Treatments	0.127569	3	0.042523	76.44569**
Error	0.005006	9	0.000556	
C/P Ratio				
Time Intervals	4035.872	3	1345.291	636.1514**
Treatments	295.7819	3	98.59395	46.6224**
Error	19.0326	9	2.114733	
K				
Time Intervals	0.062619	3	0.020873	81.45528**
Treatments	0.072769	3	0.024256	94.65854**
Error	0.002306	9	0.000256	
Ca				
Time Intervals	2.90885	3	0.969617	23.82676**
Treatments	3.5505	3	1.1835	29.08259**
Error	0.36625	9	0.040694	
Mg				
Time Intervals	0.1621	3	0.054033	35.62637**
Treatments	0.31855	3	0.106183	70.01099**
Error	0.01365	9	0.001517	

Level of significance: **$P < .001$

respectively in OC; whereas that of *E. fetida* increased by 91.1, 128.0, 127.8, 161.3, and 188.2%; and 173.3, 284.0, 338.9, 716.1, and 394.1% while decreased by 41.2% and 68.1% after 15 and 60 days of processing, respectively. The N, P, K, Ca, and Mg contents in vermicompost produced by *P. excavatus* increased by 51.1, 76.0, 83.3, 50.0 and 100.0%, respectively and the OC decreased by 50.5%, at 15 days of processing; whereas the increase was 137.8, 212.0, 283.3, 648.4 and 323.5% and the decrease was 73.1% at 60 days of processing, respectively. In compost, the increase was relatively less and was 2.2, 36.0, 38.9, 4.8, and 35.3% and 80.0, 168.0, 216.7, 572.6, and 264.7% in N, P, K, Ca, and Mg, respectively and its decrease in OC was 59.7, and 79.1% compared to that of substrate after 15 and 60 days of composting process, respectively. The C/N ratio reduction was 76.9, 69.2, 67.3, and 60.6% after 15 days of processing and 88.7, 88.4, 88.7, and 88.4% after 60 days while the C/P ratio reduction was respectively 80.2, 74.2, 71.9, and 70.4% at 15 days of processing and 90.0, 91.7, 91.2, and 92.2% at 60 days of processing in the vermicompost produced by *E. eugeniae, E. fetida, P. excavatus,* and in sole compost compared to that of the substrate.

The vermicompost of FW produced by *E. eugeniae* increased by 317.6, 254.5, 750.0, 1057.1, and 700.0% after 15 days of processing and 482.3, 545.4, 1800.0, 3285.7, and 1525.0% after 60 days of processing in N, P, K, Ca, and Mg, respectively compared to the substrate, whereas it decreased by 35.7 and 52.6% after 15 and 60 days, respectively in OC, while that of *E. fetida* increased by 200.0, 190.9, 500.0, 814.3 and 575.0% and 376.5, 400.0, 1350.0, 2728.6, and 1300%; while decreased by 44.3 and 60.9% after 15 and 60 days of processing, respectively. The N, P, K, Ca, and Mg contents in vermicompost produced by *P. excavatus* increased by 129.4, 145.4, 250.0, 285.7, and 200.0%, respectively, and the OC decreased by 55.2% at 15 days of processing, whereas the increase was 282.3, 345.4, 1000.0, 1785.7, and 950.0% and the decrease was 68.5% at 60 days of processing, respectively. In compost, there was less increase and was 23.5, 72.7, 50.0, 28.6, and 75.0% and 141.2, 254.5, 650.0, 742.8, and 475.0% in N, P, K, Ca, and Mg, respectively, and its decrease in OC was 73.4, and 79.9% after 15 and 60 days, respectively of composting process compared to that of substrate. The C/N ratio reduction was 84.6, 81.4, 80.5 and 78.5% after 15 days of processing and 91.9, 91.8, 91.7, and 91.7% after 60 days while the C/P ratio reduction was respectively 81.9, 80.8, 81.7, and 84.6% at 15 days of processing and 92.6, 92.2, 92.9, and 94.3% at 60 days of processing in the vermicompost produced by *E. eugeniae, E. fetida, P. excavatus* and in sole compost more than that of the substrate.

The considerable enrichment of nutrients of the vermicomposts of the three species of earthworms—*E. eugeniae E. fetida* and *P. excavatus*—compared to that of composts of substrates, that is, MW and FW ($P < .01$) were in consistence with the findings of earlier reports [2, 25, 26, 30]. At the end of the experiment, the increase in OC, N, P, K, Ca, and Mg was 55.8, 56.9, 43.2, 40.0, 31.8, and 36.7% in the vermicompost of MW and 57.7, 58.6, 45.1, 60.5, 75.1, and 64.6% in that of FW produced by *E. eugeniae;* 34.5, 34.1, 30.2, 27.8, 17.6, and 26.2% in that of MW and 48.6, 49.4, 29.1, 48.3, 70.2, and 58.9% in that of FW produced by *E. fetida;* and 22.5, 24.3, 14.1, 17.4, 10.1, and 13.9% in that of MW and 36.3, 36.9, 20.4, 31.8, 55.3, and 45.2% in that of FW produced by *P. excavatus*, compared to that of sole compost, respectively.

The nutrients and OC were found higher in MW compared to that of FW, which was most probably because of mosaic nature of the MW. In all the vermicompost and compost of the present study the nutrients increased and OC, C/N ratios and C/P ratio decreased significantly with the passage of time (from 0 to 15, 30, 45, and 60 days), from the substrate (organic waste) to compost and vermicompost, respectively [2]. The present findings are in agreement with the findings of earlier workers: Nagavallemma et al. [35], Uthaiah [55], Muthukumarasamy et al. [56], Parthasarathi and Ranganathan [57], and Khwairakpam and Bhargava [58]. The waste materials ingested by the earthworms undergo physical decomposition and biochemical changes contributed by the enzymatic and enteric microbial activities while passing through the earthworm gut due to the grinding action of the muscular gizzard releasing the nutrients in the form of microbial metabolites enriching the feed residue with plant nutrients and growth promoting substances in an assimilated form, which is excreted in the form of vermi-cast [31, 59].

Comparing the nutrients of vermicompost produced by the three earthworm species (*E. Eugeniae, E. fetida,* and *P. excavatus),* it was found that the vermicompost of *E. eugeniae* possessed significantly higher concentrations of the nutrients followed by *E. fetida* and *P. excavates,* and the sole compost, in the order of *E. Eugeniae* > *E. fetida* > *P. excavatus* > compost, which may indicate that the earthworm is more efficient in recovering nutrients from the waste through vermicomposting process [2, 60]. However, the findings of Sangwan et al. [61], in contrast to the present findings, reported decrease in potassium content in the vermicompost produced by *E. fetida* compared to that of the substrate. Khwairakpam and Bhargava [58] compared the vermicompost of sewage sludge processed by these three earthworm species in order to report the suitability of worm species for composting. Reddy and Okhura [5] have assessed the vermicomposts produced by different earthworm species—*Perionyx excavatus, Octohaetona phillotti,* and *Octonachaeta rosea* using the rice straw as substrate and found that vermicompost produced *P. excavatus* possessed possessed higher concentration of nutrients than that of *O. rosea* and *O. phillotti*.

Further, it was found that the OC, N, P, K, Ca, Mg was 85.4, 164.7, 127.3, 800.0, 785.7, and 325.0%, respectively increased in MW than that of FW, and the nutrients were also significantly higher in the vermicompost and compost of MW than that of FW ($P < .05$). The vermicompost of MW produced by *E. eugeniae* showed 84.9, 76.0, 107.7, 182.3, 203.7, and 93.7% increase at 15 days and 84.8, 89.9, 66.2, 150.0, 158.2, and 50.8% increase at 60 days of processing in OC, N, P, K, Ca, Mg than that of FW; whereas the increase was 95.8, 68.6, 78.1, 241.7, 153.1, and 81.5% at 15 days of composting and 51.4, 51.8, 74.5, 172.4, 155.6 and 50.0% at 60 days in the vermicompost produced by *E. fetida*, and the increase of OC, N, P, K, Ca, and Mg (Figures 1 and 2) in vermicompost of MW produced by *P. excavatus* than that of FW was 104.7, 74.4, 62.9, 371.4, 244.4, and 183.3% and 58.5, 64.6, 59.2, 213.6, 251.5, and 71.4% after 15 and 60 days of processing, respectively. The compost of MW was higher by 181.1 and 92.9% in OC, 119.0 and 97.6% in N, 78.9 and 71.8% in P, 733.3 and 280.0% in K, 622.2 and 606.8% in Ca, and 228.6 and 169.6% in Mg after 15 and 60 days of processing, respectively compared to that of FW.

3.10. Total N. The total nitrogen content of vermicompost of the tree earthworm species was higher than that of compost and substrate. The increasing trend of N in the vermicomposts produced by the earthworm species in the present study corroborated with the findings of earlier reports [62, 63]. The enhancement of N in vermicompost was probably due to mineralization of the organic matter containing proteins [3, 8] and conversion of ammonium-nitrogen into nitrate [1, 64]. Earthworms can boost the nitrogen levels of the substrate during digestion in their gut adding their nitrogenous excretory products, mucus, body fluid, enzymes, and even through the decaying dead tissues of worms in vermicomposting subsystem [25]. The vermicompost prepared by all the three earthworm species showed a substantial difference in total N content ($P < .01$), which could be attributed directly to the species-specific feeding preference of individual earthworm species and indirectly to mutualistic relationship between ingested microorganisms and intestinal mucus [1].

3.11. OC. Total organic carbon decreased with the passage of time during vermicomposting and composting processes in both the substrates. These findings are in consistence with those of earlier authors [12, 46]. The organic carbon is lost as carbon dioxide through microbial respiration and mineralization of organic matter causing increase in total N [65]. Part of the carbon in the decomposing residues released as CO_2 and a part was assimilated by the microbial biomass [11, 66, 67]; microorganisms used the carbon as a source of energy decomposing the organic matter. The reduction was higher in vermicomposting compared to the ordinary composting process, which may be due to the fact that earthworms have higher assimilating capacity. 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 of OC.

3.12. C/N Ratio. The C/N ratios of vermicomposts of three earthworm species were around 20 : 1; such ratios make nutrients easily available to the plants. Plants cannot assimilate mineral N unless the C/N ratio is about 20 : 1, and this ratio is also an indicative of acceptable maturity of compost [68]. The C/N ratio of the substrate material reflects the organic waste mineralization and stabilization during the process of composting or vermicomposting. Higher C/N ratio indicates slow degradation of substrate [69], and the lower the C/N ratio, the higher is the efficiency level of mineralization by the species. Lower C/N ratio in vermicompost produced by *E. eugeniae* implied that this species enhanced the organic matter mineralization more efficiently than *E. fetida* and *P. excavatus* [1, 60]. The loss of carbon through microbial respiration and mineralization and simultaneous addition of nitrogen by worms in the form of mucus and nitrogenous excretory material lowered the C/N ratio of the substrate [25, 70–72].

3.13. P. The total P was higher in the vermicompost harvested at the end of the experiment compared to that of the initial substrate [8, 25, 73]. The enhanced P level in vermicompost suggests phosphorous mineralization during the process. The worms during vermicomposting converted the insoluble P into soluble forms with the help of P-solubilizing microorganisms through phosphatases present in the gut, making it more available to plants [1, 60, 74]. This was buttressed by increased trend of EC showing enhancement of exchangeable soluble salts in vermicompost of all the three earthworm species.

3.14. K. Vermicomposting proved to be an efficient process for recovering higher K from organic waste [1, 25, 73]. The present findings corroborated to those of Delgado et al. [75], who demonstrated that higher K concentration in the end product prepared from sewage sludge. The increase in K of the vermicompost in relation to that of the simple compost and substrate was probably because of physical decomposition of organic matter of waste due to biological grinding during passage through the gut, coupled with enzymatic activity in worm's gut, which may have caused its increase [76]. The microorganisms present in the worm's gut probably converted insoluble K into the soluble form by producing microbial enzymes [48].

3.15. Ca and Mg. The higher Ca content in vermicompost compared to that of compost and substrate is attributable to the catalytic activity of carbonic anhydrase present in calciferous glands of earthworms generating $CaCO_3$ on the fixation of CO_2 [60]. The higher concentration of Mg in vermicompost reported in present study was also in consistence with the findings of earlier workers [60, 77].

4. Conclusions

It is concluded that among the three species, the indigenous species, *P. excavates,* exhibited better growth and reproduction performance compared to the other two exotic species. *E. eugeniae* was more efficient in bioconversion of urban green waste into nutrient rich vermicompost compared to *E. fetida* and *P. excavatus*; the vermicompost produced by *E. eugeniae* possessed higher nutrients—N, P, K, Ca and Mg—compared to that of *E. fetida* and *P. excavatus*. Vermicomposts produced by all the earthworm species showed higher contents of nutrients compared to that of the sole compost as well as substrates—the green waste (vegetable market and floral waste). Moreover, the vermicompost and compost of vegetable market waste possessed higher nutrient contents probably because it comprised of a mosaic of materials compared to that of floral waste. Thus, vermicomposting was proved to be a better technology than that of sole composting and may be preferred for the management and nutrient recovery from the urban waste such as market waste and floral waste.

Acknowledgments

The University Grants Commission (New Delhi) provided grants in the form of a Major Research Project for this research, which covered a project fellowship to the first author The earthworm species were procured from the Vermiculture unit of Lake Estate (Auorbindo Ashram, Puducherry, India).

References

[1] S. Suthar and S. Singh, "Vermicomposting of domestic waste by using two epigeic earthworms (Perionyx excavatus and Perionyx sansibaricus)," *International Journal of Environment Science and Technology*, vol. 5, no. 1, pp. 99–106, 2008.

[2] R. M. Venkatesh and T. Eevera, "Mass reduction and recovery of nutrients through vermicomposting of fly ash," *Applied Ecology and Environmental Research*, vol. 6, pp. 77–84, 2008.

[3] S. Bansal and K. K. Kapoor, "Vermicomposting of crop residues and cattle dung with *Eisenia foetida*," *Bioresource Technology*, vol. 73, no. 2, pp. 95–98, 2000.

[4] A. Singh and S. Sharma, "Composting of a crop residue through treatment with microorganisms and subsequent vermicomposting," *Bioresource Technology*, vol. 85, no. 2, pp. 107–111, 2002.

[5] M. V. Reddy and Okhura, "Vermicomposting of rice-straw and its effects on sorghum growth," *Tropical Ecology*, vol. 45, pp. 327–331, 2004.

[6] K. E. Lee, *Earthworms: Their Ecology and Relationships with Soils and Land Use*, Academic Press, London, UK, 1985.

[7] R. M. Atiyeh, S. Lee, C. A. Edwards, N. Q. Arancon, and J. D. Metzger, "The influence of humic acids derived from earthworm-processed organic wastes on plant growth," *Bioresource Technology*, vol. 84, no. 1, pp. 7–14, 2002.

[8] P. Kaushik and V. K. Garg, "Vermicomposting of mixed solid textile mill sludge and cow dung with the epigeic earthworm *Eisenia foetida*," *Bioresource Technology*, vol. 90, no. 3, pp. 311–316, 2003.

[9] R. D. Kale, K. Bano, and R. V. Krishnamoorthy, "Potential of *Perionyx excavatus* for utilizing organic wastes," *Pedobiologia*, vol. 23, no. 6, pp. 419–425, 1982.

[10] V. Tomati, A. Grappel, E. Galli, and W. Rossi, "Fertilizers from vermiculture—an option for organic wastes recovery," *Agrochimica*, vol. 27, no. 2-3, pp. 244–251, 1983.

[11] C. Elvira, L. Sampedro, E. Benítez, and R. Nogales, "Vermicomposting of sludges from paper mill and dairy industries with *Eisena andrei*: a pilot-scale study," *Bioresource Technology*, vol. 63, no. 3, pp. 205–211, 1998.

[12] V. K. Garg and P. Kaushik, "Vermistabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*," *Bioresource Technology*, vol. 96, no. 9, pp. 1063–1071, 2005.

[13] S. Suthar, "Potential utilization of guar gum industrial waste in vermicompost production," *Bioresource Technology*, vol. 97, no. 18, pp. 2474–2477, 2006.

[14] P. L. Graziano and G. Casalicchio, "Use of worm-casting techniques on sludges and municipal wastes: development and application," in *On Eurthworms*, A. M. B. Pagliai and P. Omodeo, Eds., pp. 459–464, Mucchi Editore, Modena, Italy, 1987.

[15] J. Frederickson and D. Knight, "The use of anaerobically digested cattle solids for vermiculture," in *Earthworms in Waste and Environmental Management*, C. A. Edwards and E. F. Neuhauser, Eds., pp. 33–47, SPB Academie, The Hague, Netherlands, 1988.

[16] J. Frederickson, K. R. Butt, R. M. Morris, and C. Daniel, "Combining vermiculture with traditional green waste composting systems," *Soil Biology and Biochemistry*, vol. 29, no. 3-4, pp. 725–730, 1997.

[17] V. Karthikeyan, G. L. Sathyamoorthy, and R. Murugesan, "Vermi composting of market waste in Salem, Tamilnadu, India," in *Proceedings of the International Conference on Sustainable Solid Waste Management*, pp. 276–281, Chennai, India, September 2007.

[18] C. D. Jadia and M. H. Fulekar, "Vermicomposting of vegetable waste: a bio-physicochemical process based on hydro-operating bioreactor," *African Journal of Biotechnology*, vol. 7, pp. 3723–3730, 2008.

[19] A. Walkley 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 Science*, vol. 34, pp. 29–38, 1934.

[20] M. L. Jackson, *Soil Chemical Analysis*, Prentice Hall of India Private Limited, New Delhi, India, 1st edition, 1973.

[21] J. M. Anderson and J. S. I. Ingram, "Soil organic matter and organic carbon," in *Tropical Soil Biology and Fertility: A Hand Book of Methods*, J. M. Anderson and J. S. I. Ingram, Eds., p. 221, CAB International, Wallingford, UK, 1993.

[22] R. R. Simard, "Ammonium acetate extractable elements," in *Soil Sampling and Methods of Analysis*, R. Martin and S. Carter, Eds., pp. 39–43, Lewis, Boca Raton, Fla, USA, 1993.

[23] A. J. Reinecke, S. A. Viljoen, and R. J. Saayman, "The suitability of *Eudrilus eugeniae, Perionyx excavatus* and *Eisenia fetida* (Oligochaeta) for vermicomposting in southern Africa in terms of their temperature requirements," *Soil Biology and Biochemistry*, vol. 24, pp. 1295–1307, 1992.

[24] C. A. Edwards, J. Dominguez, and E. F. Neuhauser, "Growth and reproduction of *Perionyx excavatus* (Perr.) (Megascolecidae) as factors in organic waste management," *Biology and Fertility of Soils*, vol. 27, no. 2, pp. 155–161, 1998.

[25] S. Suthar, "Nutrient changes and biodynamics of epigeic earthworm *Perionyx excavatus* (Perrier) during recycling of some agriculture wastes," *Bioresource Technology*, vol. 98, no. 8, pp. 1608–1614, 2007.

[26] P. Garg, A. Gupta, and S. Satya, "Vermicomposting of different types of waste using *Eisenia foetida* a comparative study," *Bioresource Technology*, vol. 97, no. 3, pp. 391–395, 2006.

[27] J. Nair, V. Sekiozoic, and M. Anda, "Effect of pre-composting on vermicomposting of kitchen waste," *Bioresource Technology*, vol. 97, no. 16, pp. 2091–2095, 2006.

[28] L. K. Wang, K. S. Nazih, and H. Yung-Tse, "Vermicomposting process," in *Biosolids Treatment Processes*, vol. 6, pp. 689–704, Humana Press, Totowa, NJ, USA, 2007.

[29] P. Pramanik, G. K. Ghosh, P. K. Ghosal, and P. Banik, "Changes in organic—C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants," *Bioresource Technology*, vol. 98, no. 13, pp. 2485–2494, 2007.

[30] R. Gupta and V. K. Garg, "Vermiremediation and nutrient recovery of non-recyclable paper waste employing *Eisenia fetida*," *Journal of Hazardous Materials*, vol. 162, no. 1, pp. 430–439, 2009.

[31] M. S. Kitturmath, R. S. Giraddi, and B. Basavaraj, "Nutrient changes during earthworm, eudrilus eugeniae (Kinberg) mediated vermicomposting of agro-industrial wastes," *Karnataka Journal of Agriculture Science*, vol. 20, pp. 653–654, 2007.

[32] C. A. Edwards and J. Dominguez, "Vermicomposting of sewage sludge: effect of bulking materials on the growth and reproduction of the earthworm *E. andrei*," *Pedobiologia*, vol. 44, no. 1, pp. 24–32, 2000.

[33] J. Peigne and P. Girardin, "Environmental impacts of farm—scale composting practices," *Water, Air, and Soil Pollution*, vol. 153, no. 1–4, pp. 45–68, 2004.

[34] L. M. Zibilske, "Composting of organic wastes," in *Principles and Applications of Soil Microbiology*, D. M. Sylvia, J. J. Fuhrmann, P. G. Hartel, and D. A. Zuberer, Eds., pp. 482–497, Prentice Hall, Upper Saddle River, NJ, USA, 1999.

[35] K. P. Nagavallemma, S. P. Wani, L. Stephane, et al., "Vermicomposting: recycling wastes into valuable organic fertilizer," *Journal of SAT Agricultural Research*, vol. 2, no. 1, pp. 1–17, 2006.

[36] C. A. Edwards and J. E. Bater, "The use of earthworms in environmental management," *Soil Biology and Biochemistry*, vol. 24, no. 12, pp. 1683–1689, 1992.

[37] N. B. Singh, A. K. Khare, D. S. Bhargava, and S. Bhattacharya, "Optimum moisture requirement during vermicomposting using *Perionyx excavatus*," *Applied Ecology and Environmental Research*, vol. 2, pp. 53–62, 2004.

[38] C. Liang, K. C. Das, and R. W. McClendon, "The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend," *Bioresource Technology*, vol. 86, no. 2, pp. 131–137, 2003.

[39] A. Mitchell and D. Alter, "Suppression of labile aluminium in acidic soils by the use of vermicompost extract," *Communications in Soil Science and Plant Analysis*, vol. 24, no. 11-12, pp. 1171–1181, 1993.

[40] J. Haimi and V. Huhta, "Comparison of composts produced from identical wastes by vermistabilization and conventional composting," *Pedobiologia*, vol. 30, no. 2, pp. 137–144, 1987.

[41] G. Tripathi and P. Bhardwaj, "Comparative studies on biomass production, life cycles and composting efficiency of *Eisenia fetida* (Savigny) and *Lampito mauritii* (Kinberg)," *Bioresource Technology*, vol. 92, no. 3, pp. 275–283, 2004.

[42] T. C. Loh, Y. C. Lee, J. B. Liang, and D. Tan, "Vermicomposting of cattle and goat manures by *Eisenia foetida* and their growth and reproduction performance," *Bioresource Technology*, vol. 96, no. 1, pp. 111–114, 2005.

[43] P. M. Ndegwa, S. A. Thompson, and K. C. Das, "Effects of stocking density and feeding rate on vermicomposting of biosolids," *Bioresource Technology*, vol. 71, no. 1, pp. 5–12, 2000.

[44] L. Guoxue, F. Zhang, Y. Sun, J. W. C. Wong, and M. Fang, "Chemical evaluation of sewage composting as mature indicator for composting process," *Water Air Soil Sludge Pollution*, vol. 132, pp. 333–345, 2001.

[45] J. H. Crawford, "Composting of agriculture waste," in *Biotechnology: Applications and Research*, P. N. Cheremisinoff and R. P. Onellette, Eds., vol. 71, Technomic Publishing, Lancaster, Pa, USA, 1985.

[46] C. Tognetti, F. Laos, M. J. Mazzarino, and M. T. Hernandez, "Composting vs. vermicomposting: a comparison of end product quality," *Compost Science and Utilization*, vol. 13, no. 1, pp. 6–13, 2005.

[47] F. Fares, A. Albalkhi, J. Dec, M. A. Bruns, and J. M. Bollag, "Physicochemical characteristics of animal and municipal wastes decomposed in arid soils," *Journal of Environmental Quality*, vol. 34, no. 4, pp. 1392–1403, 2005.

[48] Kaviraj and S. Sharma, "Municipal solid waste management through vermicomposting employing exotic and local species of earthworms," *Bioresource Technology*, vol. 90, no. 2, pp. 169–173, 2003.

[49] C. D. Jadia and M. H. Fulekar, "Vermicomposting of vegetable waste: a bio-physicochemical process based on hydro-operating bioreactor," *African Journal of Biotechnology*, vol. 7, pp. 3723–3730, 2008.

[50] C. A. Edwards, *Earthworm Ecology*, CRC Press LLC, Boca Raton, Fla, USA, 2nd edition, 2004.

[51] E. Albanell, J. Plaixats, and T. Carbrero, "Chemical changes during vermicomposting (*Eisenia fetida*) of sheep manure mixed with cotton industrial wastes," *Biology and Fertility of Soils*, vol. 6, pp. 266–269, 1988.

[52] C. Tognetti, M. J. Mazzarino, and F. Laos, "Improving the quality of municipal organic waste compost," *Bioresource Technology*, vol. 9, pp. 1067–1076, 2007.

[53] J. C. P. Short, J. Frederickson, and R. M. Morris, "Evaluation of traditional windrow-composting and vermicomposting for the stabilization of was e paper sludge (WPS)," *Pedobiologia*, vol. 43, pp. 735–743, 1999.

[54] T. Saradha, "The culture of earthworms in the mixture of pond soil and leaf litter and analysis of vermi fertilizer," *Journal of Ecobiology*, vol. 9, pp. 185–188, 1997.

[55] P. A. Uthaiah, *Acceleration of pressmud decomposition by microbial inoculation for quality product*, M.S. thesis, University of Agricultural Sciences, Bangalore, India, 1997.

[56] R. Muthukumarasamy, G. Revathi, V. Murthy, S. R. Mala, M. Vedivelu, and A. R. Solayappan, "An alternative carrier material for bio-fertilizers," *Co-Operative Sugar*, vol. 28, pp. 677–680, 1997.

[57] K. Parthasarathi and L. S. Ranganathan, "Aging effect on enzyme activities in pressmud vermicasts of Lampito mauritii (Kinberg) and Eudrilus eugeniae (Kinberg)," *Biology and Fertility of Soils*, vol. 30, no. 4, pp. 347–350, 2000.

[58] M. Khwairakpam and R. Bhargava, "Vermitechnology for sewage sludge recycling," *Journal of Hazardous Materials*, vol. 161, no. 2-3, pp. 948–954, 2009.

[59] B. K. Senapati, "Vermitechnology: an option for recycling cellulosic waste in India," in *New Trends in Biotechnology*, pp. 347–358, Oxford and IBH Publications, Calcutta, India, 1992.

[60] P. K. Padmavathiamma, L. Y. Li, and U. R. Kumari, "An experimental study of vermi-biowaste composting for agricultural soil improvement," *Bioresource Technology*, vol. 99, no. 6, pp. 1672–1681, 2008.

[61] P. Sangwan, C. P. Kaushik, and V. K. Garg, "Vermiconversion of industrial sludge for recycling the nutrients," *Bioresource Technology*, vol. 99, no. 18, pp. 8699–8704, 2008.

[62] M. Bouche, F. Al-addan, J. Cortez, et al., "Role of earthworms in the N cycle: a falsifiable assessment," *Soil Biology and Biochemistry*, vol. 29, no. 3-4, pp. 375–380, 1997.

[63] V. Balamurugan, M. Gobi, and G. Vijayalakshmi, "Comparative studies on degradation of press mud using cellulolytic fungi and exotic species of earthworms with a note on its gut microflora," *Asian Journal of Microbiology, Biotechnology and Environmental Sciences*, vol. 1, pp. 131–134, 1999.

[64] R. M. Atiyeh, S. Lee, C. A. Edwards, S. Subler, and J. D. Metzger, "Earthworm processed organic wastes as components of horticulture potting media for growing marigolds and vegetable seedlings," *Compost Science and Utilization*, vol. 8, pp. 215–223, 2000.

[65] J. H. Crawford, "Review of composting," *Process of Biochemistry*, vol. 8, pp. 14–15, 1983.

[66] M. L. Cabrera, D. E. Kissel, and M. F. Vigil, "Nitrogen mineralization from organic residues: research opportunities," *Journal of Environmental Quality*, vol. 34, no. 1, pp. 75–79, 2005.

[67] M. Fang, M. H. Wong, and J. W. C. Wong, "Digestion activity of thermophilic bacteria isolated from ash-amended sewage sludge compost," *Water Air and Soil Pollution*, vol. 126, pp. 1–12, 2001.

[68] F. M. C. Morais and C. A. C. Queda, "Study of storage influence on evolution of stability and maturity properties of MSW composts," in *Proceedings of the 4th International Conference of ORBIT Association on Biological Processing of Organics: Advances for a Sustainable Society*, Perth, Australia, May 2003.

[69] R. T. Haug, *The Practical Handbook of Compost Engineering*, Lewis, CRC Press, Boca Raton, Fla, USA, 2nd edition, 1993.

[70] M. C. Dash and B. K. Senapati, "Vermitechnology, an option for organic wastes management in India," in *Verms and Vermicomposting*, M. C. Dash, B. K. Senapati, and P. C. Mishra, Eds., pp. 157–172, Sambalpur University, Sambalpur, Orissa, India, 1986.

[71] S. C. Talashilkar, P. P. Bhangarath, and V. B. Mehta, "Changes in chemical properties during composting of organic residues as influenced by earthworm activity," *Journal of the Indian Society of Soil Science*, vol. 47, pp. 50–53, 1999.

[72] M. A. V. Christry and R. Ramaligam, "Vermicomposting of sago industrial soild waste using epigeic earthworm *Eudrilus eugeniae* and macronutrients analysis of vermicompost," *Asian Journal of Microbiology, Biotechnology and Environmental Sciences*, vol. 7, pp. 377–381, 2005.

[73] M. C. Manna, S. Jha, P. K. Ghosh, and C. L. Acharya, "Comparative efficacy of three epigeic earthworms under different deciduous forest litters decomposition," *Bioresource Technology*, vol. 88, no. 3, pp. 197–206, 2003.

[74] M. Ghosh, G. N. Chattopadhyay, and K. Baral, "Transformation of phosphorus during vermicomposting," *Bioresource Technology*, vol. 69, pp. 149–154, 1999.

[75] M. Delgado, M. Bigeriego, I. Walter, and R. Calbo, "Use of California red worm in sewage sludge transformation," *Turrialba*, vol. 45, pp. 33–41, 1995.

[76] S. Rao, A. S. Rao, and P. N. Takkar, "Changes in different forms of K under earthworm activity," in *Proceedings of the National Seminar on Organic Farming and Sustainable Agriculture*, pp. 9–11, Ghaziabad, India, October 1996.

[77] S. C. Tiwari, B. K. Tiwari, and R. R. Mishra, "Microbial populations, enzyme activities and nitrogen–phosphorous–potassium enrichment in earthworm casts and in the surrounding soil of a pineapple plantation," *Biology and Fertility of Soils*, vol. 8, pp. 178–182, 1989.