Potential of *Perionyx excavatus* (Perrier) in lignocellulosic solid waste management and quality vermifertilizer production for soil health

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Abstract

Purpose The aim of this study was to recycle and reuse the enormously available unutilized lignocellulosic solid organic waste resource, cashew leaf litter (CLL) admixed with various animal dungs, cowdung, sheepdung and horsedung by employing predominantly available indigenous epigeic earthworm—*Perionyx excavatus* (Perrier, 1872) and produce quality vermifertilizer.

Methods Four different combinations of each [(100 % dung alone, 3:1 (75 % dung + 25 % CLL), 2:2 (50 % dung + 50 % CLL) and 1:3 (25 % dung + 75 % CLL)] vermibeds were allowed for vermicomposting process under laboratory conditions. After 60 days, the worm worked vermicompost and worm unworked normal compost were harvested and characterized. The earthworm activity—growth, reproductive performance (cocoon production and hatchling number) and recovery of vermicompost was also studied.

Results The obtained results clearly showed that vermicompost from CLL admixed with cowdung at 2:2 ratio had lower pH, organic carbon, C–N ratio, C–P ratio, lignin, cellulose, hemicellulose and phenol content, and higher nitrogen, phosphorus, potassium dehydrogenase and humic acid content than the raw substrates and worm unworked normal compost. In addition, pronounced and better earthworm activity was found in the above combination.

Conclusion Through vermitechnology way of producing agronomic valid vermicompost using natural waste resources like CLL and animal dungs can be used as bio-organic fertilizer. These vermiresources have vast and diversified potential for maintaining sustainable soil health, fertility, productivity, waste degradation, soil reclamation, land restoration practices and environment health.

Keywords *Perionyx excavatus* · Solid waste management · Vermicomposting · Cashew leaf litter · Animal dungs · Vermifertilizer

Introduction

The recycling of organic wastes for increasing soil fertility has gained importance in recent years due to high cost of fertilizers and reduced availability of organic manures. Vermicompost application may be a source of nutrient for organic farming practices with several other options, e.g., biofertilizer, compost, vesicular–arbuscular mycorrhiza, blue–green algae, etc. Decomposition of complex organic waste resources into odor free humus like substance through combined action of earthworm and microorganism is called as vermicomposting. The vermicompost of organic wastes results in a product with relatively high content of microbial-enzyme activities, macro and micro nutrients and plant metabolites. Disposal and eco-friendly management of day by day formed organic waste materials from various resources has become a serious global problem. Vermicomposting, a novel technique of converting decomposable organic waste into valuable vermicompost through earthworm activity is a faster and better process when compared with the conventional methods of composting. Vermicomposting of organic waste using epigeic

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Table 1 Types of leaf litter and earthworm species employed for vermicomposting so far across the world (1996–2014)

Substrates	Earthworm species	References
Cashew leaf litter with animal dungs	<i>Perionyx excavatus</i>	Present study
Wheat straw, wood chips, shredded tree leaves with sewage sludge	<i>Eisenia fetida</i>	Hashemimajd and Somarin (2011)
Leaf litter (Acacia, Eucalyptus with cowdung	<i>E. fetida</i>	Srivastava et al. (2011)
Leaf litter with cowdung fresh slurry	<i>Eudrilus eugeniae</i>	Ravindran et al. (2011)
Dry leaves (Avenue, fruit tree) with cowdung	<i>P. excavatus</i>	Sannigarhi (2009)
Leaf litter (Ipomoea) and used paper with cowdung	<i>E. eugeniae</i> , <i>E. fetida</i>	Makhija (2012)
Silkworm litter with cowdung	<i>E. fetida</i>	Rajasekar and Karmegam (2009)
Cassia and leucaena leaf litter with cowdung	<i>E. fetida</i> , <i>E. eugeniae</i>	Sivasankari et al. (2010)
Crop residues + sheep manure, cow shed manure and kitchen waste + leaf litter	<i>E. eugeniae</i> , <i>P. excavatus</i> , <i>P. sansibaricus</i>	Suthar and Ram (2008)
Pineapple leaf agro wastes with cowdung	<i>E. eugeniae</i>	Banik et al. (2011)
Mango leaf litter with saw dust and soil	<i>E. eugeniae</i>	Gajalakshmi et al. (2004)
Neem leaves with cowdung	<i>E. eugeniae</i>	Gajalakshmi et al. (2005)
Guava leaves with cowdung	<i>E. eugeniae</i>	Mba (1983)
Bamboo leaf litter, straw leaf litter, kitchen wastes with cowdung	<i>P. excavatus</i>	Chaudhuri and Bhattacharjee (2002)
Mango leaf litter with cowdung	<i>P. ceylanensis</i>	Prakash (2010)
Leaf litter (polyalthia) with cowdung	<i>P. ceylanensis</i>	Prakash et al. (2008)
Agricultural crop residues with cattle farm yard manure, urban solid waste and cowdung	<i>P. sansibaricus</i>	Suthar (2007a, b)
Leaf litter with cowdung	<i>Lampito mauritii</i>	Shanmuga and Prabha (2011)
Coconut leaf litter with cowdung	<i>L. mauritii</i>	Manimegala et al. (2009)
	<i>E. eugeniae</i>	Gopal et al. (2010)
Leaf litter (Pearl millet), weed (Rottboethia) with cowdung	<i>L. mauritii</i>	Karmegam and Daniel (2009)
	<i>P. ceylanensis</i>	
Rubber leaf litter with cowdung	<i>P. excavatus</i> , <i>E. eugeniae</i> , <i>E. fetida</i>	Chaudhuri et al. (2003)
Leaf and twig litters with farm yard manure	<i>E. fetida</i> , <i>P. excavatus</i> , <i>Drawida bolaui</i>	Manna et al. (2003)
Biogas slurry with cowdung, wheat straw, leaf litter	<i>E. fetida</i> , <i>L. mauritii</i>	Tripathi and Bhardwaj (2004)
Dry leaves, water hyacinth with cowdung	<i>E. fetida</i>	Ansari and Rajpersand (2012)
Water hyacinth with cowdung	<i>P. excavatus</i>	Zirbes et al. (2012)
River weed with cowdung	<i>E. anderi</i>	Frederickson et al. (1997)
Agricultural wastes (Eichhornia, Salvinia, Lantana) with cowdung	<i>E. fetida</i> , <i>E. eugenia</i> , <i>P. excavatus</i>	Barik et al. (2010)
Leaf litter (Polyalthia longifolia) with cowdung	<i>E. eugenia</i>	Senthamizhselvan and Lakshmipraba (2014)
Leaf litter with cowdung	<i>Amyntas morrisi</i>	Khan et al. (2013)
Leaf litter (Acacia) with cowdung	<i>E. eugeniae</i> , <i>L. mauritii</i>	Ganesh et al. (2009)

From: Ranganathan (2006), Makhija (2012), Parthasarathi et al. (2014)

earthworm is one of the recent technique for the recycling of organic wastes and is a viable, eco-friendly efficient, ecologically sound method for waste management and manure production (Manyuchi and Phiri 2013).

Cashew tree is one of the most important cash crops of India. Approximately 8 lakhs hectares are planted with this crop giving employment to more 3–40,000 people and providing an annual turnover of 320,250 US\$. “Through

Table 2 Characteristic features of the raw materials used for experiment ($n = 6, \bar{X}$)

Parameters	CD	HD	SD	CLL
pH	8.03	8.08	8.05	6.13
OC (%)	27.9	26.7	26.2	42.79
N (%)	1.09	1.05	1.03	1.07
P (%)	0.50	0.46	0.44	0.37
K (%)	0.82	0.76	0.73	0.28
C:N ratio	26:1	25:1	25:1	40:1
C:P ratio	56:1	58:1	60:1	116:1
Dehydrogenase ^a	4.35	3.92	3.86	1.32
Lignin (g/kg)	22	3.88	3.77	193
Cellulose (g/kg)	86	79	76	459
Hemicellulose (g/kg)	14	12	11	46
Phenol (g/kg)	29	24	23	68
Humic acid (mg/g)	6.06	5.82	5.76	0.42

CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter

^a $\mu\text{H}/5 \text{ g}$ substrate

socio-economic scenario of our country the cashew tree is very important” and approximately 25–30 kg of leaf litter is fall on the ground per annum per plant which is not properly managed and or utilized, causing environmental pollution problem and also normal decomposition of this cashew leaf litter (CLL) takes about 8–9 months due to presence of higher amount of lignin (134 g/Kg) and phenol (48 g/Kg) contents (Isaac and Nair 2005). In general, the degradation of the lignin-cellulose-hemicellulose complex in leaf litter takes more time because of its structural complexity (Buswell and Odier 1995). Lignin is a natural polymer having a complex three-dimensional structure, the phenolic compounds. While cellulose and starch contain glucose units and hemicelluloses contain mannans, xylans and galactans. The accumulated cashew litter in the cashew field causes environmental pollution, fire problem, nutrient loss among other problems (Verghese et al. 2001). In India and several other countries in the southern hemisphere, leaf litter often piled-up and set on fire. The resulting ash return some of the NPK content of the litter to the soil, but much of nutrients get lost, due to improper waste management technique. The burning of litter also adds to air pollution (Makhija 2012; Pandit and Maheswari 2012). To overcome these problems, CLL can be composted and the compost could be used as fertilizer or soil conditioner. In our country, using variety of earthworms, types of organic waste those containing high quantity of cellulose, hemicellulose, lignin, starch, etc., can be converted into

vermicompost (Table 1). The objectives of this study were to recycle the lignocellulosic solid waste resources—CLL with animal dungs through vermitechnology using indigenous epigeic earthworm, *Perionyx excavatus* (Perrier) and to produce agronomic value added vermifertilizer. Besides, we want to study the earthworm activities for vermiculture and vermicomposting practices.

Materials and methods

Collection of earthworm, animal dung and CLL

Earthworm, *P. excavatus* (Perrier) was obtained from the breeding stocks, Department of Zoology, Annamalai University, Annamalaiagar, Tamilnadu, India. Cowdung (CD) and Sheepdung (SD) were obtained from Agricultural Experimental Farm of Annamalai University, Annamalaiagar and Horsedung (HD) was obtained from Vandayar Horse Farm, Chidambaram, Tamilnadu, India. Cashew leaf litters (CLL) were collected from cashew forest, Mutlur, Cuddalore district, Tamilnadu, India.

Preparation of experimental substrates

Three different animal dung (AD) alone and each mixed with different proportion of CLL in total of 12 vermibeds was prepared in the following manner: CD (100 %) (1000 g); (3:1) CD (75 %) + CLL (25 %) + with *P. excavatus* (750 + 250 g); (2:2) CD (50 %) + CLL (50 %) + with *P. excavatus* (500 + 500 g); (1:3) CD (25 %) + CLL (75 %) + with *P. excavatus* (250 + 750 g); HD (100 %) (1000 g); (3:1) HD (75 %) + CLL (25 %) + with *P. excavatus* (750 + 250 g); (2:2) HD (50 %) + CLL (50 %) + with *P. excavatus* (500 + 500 g); (1:3) HD (25 %) + CLL (75 %) + with *P. excavatus* (250 + 750 g); SD (100 %) (1000 g); (3:1) SD (75 %) + CLL (25 %) + with *P. excavatus*—750 + 250 g; (2:2) SD (50 %) + CLL (50 %) + with *P. excavatus* (500 + 500 g) and (1:3) SD (25 %) + CLL (75 %) + with *P. excavatus* (250 + 750 g). The chopped CLL (3–5 cm) and different animal dung (dry weight) in the above said proportions were mixed well with 62–65 % moisture, 65 % relative humidity (measured by hygrometer) and at a temperature of $30 \pm 2^\circ\text{C}$. In addition, the characteristic features of the raw materials used for experiments are given in the Table 2. The organic substrate served as bedding as well as

Table 3 Earthworm (*P. excavatus*) activity during vermicomposting of cashew leaf litter admixed with different animal dung ($n = 6, \bar{X}$)

Vermibeds	Biomass (g)		Cocoon production (number)		Hatchling number		Vermicompost recovery (g)	
	Initial (0-day)	Final (after 60 day)	Initial (0-day)	Final (after 60 day)	Initial (0-day)	Final (after 60 day)	Initial (0-day)	Final (after 60 day)
100 % CD	15.5 ^b	38.7 ^b	0	148.6 ^b	0	224.6 ^b	0	688.4 ^b
75 % CD + 25 % CLL	15.6 ^{ab}	36.2 ^{ab}	0	132.3 ^{ab}	0	193.8 ^{ab}	0	667.3 ^{ab}
50 % CD + 50 % CLL	15.4 ^{ab}	37.5 ^{ab}	0	141.6 ^b	0	206.7 ^c	0	676.6 ^{ab}
25 % CD + 75 % CLL	15.6 ^{ab}	35.1 ^{ab}	0	126.7 ^{ab}	0	182.5 ^{ab}	0	653.5 ^{ab}
100 % HD	15.9 ^{ab}	37.3 ^{ab}	0	126.3 ^{ab}	0	196.6 ^{ab}	0	661.2 ^{ab}
75 % HD + 25 % CLL	15.6 ^{ab}	35.5 ^{ab}	0	118.5 ^a	0	161.9 ^a	0	645.6 ^{ab}
50 % HD + 50 % CLL	15.5 ^{ab}	36.7 ^{ab}	0	101.7 ^a	0	173.4 ^a	0	652.5 ^{ab}
25 % HD + 75 % CLL	15.3 ^{ab}	34.6 ^{ab}	0	98.8 ^a	0	155.6 ^a	0	638.3 ^{ab}
100 % SD	15.4 ^{ab}	36.8 ^{ab}	0	112.8 ^a	0	182.8 ^{ab}	0	644.6 ^{ab}
75 % SD + 25 % CLL	15.7 ^{ab}	33.8 ^{ab}	0	104.6 ^a	0	153.5 ^a	0	619.8 ^{ab}
50 % SD + 50 % CLL	15.3 ^{ab}	34.6 ^{ab}	0	97.5 ^a	0	168.3 ^a	0	631.3 ^{ab}
25 % SD + 75 % CLL	15.2 ^a	32.8 ^a	0	93.2 ^a	0	144.7 ^a	0	607.2 ^a

ANOVA

Substrates				
Sum of squares	2472.5	81,970.2	191,548.5	2,526,102.8
Mean of squares	207.4	6985.1	16,221.9	210,753.9
F value	1819.2	486.8	676.543	9437.4
P value	0.000	0.000	0.000	0.000
Treatments				
Sum of squares	17.4	1851.9	3114.4	2944.3
Mean of squares	1.586	168.3	283.1	267.6
F value	1.167	1.00	1.000	1.000
P value	0.401	0.500	0.500	0.500

CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter

Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$)

food material for earthworms. The feed mixture was transferred to separate plastic troughs (40 cm diameter $\times$ 15 cm depth) and allowed for 7 days of initial natural decomposition (Parthasarathi 2007a, b). Experimental bedding was kept in triplicate for each vermibed with earthworm and same another triplicate for each vermibed without earthworm as control.

Earthworm inoculation and their activity

Fifteen grams of sexually immature, preclitellate *P. excavatus* (15–18 days old) (± 34 –36 numbers) were inoculated into each plastic troughs separately, each trough containing 1 kg of feed substrate of different proportions

(initial 0-day) (Parthasarathi 2007a, b). Six replicates for each vermibed were maintained up to 60-days. The worms were not fed with additional CLL + AD in the duration of the experiment (60 days). The growth of the worms (biomass in wet weight) was determined before the animals were inoculated into each treatment and thereafter 60th day. The worm biomass(g) was weighed in an electronic balance (Model—ATY224). The reproductive parameters like number of cocoon production and number of hatchlings were counted on the 60th day by hand sorting (Parthasarathi 2007a, b). The vermifertilizer was collected on the 60th day by hand sorting (Parthasarathi 2004), weighed, and used for determining various quality parameters.

Fig. 1 pH content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. *CD* Cowdung, *HD* Horsedung, *SD* Sheepdung, *CLL* Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); *OD* chemical composition of raw materials

used in different vermibed (initial 0-day); *WU* chemical composition of compost proceed without *P. excavatus* (normal compost); *WW* chemical composition of compost proceed with *P. excavatus* (vermicompost)

Quality analysis of vermifertilizer

The nutrient contents of the substrates before and after composting were analyzed using standard methods. The pH was measured by the method described by ISI Bulletin (1982). Organic carbon was determined by the partially oxidation method (Walkley and Black 1934). The total *N* content of substrates was analyzed according to the method of Jackson (1962) by Macro Kjeldahl method and phosphorus (Olsen et al. 1954) and potassium (Jackson 1973) were determined by colorimetrically and flame photometer methods, respectively. The *C/N* ratio was calculated by dividing the percentage of carbon in the substrates by the percentage of nitrogen in the same substrates. The *C/P* ratio was calculated by dividing the percentage of carbon in the substrates by the percentage of phosphorus in the same substrates. The microbial activity in terms of dehydrogenase activity (Pepper et al. 1995), lignin, cellulose and hemicellulose (Ververis et al. 2007), phenol (Dolatto et al. 2012) and humic acid content (Valdrighi et al. 1996) was estimated by the standard methods.

Statistical analysis

Two-way ANOVA procedures were applied to the data to determine significant differences. Duncan's multiple-ranged test was also performed to identify the homogenous type of the treatments for the various assessment variables (NPRS statistical package, version 9/98).

Results

As summarized in Table 3 the rate of growth (biomass), reproduction (cocoon production and hatchlings) and recovery of vermicompost of *P. excavatus* was highest in 100 % AD vermibeds and AD mixed with CLL in 50:50 vermibeds than the values obtained from other vermibeds. In general, regarding vermicomposting of CLL mixed with various AD, biomass of earthworms had increased significantly ($p < 0.05$) in all vermibeds, but the overall rate of biomass production was maximum in the 50 % CD + 50 % CLL vermibed followed by 50 % HD + 50 %

CLL and 50 % SD + 50 % CLL vermicomposts than other vermicomposts. Like the growth rate of earthworms, the cocoon production also varies in different vermicomposts. Among the 12 vermicomposts, earthworm reared on 50 % CD + 50 % CLL vermicompost, followed by 50 % HD + 50 % CLL and 50 % SD + 50 % CLL vermicomposts were shown significantly ($p < 0.05$) increased cocoon production than other vermicomposts. In addition, significantly ($p < 0.05$) highest hatchling number was observed in the 50 % CD + 50 % CLL vermicompost, followed by 50 % HD + 50 % CLL and 50 % SD + 50 % CLL vermicomposts than other vermicomposts. Similar to growth and reproductive performance of *P. excavatus* cultured on the 12 different vermicomposts, recovery of vermicompost was significantly ($p < 0.05$) highest in 50 % CD + 50 % CLL vermicompost, followed by 50 % HD + 50 % CLL and 50 % SD + 50 % CLL vermicomposts than other vermicomposts.

As depicted in Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13, the vermicomposting process of CLL with AD in different vermicomposts caused significant ($p < 0.05$) changes

in the chemistry and biochemical levels after 60 days of experimentation. As compared to initial substrate and worm unworked compost values from 12 vermicomposts, vermicompost showed significantly ($p < 0.05$) more reduction in pH, OC, C:N ratio, C:P ratio, lignin cellulose, hemicellulose and phenol values more being in the 50 % CD + 50 % CCL vermicompost followed by 50 % HD + 50 % CCL and 50 % SD + 50 % CCL vermicomposts than other vermicomposts. At the end of the experiment, N, P, K, dehydrogenase activity and humic acid contents in the vermicompost were significantly ($p < 0.05$) higher than that in the initial substrate and normal compost. Comparatively, the maximum increase in these values occurred in the vermicompost from 50 % CD + 50 % CCL vermicompost followed by 50 % HD + 50 % CCL and 50 % SD + 50 % CCL vermicomposts than other vermicomposts.

Finally, in the present experimental observation, 50 % CD + 50 % CCL vermicompost alone was found to show prolonged and sustainable earthworm activity and nutrient quality of vermicompost even though better growth,

Fig. 2 Organic carbon content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition

of raw materials used in different vermicompost (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

Fig. 3 Nitrogen content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition

of raw materials used in different vermicomposting (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

reproduction and more recovery of vermicompost, and nutrient quality of vermicompost, i.e., increased N, P, K, dehydrogenase activity and humic acid content and reduced pH, OC, C:N ratio, C:P ratio, lignin, cellulose, hemicellulose and phenol were found to be observed in the other vermicomposts.

Discussion

Vermicomposting is also considered in terms of production patterns of earthworm biomass, numbers of cocoon, numbers of hatchling and vermicompost. Quality of the organic waste is also one of the factors determining the onset and rate of reproduction (Dumínguez et al. 2001), and recovery

rate of vermicompost (Parthasarathi 2010). Murchie (1960) proved experimentally the existence of a significant relationship between weight increase and substrate type, which may reasonably be attributed to nutritional quality of the substrate. Growth and reproduction in earthworms require OC, N and P which are obtained from litter, grit and microbes (Edwards and Bohlen 1996; Parthasarathi and Ranganathan 2000a, b). In the present study, the biomass, number of cocoon production, number of hatchling and recovery of vermicompost were highest in 100 % AD vermicomposts and 50 % CD + 50 % CCL vermicompost followed by 50 % HD + 50 % CCL and 50 % SD + 50 % CCL vermicomposts than other vermicomposts. *P. excavatus* exhibited highest biomass, more cocoon, hatchling and vermicompost production, very particular in 50 % CD + 50 % CCL

Fig. 4 Phosphorus content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition

of raw materials used in different vermibed (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

vermibed followed by 50 % HD + 50 % CCL and 50 % SD + 50 % CCL vermibeds. The reasons for the enhanced growth and reproduction in 50 % CD + 50 % CCL vermibed in the present study seems to be due to : nitrogen rich organic matter, microbial population and activity and enhanced water holding capacity (39–41 %) which enable the substrates in the vermibed to maintain good and ideal moisture. The dependency of earthworm on soil moisture for their survival and activity and on organic matter rich in N for growth and reproduction is well known (Edwards and Bohlen 1996; Parthasarathi 2010). The physical structure of the substrate depends on the chemical composition of the constituents particularly organic matter rich in N; it is only in such type of substrate (vermibed) that earthworm could reproduce. This vermibed provides such ideal

physico-chemical conditions suitable for better growth and maximum reproduction. Hence, it may be concluded that though CLL are nutritionally inferior and slow degrading, the presence of high cellulose in this vermibed develop better water holding capacity and become more palatable and nutritive supporting better growth, reproduction and more compost recovery. Earlier studies of Ranganathan and Parthasarathi (1999), Parthasarathi and Ranganathan (1999; 2000) and Parthasarathi (2010) have shown the higher N, P, OC, microbial content of pressmud to support better growth, reproduction and more vermicompost production of *L. mauritii*, *P. excavatus*, *Eudrilus eugeniae* and *Eisenia fetida*. This was supported by Kale (1998), Edwards and Bohlen (1996), Suthar (2007a, b) who reported that the factors relating to the growth,

Fig. 5 Potassium content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition

of raw materials used in different vermibed (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

reproduction and compost production of earthworms may also be considered in terms of physico-chemical and nutrient characteristics of waste feed stocks.

Organic waste palatability for earthworms is directly related to the chemical nature of the waste material that consequently affects the earthworm growth, reproduction and compost production parameters. Garg et al. (2005), Suthar (2007a, b) and Parthasarathi (2007a, b; 2010) concluded that growth and reproductive performance of *E. fetida*, *P. sansibaricus* and *P. excavatus* was directly related to the quality of the feed stock. Edwards et al. (1998) and Suthar (2006) concluded that the important difference between the rates of cocoon production in the two organic wastes must be related to the quality of the waste. The variability in the earthworm biomass gain and

reproduction rate in different treatments was probably related to the palatability, microbiology as well as the chemistry of the feeding stuff. The difference in cocoon production pattern among different treatment suggests a physiological trade-off (Streans 1992) related to N limitations. Recently, Suthar (2007a, b) and Parthasarathi (2007a, b; 2010) demonstrated that earthworm growth, reproduction and vermicompost production is related to initial N content of the substrate. Our present experimental results are confirmatory of above hypothesis.

Earthworms are very sensitive to pH and in general are neutrophilic in nature (Edwards and Bohlen 1996). Vermicomposting of CLL in combination with different ratio of AD seems to be advantageous over conventional process of composting. Lowering of pH, in the present study, in the

Fig. 6 C–N ratio of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition of raw materials

used in different vermibed (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

vermicompost from vermibeds was probably due to mucus secretion by the earthworms that had a ‘priming effect’ on microbial activity (Trigo et al. 1999) and CO₂ and organic acids produced during microbial metabolism (Edwards and Bohlen 1996). It is likely that comparatively lower pH (towards neutral) during vermicomposting was due to additional contribution made by the earthworms. Elvira et al. (1998) suggested that production of CO₂, ammonia, NO₃ and organic acids by microbial decomposition during vermicomposting lowers the pH of substrate. Similarly, Ndegwa et al. (2000) and Suthar (2007a) pointed out that shifting of pH could be related to the mineralization of the nitrogen and phosphorus into nitrites/nitrates and orthophosphates and bioconversion of the organic material into intermediate species of the organic acids.

The value of organic matter is very important for soil health. The deficiency in OC reduces storage capacity of soil nitrogen, phosphorus, sulfur and leads to reduction in soil fertility (Edwards and Bohlen 1996). Further, microbial biomass in soil is mainly related to the OC content (Schneuer et al. 1985). Vermicomposting refers to the breakdown of organic matter by earthworm and subsequent microbial degradation. Earthworm modify substrate conditions, which consequently affects carbon losses from substrates through microbial respiration in the form of CO₂ and even through mineralization of OC. Body fluids and excreta, secreted by earthworms (e.g., mucous, high concentration of organic matter, ammonia and urea) promote microbial communities in vermicomposting sub-system. OC content of vermicompost in the present study indicated

Fig. 7 C–P ratio of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition of raw materials

used in different vermibed (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

that during the process of vermicomposting the level of OC was reduced in the vermicompost obtained from vermibeds when compared to compost and initial substrates. The results revealed that during the process of vermicomposting the level of OC was reduced to lesser extent in the vermicompost obtained from various vermibeds and retained the quantity of OC ranging between 18 and 50 %. Many earlier investigators have reported and confirmed the reduction of OC content in organic wastes after conversion to vermicompost (Satchell and Martin 1984; Suthar 2007a, b; Parthasarathi 2010). The obtained reduction in the level of OC in the present study falls in line with the earlier reported results. Drop in the level of OC due to the combined action of earthworm and microbes during

vermicomposting revealed that earthworm accelerate the decomposition of organic matter.

The main index to assess the rate of organic matter decomposition is the reduction of C–N and C–P ratio during vermicomposting. Carbon to nitrogen ratio is one of the criteria to assess the rate of decomposition of organic wastes and a reduction in the ratio indicates increased rate of decomposition (Edwards and Bohlen 1996; Suthar 2009; Parthasarathi and Ranganathan 2000a, b). A similar reduction in carbon to phosphorus ratio indicates enhanced rate of decomposition (Pore et al. 1992). Further, plants cannot assimilate mineral nitrogen unless the C:N ratio is 20:1 or lower (Edwards and Bohlen 1996). Hence the NPK and OC analysis of vermicompost is essential and

Fig. 8 Dehydrogenase activity of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. *CD* Cowdung, *HD* Horsedung, *SD* Sheepdung, *CLL* Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); *OD* chemical composition

of raw materials used in different vermicbed (initial 0-day); *WU* chemical composition of compost proceed without *P. excavatus* (normal compost); *WW* chemical composition of compost proceed with *P. excavatus* (vermicompost)

inevitable to confirm its manurial maturity and quality. Many earlier investigators have reported and confirmed the reduction of OC, *C:N* and *C:P* ratios and increase in NPK content in organic wastes after conversion into vermicompost (Lee 1985; Edwards and Bohlen 1996; Kale 1998; Parthasarathi 2010). The *C:N* ratio is considered as an important indicator of compost maturity. The parameters traditionally considered to determine the degree of maturity of compost and to define its agronomic quality is the *C:N* ratio. According to Morais and Queda (2003) and Jordening and Winter (2008), a *C:N* ratio below 20 is indicative of acceptable maturity, while a ratio of 15 or lower is being preferable for agronomic use of composts. The vermicompost obtained in the present study in the vermicbeds showed the *C:N* ratio within the acceptable limit and agronomically preferable as described by Morais and Queda (2003) and Jordening and Winter (2008) and that is why, the obtained vermicompost is called as vermifertilizer (Tables 4, 5).

The significant reduction and narrow range of *C:N* ratio below 20:1 and reduction in *C:P* ratio recorded in the vermifertilizer obtained from vermicbeds compared to initial substrates and compost reflected the high rate of organic matter decomposition, and mineralization thereby resulting in mature and nutrient rich and agronomic value added vermifertilizer. The observed significant reduction in the levels of *C:N* and *C:P* ratio in the vermifertilizer obtained from the vermicbeds was in accordance with the work of Mba (1983), who found that in *E. eugeniae* worked cassava peel compost *C:N* and *C:P* ratios decreased. In most of earlier reports a decrease and narrow down of *C:N* and *C:P* ratios were recorded in the vermicompost produced from different types of organic wastes (Syers et al. 1979; Kale 1998; Garg et al. 2005; Suthar 2009). The reduction in OC and lowering *C:N* ratio and *C:P* ratio in the vermicompost could be achieved on one hand by the combustion of carbon or loss of C as CO₂ during respiration and worm gut microbial utilization (Edwards et al.

Fig. 9 Lignin content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition of raw materials

used in different vermibed (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

1998) and on the other hand simultaneous enhancement of higher proportion of total N and ionic protein content in the vermicompost due to loss of dry matter (Viel et al. 1987) coupled with the addition of earthworm's activities (i.e., production of mucus, enzymes and nitrogenous excrements (Curry et al. 1995). The decrease in C:N ratio over time might also be attributed to increase in the earthworm population which led to rapid decrease in OC due to enhanced oxidation of the organic matter (Ndegwa et al. 2000).

In addition, the presence of large number of microflora in the gut of earthworms (Parthasarathi et al. 2007) might play an important role in increasing P and K content during the process of degradation of organic wastes thereby decreasing C:P ratio (Parthasarathi 2010). Enhancement of P and K content during vermicomposting is probably due to the mineralization, solubilization and mobilization of phosphorus and potassium because of earthworm—microbial

activity (Parthasarathi and Ranganathan 1999; Parthasarathi 2010). Parthasarathi and Ranganathan's (1999); Suthar's (2006); Parthasarathi's (2007a, b; 2010) investigation support the hypothesis that earthworms can enhance the NPK content during their inoculation in waste system. So, from the present findings it can be concluded that the reduction in C:N and C:P ratios of vermicompost indicates the enhanced biodegradation process of the organic matter in the different ratios of substrates like CLL and AD. Further, reduction in C:N and C:P ratios of vermicompost is the indices for the effective biodegradation of CLL with AD and production of good quality vermifertilizer.

The significantly enhanced levels of NPK in the vermicompost obtained from all vermibeds especially in 2:2 ratios of CLL and AD over initial substrates and compost which indicates the effective decomposition of CLL with AD by the combined action of earthworm—microbes. Earthworms enrich the vermicompost with N through

Fig. 10 Cellulose content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition

of raw materials used in different vermibed (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

excretory products, mucous, enzymes and growth stimulating hormones and even by decaying earthworm tissue after their death. Studies revealed that decomposition of organic material by earthworms accelerates the N mineralization process and subsequently changes the N profile of the substrate (Elvira et al. 1998; Benitez et al. 2002; Suthar 2009; Parthasarathi 2010). In general, earthworm contains about 60–70 % (of dry mass) protein in their body tissue, and this pool of N returned to the soil upon mineralization. Satchell (1967) reported that over 70 % of the N in the tissues of dead earthworm was mineralized in less than 20 days. However, decomposition activities and N enrichment by earthworms also depend upon the quality of the substrate material.

After vermicomposting of different ratio of CLL with AD, in the vermibeds showed significantly higher

concentration of available P in the vermicompost than normal compost and initial substrates. According to Lee (1992) the passes of organic residue through the gut of earthworms, results in phosphorus converted to forms, which are more available to plants. The release of phosphorus in forms available to plants is mediated by phosphatases, which are produced in earthworm's gut (Vinotha et al. 2000). Further, release of P may occur by the presence of P-solubilizing microbes in the vermicompost (Parthasarathi et al. 2007). Recently, Parthasarathi (2010) reported about 6–8-fold increment in available P content in the vermicasts, after inoculation of agro-industrial wastes with *E. eugeniae*, *E. fetida*, *L. mauritii* and *P. excavatus*. Earthworm gut flora provides enzymes required for P metabolism and these enzyme release phosphorus from ingested waste material (Parthasarathi and Ranganathan

Fig. 11 Hemicellulose content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition

of raw materials used in different vermibed (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

2000; Vinotha et al. 2000; Parthasarathi et al. 2007; Parthasarathi 2010).

In the present study, K content in the vermicompost was significantly higher than initial substrates and normal compost. However, when organic waste passes through the gut of earthworm some quantity of organic minerals are then converted into more available forms though the action of enzymes produced by gut associated microorganisms. The vermicomposting plays an important role in microbial-mediated nutrient mineralization in wastes. The results of this study agree with previous reports that the vermicomposting process accelerates the microbial populations in the waste and subsequently enriches the vermicompost with more available forms of plant nutrients. In addition, the present result is similar to those by Parthasarathi and Ranganathan (1999), Parthasarathi (2007a, b; 2010) and

Suthar (2009) who reported enhancement of K content in the vermicompost. Thus, vermicompost obtained from 2:2 ratio of CLL with AD by the action of *P. excavatus* evidenced with increased levels of NPK and drastically reduced C:N and C:P ratios and hence can be considered as quality rich vermicompost/vermifertilizer.

Lignin is the most resistant form of plant products of photosynthesis in nature and accounts for 25–50 % of the plant biomass generated. CLL consists of 134 g/kg of lignin, 454 % of cellulose and 48 % of phenol. So requires long time for natural decomposition (Isaac and Nair 2005). Hubbe et al. (2010) and Singh and Nain (2014) stated that many studies on the decomposition of leaf litter with lack of information on the lignin, cellulose, hemicellulose, phenol and humic acid. No study is available regarding the levels of this content in the CLL after vermicomposting

Fig. 12 Phenol content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horse dung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition of raw

materials used in different vermibed (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

process. In the present study, the lignin, cellulose, hemicellulose and phenol content in the vermicompost from vermibeds were reduced significantly when compared to compost and initial substrates. This is due to the combined action of gut lignocellulolytic microflora and earthworm in the decomposition process. Parthasarathi et al. (2007) and Parthasarathi (2010) reported the presence of more cellulolytic, amylolytic, proteolytic and phosphate solubilizing microbes in the gut and casts of *E. eugeniae*, *E. fetida*, *L. mauritii* and *P. excavatus* and also the presence of lignocellulosic degrading enzymes as well as enzyme producing microbes in the gut of earthworms (Parthasarathi and Ranganathan 2000a, b; Parthasarathi 2010). In addition,

Loquet et al. (1984) reported that the combined activity of microflora in the gut of worm and inoculated lignocellulolytic fungi might have intensified cellulolysis and lignolysis. In the present study, minimum decrease of cellulose, hemicellulose, lignin and phenol content in the vermibeds containing either CLL admixed with CD/HD/SD confirmed the fact that it is necessary to inoculate suitable lignocellulolytic microbes and nitrogen rich boosters for the quick degradation of lignocellulolytic material like CLL as suggested by Makhija (2012).

The enhancement of HA in the casts is mainly due to large number of microbial population, their activity and also due to gut associated process of the earthworm.

Fig. 13 Humic acid content of compost and vermicompost of *P. excavatus* obtained from lignocellulosic wastes. CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter; Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$); OD chemical composition

of raw materials used in different vermibed (initial 0-day); WU chemical composition of compost proceed without *P. excavatus* (normal compost); WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

Earthworm gut is known to stimulate biological activity, modify the composition of microbial communities and speed up the humification of organic matter (Lee 1985). Now, it is well established that the earthworm gut harbors specific symbiotic microflora (Edwards and Bohlen 1996; Parthasarathi 2010). Earthworms are known to accelerate humification process and vermicompost was shown to contain HA (Mulongoy and Bedoret 1989; Edwards and Bohlen 1996; Muscola et al. 1999; Parthasarathi 2010). Numerous earlier studies have shown that the guts of earthworms and vermicasts have enhanced microbial

population and their activity than the ingested food material or the surrounding soil (Edwards and Bohlen 1996; Parthasarathi and Ranganathan 1999; Parthasarathi 2007a, b; 2010; Parthasarathi et al. 2007). The humus will hold on the nutrients such as P and S and prevent their ready leaching. This fact has been proved in the field experiments conducted by Parthasarathi et al. (2008), Parthasarathi (2010) and Jayanthi et al. (2014) where vermicompost was supplemented with 50 % NPK applied to black grams, ground nut, beans and chili, the yield was more than that of the NPK or vermicompost alone.

Table 4 Chemical composition of compost and vermicompost obtained from cashew leaf litter admixed with different animal dung ($n = 6, \bar{X}$)

Parameters	Vermibeds											
	100 % CD	75 % CD + 25 % CLL	50 % CD + 50 % CLL	25 % CD + 75 % CLL	100 % HD	75 % HD + 25 % CLL	50 % HD + 50 % CLL	25 % HD + 75 % CLL	100 % SD	75 % SD + 25 % CLL	50 % SD + 50 % CLL	25 % SD + 75 % CLL
Ph												
OD	8.03 ^a	10.17 ^b	10.52 ^b	11.61 ^b	8.08 ^b	10.06 ^b	10.49 ^b	11.56 ^b	8.05 ^b	10.10 ^b	10.55 ^b	11.60 ^b
WU	7.64 ^a	9.72 ^b	9.68 ^b	9.86 ^b	7.71 ^a	9.76 ^b	9.57 ^b	9.90 ^b	7.74 ^a	9.83 ^b	9.86 ^b	9.98 ^b
WW	7.05 ^a	7.14 ^a	7.02 ^a	7.20 ^a	7.09 ^a	7.18 ^a	7.24 ^a	7.27 ^a	7.14 ^a	7.20 ^a	7.28 ^a	7.31 ^a
Organic carbon (%)												
OD	27.9 ^a	30.6 ^{abc}	38.8 ^{cd}	40.6 ^d	26.7 ^{ab}	29.4 ^{bc}	35.5 ^{cd}	38.7 ^{ad}	26.2 ^{ab}	28.7 ^{abc}	31.1 ^{bc}	34.8 ^d
WU	21.2 ^a	27.7 ^{abc}	29.3 ^{cd}	36.5 ^d	23.5 ^{ab}	27.2 ^{bc}	32.4 ^{cd}	36.2 ^{ad}	24.0 ^{ab}	24.4 ^{abc}	28.3 ^{bc}	32.6 ^e
WW	16.6 ^a	21.3 ^{abc}	19.4 ^{cd}	23.5 ^d	17.4 ^{ab}	22.8 ^{bc}	20.6 ^{cd}	25.6 ^{ad}	18.6 ^{ab}	22.5 ^{abc}	21.8 ^{bc}	28.4 ^d
Nitrogen (%)												
OD	1.09 ^c	1.42 ^f	1.58 ^g	1.34 ^{ef}	1.05 ^{ab}	1.28 ^{cd}	1.33 ^{ef}	1.18 ^c	1.03 ^a	1.21 ^{cd}	1.26 ^{de}	1.15 ^{bc}
WU	1.27 ^c	1.51 ^f	1.81 ^g	1.46 ^{ef}	1.19 ^{ab}	1.34 ^{cd}	1.46 ^{ef}	1.32 ^c	1.14 ^a	1.31 ^{cd}	1.38 ^{de}	1.29 ^{bc}
WW	1.86 ^c	2.17 ^f	2.49 ^g	2.07 ^{ef}	1.61 ^{ab}	1.86 ^{cd}	2.06 ^{ef}	1.72 ^c	1.57 ^a	1.80 ^{cd}	1.96 ^{de}	1.70 ^{bc}
Phosphorus (%)												
OD	0.50 ^{cde}	0.61 ^{fg}	0.76 ^h	0.58 ^{def}	0.46 ^a	0.54 ^{cde}	0.65 ^{fg}	0.49 ^{bc}	0.44 ^a	0.51 ^{bcd}	0.62 ^{efg}	0.46 ^{ab}
WU	0.78 ^{cde}	0.85 ^{fg}	1.16 ^h	0.82 ^{def}	0.54 ^a	0.78 ^{cde}	0.97 ^{fg}	0.71 ^{bc}	0.51 ^a	0.72 ^{bcd}	0.80 ^{efg}	0.58 ^{ab}
WW	1.06 ^{cde}	1.28 ^{fg}	1.42 ^h	1.14 ^{def}	0.91 ^a	1.14 ^{cde}	1.31 ^{fg}	1.02 ^{bc}	0.86 ^a	1.07 ^{bcd}	1.22 ^{efg}	0.98 ^{ab}
Potassium (%)												
OD	0.82 ^d	0.71 ^d	0.64 ^d	0.51 ^{bcd}	0.76 ^{cd}	0.62 ^{bcd}	0.44 ^{abc}	0.31 ^{ab}	0.73 ^{bcd}	0.56 ^{abcd}	0.41 ^{abc}	0.28 ^a
WU	0.91 ^d	0.88 ^d	0.79 ^d	0.65 ^{bcd}	0.82 ^{cd}	0.74 ^{bcd}	0.52 ^{abc}	0.43 ^{ab}	0.78 ^{bcd}	0.67 ^{abcd}	0.50 ^{abc}	0.35 ^a
WW	1.02 ^d	1.13 ^d	1.27 ^d	1.08 ^{bcd}	0.84 ^{cd}	0.98 ^{bcd}	1.01 ^{abc}	0.95 ^{ab}	0.81 ^{bcd}	0.86 ^{abcd}	0.90 ^{abc}	0.83 ^a
C:N ratio												
OD	26:1 ^{bc}	22:1 ^a	25:1 ^a	30:1 ^{bcd}	25:1 ^{ab}	23:1 ^{ab}	27:1 ^{ab}	33:1 ^d	25:1 ^{ab}	24:1 ^{ab}	26:1 ^{ab}	30:1 ^{cd}
WU	17:1 ^{bc}	18:1 ^a	16:1 ^a	25:1 ^{bcd}	20:1 ^{ab}	20:1 ^{ab}	22:1 ^{ab}	27:1 ^d	21:1 ^{ab}	19:1 ^{ab}	21:1 ^{ab}	25:1 ^{cd}
WW	9:1 ^{bc}	10:1 ^a	8:1 ^a	11:1 ^{bcd}	11:1 ^{ab}	12:1 ^{ab}	10:1 ^{ab}	15:1 ^d	12:1 ^{ab}	13:1 ^{ab}	11:1 ^{ab}	17:1 ^{cd}
C:P ratio												
OD	56:1 ^{ab}	50:1 ^{ab}	51:1 ^a	70:1 ^e	58:1 ^{bcd}	54:1 ^{abc}	55:1 ^{ab}	79:1 ^{ef}	60:1 ^{cd}	56:1 ^{abc}	53:1 ^{abc}	76:1 ^f
WU	27:1 ^{ab}	33:1 ^{ab}	25:1 ^a	46:1 ^{de}	44:1 ^{bcd}	35:1 ^{abc}	33:1 ^{ab}	51:1 ^{ef}	47:1 ^{cd}	34:1 ^{abc}	35:1 ^{abc}	56:1 ^f
WW	16:1 ^{ab}	17:1 ^{ab}	14:1 ^a	21:1 ^{de}	19:1 ^{bcd}	20:1 ^{abc}	16:1 ^{ab}	25:1 ^{ef}	22:1 ^{cd}	21:1 ^{abc}	18:1 ^{abc}	29:1 ^f
Parameters	pH		Organic carbon		Nitrogen		Phosphorus		Potassium		C/N ratio	
C/P ratio												
Anova												
Substrates												
Sum of squares	53.52		730.8		2.95		1.95		1.07		1367.7	
Mean of squares	26.76		365.4		1.47		0.95		0.538		683.8	
											9608.0	
											4804.0	

Table 4 continued

Parameters	pH	Organic carbon	Nitrogen	Phosphorus	Potassium	C/N ratio	C/P ratio
<i>F</i> value	57.653	61.04	337.87	323.002	41.664	170.427	267.33
<i>P</i> value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Treatments							
Sum of squares	19.67	549.5	1.28	0.708	0.644	231.5	1881.6
Mean of squares	1.78	49.9	0.117	0.064	0.059	21.05	171.0
<i>F</i> value	3.853	8.347	26.637	21.242	4.532	5.246	9.519
<i>P</i> value	0.003	0.000	0.000	0.000	0.001	0.000	0.000

CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter

Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$), OD chemical composition of raw materials used in different vermicomposts (initial 0-day), WU chemical composition of compost proceed without *P. excavatus* (normal compost), WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

The analysis of results in the present study indicated that HA content was significantly higher in the vermicompost obtained from all vermicomposts especially more in 50 % CD + 50 % CCL vermicompost (37 and 25 %), 50 % HD + 50 % CCL vermicompost (30 and 18 %) and 50 % SD + 50 % CCL vermicompost (37 and 12 %) than the initial substrate and normal compost. The increase of HA contents in vermicompost could mainly due to the activity of large number of microbes and also due to the gut associated process of earthworm (Parthasarathi et al. 2007; Parthasarathi 2010). Clark and Paul (1970), Mulongoy and Bedoret (1989) and Muscolo et al. (1999) have also reported that microbial population and their activity play a significant role in HA synthesis and also exhibit positive correlation with HA and FA content. In accordance with these reports in the present study also maximum enhancement of microbial activity especially in 50 % CD + 50 % CCL (28 and 15 %), 50 % HD + 50 % CCL (35 and 20 %) and 50 % SD + 50 % CCL (36 and 27 %) vermicomposts over initial substrates and compost was recorded. In general, increased microbial population and activity and more availability of nutrient content especially nitrogen content that support and stimulate the quick decomposition of organic matter. In the present study, increased nitrogen availability due to the addition of different ratio of AD to CLL in all vermicomposts might have enhanced microbial activity and earthworm activity in one hand and speed up the decomposition of CLL on the other hand. This conclusion is in accordance with the suggestion of Berg and Matzner (1997) and Manyuchi and Phiri (2013). They have stated that increasing nitrogen availability influenced the decomposition rates of plant litter and organic matter.

Conclusion

Thus, our experimental results indicate that vermicompost produced from 2:2 ratio of CLL admixed with AD evidenced with increased level of NPK and HA, drastically reduced C:N and C:P ratio, lignin, cellulose, hemicelluloses, phenol content coupled with increased microbial and earthworm activity (better and more earthworm growth and reproductive performance and vermicompost recovery). The present study proved that CLL can be served as feed stock for earthworm and converted into nutrients and microbial rich organic manure/vermicompost by the action of *P. excavatus*. In addition, 2:2 ratio of CD + CLL could be recommended for vermiculture and production of quality rich vermicompost for sustainable agricultural activity in an eco-friendly way besides abating environmental pollution. Further study is needed to develop the integrated system of vermicomposting method by enhancing the efficiency of indigenous earthworm to overcome

Table 5 Biological composition of compost and vermicompost obtained from cashew leaf litter admixed with different animal dung ($n = 6, \bar{X}$)

Parameters		Vermibeds													
		100 % CD	75 %CD + 25 %CLL	50%CD + 50 %CLL	25 %CD + 75 %CLL	100 % CD	75 %HD + 25 %CLL	50 %HD + 50 %CLL	25 %HD + 75 %CLL	100 % SD	75 %SD + 25 %CLL	50 %SD + 50 %CLL	25 %SD + 75 %CLL		
Dehydrogenase ^a															
OD	4.35 ^{de}	4.86 ^{fg}	5.13 ^g	3.58 ^b	3.92 ^{bc}	4.48 ^{de}	4.35 ^{ef}	3.18 ^a	3.86 ^b	4.31 ^{cd}	4.17 ^{de}	3.06 ^a			
WU	5.10 ^{de}	5.64 ^{fg}	6.02 ^g	4.42 ^b	4.74 ^{bc}	5.22 ^{de}	5.36 ^{ef}	4.06 ^a	4.42 ^b	4.98 ^{cd}	4.76 ^{de}	3.84 ^a			
WW	6.33 ^{de}	6.88 ^{fg}	7.10 ^g	5.47 ^b	5.66 ^{bc}	6.10 ^{de}	6.72 ^{ef}	4.63 ^a	5.41 ^b	5.95 ^{cd}	6.53 ^{de}	4.42 ^a			
Lignin (mg/g)															
OD	22.0 ^a	48.3 ^b	95.5 ^c	126.3 ^d	19.3 ^a	43.2 ^b	86.7 ^c	117.5 ^d	18.6 ^a	41.5 ^b	84.6 ^c	114.3 ^d			
WU	19.5 ^a	42.8 ^b	92.3 ^c	123.6 ^d	17.6 ^a	39.9 ^b	81.9 ^c	113.8 ^d	16.8 ^a	38.6 ^b	80.8 ^c	108.6 ^d			
WW	10.4 ^a	26.5 ^b	71.1 ^c	97.3 ^d	11.2 ^a	29.7 ^b	73.5 ^c	101.6 ^d	12.7 ^a	31.2 ^b	74.8 ^c	103.2 ^d			
Cellulose (mg/g)															
OD	86.0 ^a	171.6 ^{cd}	256.5 ^e	323.3 ^f	79.0 ^a	158.5 ^{bc}	208.6 ^d	309.7 ^f	74.0 ^a	151.2 ^b	182.4 ^{cd}	301.6 ^f			
WU	78.0 ^a	162.2 ^{cd}	237.6 ^e	296.5 ^f	67.0 ^a	144.3 ^{bc}	184.6 ^d	277.4 ^f	63.0 ^a	138.2 ^b	169.3 ^{cd}	284.6 ^f			
WW	64.0 ^a	139.2 ^{cd}	166.7 ^e	244.8 ^f	56.0 ^a	118.7 ^{bc}	122.5 ^d	226.8 ^f	52.0 ^a	102.7 ^b	119.6 ^{cd}	238.4 ^f			
Hemicellulose (mg/g)															
OD	14.0 ^{bc}	15.6 ^{cd}	28.2 ^h	23.3 ^{gh}	12.0 ^{ab}	14.8 ^{bc}	24.5 ^{gh}	20.6 ^{ef}	10.4 ^a	12.6 ^{abc}	22.8 ^{fg}	18.7 ^{de}			
WU	11.8 ^{bc}	12.7 ^{cd}	24.5 ^h	20.6 ^{gh}	9.7 ^{ab}	11.6 ^{bc}	21.8 ^{gh}	17.7 ^{ef}	8.5 ^a	10.7 ^{abc}	19.5 ^{fg}	15.3 ^{de}			
WW	8.5 ^{bc}	9.7 ^{cd}	13.3 ^h	17.4 ^{gh}	6.2 ^{ab}	8.5 ^{bc}	15.4 ^{gh}	11.6 ^{ef}	5.3 ^a	6.6 ^{abc}	13.2 ^{fg}	10.4 ^{de}			
Phenol (mg/100 g)															
OD	29.0 ^{bc}	39.5 ^e	49.1 ^e	56.1 ^f	24.0 ^{ab}	36.2 ^d	45.5 ^e	54.4 ^f	21.8 ^a	32.3 ^{cd}	43.6 ^e	53.6 ^f			
WU	24.2 ^{bc}	35.5 ^e	41.7 ^e	50.3 ^f	19.6 ^{ab}	30.6 ^d	40.4 ^e	49.2 ^f	17.8 ^a	28.1 ^{cd}	38.3 ^e	47.4 ^f			
WW	18.5 ^{bc}	28.7 ^e	26.2 ^e	38.8 ^f	15.3 ^{ab}	22.2 ^d	24.6 ^e	36.2 ^f	13.5 ^a	20.11 ^{cd}	28.2 ^e	39.4 ^f			
Humic acid (mg/5 g)															
OD	6.06 ⁱ	4.16 ^f	3.68 ^e	1.72 ^b	5.82 ^h	4.01 ^f	3.45 ^d	1.59 ^{ab}	5.76 ^h	3.90 ^{ef}	2.75 ^c	1.37 ^a			
WU	7.15 ⁱ	5.21 ^f	4.42 ^e	2.61 ^b	6.63 ^h	5.06 ^f	4.05 ^d	2.36 ^{ab}	6.42 ^h	4.73 ^{ef}	3.82 ^c	2.12 ^a			
WW	8.18 ⁱ	6.35 ^f	5.89 ^e	3.41 ^b	7.22 ^h	6.12 ^f	4.96 ^d	3.28 ^{ab}	7.04 ^h	5.76 ^{ef}	4.35 ^c	3.02 ^a			
Parameters		Dehydrogenase				Lignin	Cellulose	Hemicellulose		Phenol	Humic acid				
Anova															
Substrates															
Sum of squares	20.22				1386.2		18537.5	356.9		1286.5			18.92		
Mean of squares	10.11				693.1		9268.7	178.4		643.2			9.46		
F value	261.148				42.500		47.542	77.052		99.75			284.873		
P value	0.000				0.000		0.000	0.000		0.000			0.000

Table 5 continued

Parameters	Dehydrogenase	Lignin	Cellulose	Hemicellulose	Phenol	Humic acid
Treatments						
Sum of squares	15.85	50074.1	213844.9	775.5	3643.9	90.15
Mean of squares	1.44	4552.2	19440.4	70.5	331.2	8.19
F value	37.216	279.127	99.716	30.444	51.37	246.69
P value	0.000	0.000	0.000	0.000	0.000	0.000

CD Cowdung, HD Horsedung, SD Sheepdung, CLL Cashew leaf litter

Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $p < 0.05$), OD chemical composition of raw materials used in different vermicompost (initial 0-day), WU chemical composition of compost proceed without *P. excavatus* (normal compost), WW chemical composition of compost proceed with *P. excavatus* (vermicompost)

^a $\mu\text{L H}^+ / 5 \text{ g substrate}$

the problem of lignocellulosic waste degradation of organic solid wastes like CLL with bioinoculants.

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