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Physico-chemical changes during vermicomposting of a terrestrial weed, *Mikania micrantha* and leaf litters of *Acacia auriculiformis* and *Bambusa polymorpha* mixed with cowdung

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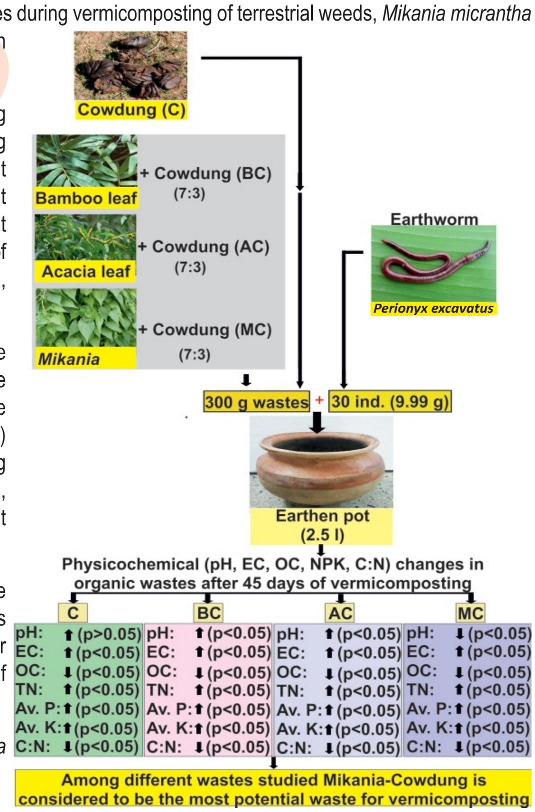
Abstract

Aim : The aim of the present study was to understand the physico-chemical changes during vermicomposting of terrestrial weeds, *Mikania micrantha* and leaf litters of *Acacia auriculiformis* and *Bambusa polymorpha* mixed with cowdung.

Methodology : Vermicomposting was done in 2.5 l earthen pot, each having 300 g waste materials [cowdung alone (300g) and different litter wastes mixed with cowdung in 7:3 ratio]. Based on our pilot study using cowdung and plant wastes in different ratios, it was observed that earthworm thrived well and acted better in 7:3 (plant wastes: cowdung) compared to other ratios. Each pot was inoculated with 30 adult earthworms, *Perionyx excavatus* [cumulative weight (g) 9.99±0.09] after 21 days of pre-composting of wastes. Samples from vermicomposting pots were collected on 0, 15, 30 and 45th day for physico-chemical analysis of wastes.

Results : Vermicomposting brought about changes in pH values near to neutral at the end of the experiment in all the treatments. Significant increase ($p<0.05$) in the electrical conductivity, total nitrogen (%), available phosphorus (mg 100g^{-1}), available potassium (mg 100g^{-1}) and a significant decrease ($p<0.05$) in total organic carbon (%) and C:N ratios from initial feed mixtures to final product in all the vermicomposting treatments were observed. The maximum rise in electrical conductivity, nitrogen, available phosphorus, and available potassium were recorded in the vermicompost obtained from Mikania-cowdung-mixtures.

Interpretation : Vermicompost derived from Mikania-cowdung mixtures may be considered as suitable organic resource. Addition of carbonaceous materials such as leaf litters, sawdust, straw etc. with Mikania-cowdung mixtures is recommended for vermicomposting to increase the C:N ratio of vermicompost for slow release of nutrients.



Key words: *Acacia auriculiformis*, *Bambusa polymorpha*, Leaf litters, *Mikania micrantha*, *Perionyx excavatus*, Vermicomposting

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Introduction

It has long been known that earthworms are an important biological agent in the breakdown of organic matter and the release of the nutrients that it contains (Darwin, 1881). In fact, large quantities of organic wastes are produced from agricultural production and farming system including animal manure. Tripura is rich in diverse bamboo resources having more than 20 species bamboos with mean litter production 1032 kg ha^{-1} $year^{-1}$ (Nath and Das, 2011). Although the stem parts of bamboo (poor man timber) are of high demand in bamboo industries in Tripura, the leaf litter are generally burnt by the local people causing air pollution. *Mikania micrantha* (bitter vine), one of the 100 worst invasive plant species in the world (Devi, 2017), is reported to cause serious problems in agricultural and silvicultural systems of Southeast Asia. Due to luxuriant growth, it is not only causing nuisance to agriculture in Tripura but also due to bushy growth around lamp post often forms obstacle against penetration of light at night. Recently, Debnath and Debnath (2017) documented *Mikania micrantha* as one of the most invasive plant species of Tripura. *Acacia auriculiformis* (Akashmoni) is an exotic tree species and planted widely throughout India, including Tripura under social forestry (afforestation programme). This plant species yields substantial quantities of leaf litter which are hard to degrade in the soil due to high contents of lignin. These leaf litters are also used as fuel by the local people. Thus, in general practice of burning out of these leaf litters or sweeping there into existing piles for municipal disposal lead to nutrient loss and air pollution in the local environment. Such wastes can be a good source of soil nutrients if the proper waste treatment plan is adopted

Vermicompost is the technology, where with the use of appropriate species of composting earthworms huge amount of plant biomass produced in the state would be reduced into available plant nutrient rich organic manure within a short time span. In the vermicomposting process, the complex organic substances are biooxidized and altered into stabilized products that are rich in microbial activities and plant growth regulators due to combined actions of earthworms and microorganisms.

A considerable amount of research on vermicomposting has been conducted for epigeic earthworm species such as *Eisenia fetida, Eisenia andrei, Eudrilus eugeniae, Aporrectodea longa, Lumbricus terrestris, Dendrodrilus rubidus, Dendrobaena veneta, Lumbricus rubellus* etc. (Dominguez and Edwards, 2011). Nevertheless, effective utilization of locally obtainable earthworm resource for waste degrading efficiencies is still ignored. In India, vermicomposting potentiality of dung worm, *Perionyx excavatus* was first established by Kale *et al.* (1982). Vermicomposting experiment with *Perionyx excavatus* was conducted mainly on animal dung such as cow dung, pig solids, horse solid and turkey wastes etc. (Edwards *et al.,* 1998). However, with rapid urbanization in Tripura, cowdung is now a very limited waste resource to be utilized as a sole substrate for vermicomposting. Later vermicomposting of kitchen wastes (Chaudhuri *et al.,* 2000) and aquatic weed (Chaudhuri *et al.,* 2001) were made with the activities of locally available species *Perionyx excavatus* to form useful organic manure for field application in Tripura. Based on the above facts, in the present study, native earthworm species *Perionyx excavatus* was selected for vermicomposting of terrestrial weed (*Mikania micrantha*) and other plant litter (*Acacia auriculiformis* and *Bambusa polymorpha*) mixed with cowdung to turn into organic manure useful in agriculture and horticulture.

Materials and Methods

The earthworm species, *Perionyx excavatus* (Perrier) were obtained from cowdung pits in the rural areas of West Tripura and maintained in earthen pots using partially decomposed cowdung as food substrate in the laboratory. Leaf litters of *Acacia auriculiformis* (A), *Bambusa polymorpha* (B) and green terrestrial weeds, *Mikania micrantha* (M) were collected from the premises of University campus. The leaf litters and plant biomass of *M. micrantha* were air dried. The plant substrates were crushed to get small fractions. Fresh urine free cowdung (C) was procured from the local cowshed. The cowdung was partially dried in the shed and homogenized manually.

Four vermicomposting treatments were established by using earthen pot (2.5 l capacity, diameter 25 cm and depth 15 cm) having 300 g of dry feed mixtures in each pot. One treatment contained only C (300 g) as control and rest three experimental treatments were prepared by mixing the different plant substrates (A,B and M) with C in 7:3 ratios (dry weight), *i.e.* 210 g A and 90 g C (AC) in 7:3 ratio, 210 g B and 90 g C (BC) in 7:3 ratio, 210 g M and 90 g C (MC) in 7:3 ratio. Before setting up the experiment, authors made pilot studies using different ratios of C with weed (M) and leaf litters (A and B) on dry weight basis and it was observed that weed (M) and leaf litters (A and B) vs. C when applied at 7:3 ratio, were suitable for earthworm inoculation and their subsequent activity. *P. excavatus* generally inhabits cowdung pits and it prefers cowdung as its best food of choice over other diets. Each treatment had three replicas. Among these diets mixtures, AC was unpalatable to earthworms up to 21 days. So these feed mixtures (C, AC, BC, and MC) were pre-composted for 3 weeks to make palatable to earthworms. After precomposting, each culture pot of four vermicomposting sets was inoculated with 30 adults of *P. excavatus* [cumulative weight 9.99±0.09 g (mean ± SE)]. The containers were covered tightly with jute cloth to prevent the escape of earthworms and entry of light inside. After earthworm inoculation, the vermicomposting experiment was continued up to 45 days in a well-ventilated room having maximum temperature ranging from 29°C to 31°C. Due to weight loss of earthworms, experiment was terminated on the 45^{th} day. The moisture content of the waste mixtures was maintained at 50-60% during the experiment by sprinkling of same quantities of tap water over the substrates at every 7 days interval.

Homogenized wastes samples (free from earthworms and cocoons) were taken from each treatment on the '0 day' (0 day sample refers to that, taken out immediately before inoculation of earthworm), 15^{th} day, 30^{th} and 45^{th} day of the vermicomposting period. The samples were dried and ground for physicochemical analysis of the samples. The vermicompost was harvested on the 45th day after the appearance of black granular structures on the surface of the composting medium. Moisture content of the substrates was determined by drying the samples at 105°C (Gravimetric wet weight method) in hot air oven. The pH of the samples produced during the experiment was measured in 1:2.5 suspensions of the materials and distilled water by using digital pH meter (Elico). Electrical conductivity value (EC) was determined by using distilled water suspension of each waste mixture in the ratio of 1:10 (W/V) by using digital EC meter (Elico).

Total organic carbon was measured by Walkley and Black titration method. Microkjeldhal method (Jackson, 1975) was used for measuring total nitrogen content of wastes. Chemical analysis of available phosphorus (Kuo, 1996) and available potassium (Jones, 2001) was carried out by using the standard methods. Double distilled water was used for analytical work. All the samples were analyzed in triplicate and means were recorded. One-way ANOVA followed by Tukey's multiple paired tests were used to analyze the significant differences for studied parameters during vermicomposting by using statistical software OriginPro 2016. All the results reported in the text are mean of three replicates.

Results and Discussion

The change in pH during vermicomposting depends largely upon the substrates on which earthworms act and intermediate organic acids produced by the substrates (Gupta and Garg, 2010). In C there was no significant changes in pH although pH decreased on the 45th day compared to initial day. The pH in the MC on the 45th day was significantly lower ($p<0.05$) than the worm worked wastes on the '0' day and 15th day but was at par ($p>0.05$) with that of 30th day (Table 1). This decline in pH from the initial near alkaline towards slightly neutral to acidic conditions was probably due to production of carbon dioxide and accumulation of organic acid (fulvic acid and humic acid) by the joint actions of earthworms and microbes as well as due to mucus secreted by earthworms that made the worm worked substrate more conducive ('priming-effect') to increase microbial activities (Trigo *et al.,* 1999). In BC, the pH in the 45th day vermicompost was significantly higher ($p<0.05$) than that of '0' day substate but was at par ($p>0.05$) with those worm worked wastes of the 15th day and the 30th day. The pH of AC in 45th day vermicompost was significantly higher ($p<0.05$) than the worm worked substates on '0' day, 15th day and the 30th day which among themselves were however at par ($p>0.05$) (Table 1).

Significant rise in pH on the 45th day was possibly due to the degradation of short-chained fatty acids (Tognetti *et al.,* 2005) and excess of organic nitrogen not required by microbes, released as ammonia which get dissolved in water and increases the pH of the vermicompost (Singh and Kalamdhad, 2013). According to Edwards and Bohlen (1996), the worm worked substrates are neutralized either by calciferous glands secretions or excretion of ammonia from the intestine or more likely by a combination of both the process. The increase in pH of the vermicompost compared to parent materials was recorded by earlier workers also (Chaudhuri *et al.,* 2001; Pattnaik and Reddy, 2010). EC indicates the level of salinity in the composting product. There was a significant ($p<0.05$) increase in EC in BC, AC, MC from 30th day onwards and C on 45th day of vermicomposting (Table 1). The percent increase over the initial value of EC was maximum in MC (40 %) and minimum in C (2.35%) waste during vermicomposting. The trend of increase in EC was MC > BC> AC > C (Table 1). The increase in EC was likely due to an increased level of soluble salts like ammonium and phosphate in available forms due to mineralization of feed mixtures (Yadav and Garg, 2011). Furthermore, Tognetti *et al.* (2005) advocated that release of exchangeable minerals such as calcium, magnesium, potassium through degradation of organic matter increase the EC. The increase in EC thus improves the pH of vermicompost (close to neutral value) to become more suitable for field application in the acidic soils of North-east India. Increase in EC during the period of the vermicomposting process is consistent with the findings of earlier worker (Bhat *et al.,* 2015).

Vermicomposting leads to significant reduction ($p<0.05$) in total organic carbon contents in C and AC from 15th day and BC and MC from 30th day onwards during the bioconversion process as compared to the initial value (Table 2). A maximum of 34.7 % and a minimum 8.29 % reduction in organic carbon were obtained in C and BC, respectively, following 45 days of vermicomposting (Table 2). The percent decrease in total organic carbon in different treatments after 45 days of vermicomposting was in the order C (35 %)> AC (25 %)> MC (14 %)> BC (8.3 %) (Table 2). Our results are in conformity with the earlier result observed by Chaudhuri *et al.* (2000) who also reported a loss of organic carbon during vermicomposting of kitchen wastes in the presence of *P. excavatus.* Deka *et al.* (2011) reported 29.32% decrease in total organic carbon content during recycling of Citronella wastes by using *P. excavatus.* Bhat *et al.* (2015) reported a decline in organic carbon in the vermicompost generated from bagasse wastes and cattle mixtures.

Through the muscular activity of gizzard, earthworms break and homogenize the ingested materials, thereby rising the surface area of feed materials for microbial action. Microorganisms biochemically degrade the organic carbon and provide some extracellular enzymes which are required for organic waste decomposition within the gut of the earthworms (Dominguez *et al.,* 2004). This biological mutuality results in significant loss of carbon as carbon dioxide (Elvira *et al.,* 1998) from the substrate through microbial and earthworm respiration and thus, carbon contents were found to be lower in the final product as compared to the initial values of the substrates (Orozco *et al.,* 1996). Besides these Suthar (2007) also reported that earthworm excreta and body secretions such as mucus promote microbial replication which in effect, promotes rapid respiration that minimizes the carbon level of the wastes., The nitrogen content in the vermicompost depends on the initial nitrogen in the feedstock and the degree of decomposition and on the earthworm operation in the sub-system of waste

Table 1: Day wise changes in pH and electrical conductivity in the substrates (C, BC, AC, MC) during vermicomposting process

Parameters	C	BC	AC	MC
pH				
Day 0	7.42±0.14^{a}	6.75±0.003^{a}	6.3±0.005^{a}	7.63±0.11^{a}
Day 15	7.13±0.006^{a}	6.81±0.01^{ab}	6.53±0.003^{a}	7.71±0.001^{a}
Day 30	7.28±0.006^{a}	6.95±0.02^{ab}	6.43±0.16^{a}	7.03±0.003^{ab}
Day 45	6.85±0.11^{a}	7.06±0.005^{b}	6.9±0.11^{b}	6.71±0.005^{b}
Electrical conductivity (μMho cm^{-1})				
Day 0	580.66±0.66^{a}	720±0.06^{a}	570.00±0.04^{a}	990.00±0.08^{a}
Day 15	586.66±3.33^{ab}	452±1.34^{b}	625.00±2.88^{b}	1175.00±0.01^{b}
Day 30	591.33±0.06^{ab}	820±23.09^{c}	659.33±0.66^{c}	1225.3±0.00^{b}
Day 45	594.33±0.05^{b}	870±24.01^{c}	680.66±0.55^{c}	1387.00±0.05^{c}

Dissimilar alphabets (a, b, c, d) in superscript indicate statistically significant differences ($p<0.05$); C – Cowdung; BC–Bamboo leaf: Cowdung; AC-Acacia leaf: Cowdung; MC- Mikania: Cowdung

Table 2: Day wise changes in total organic carbon and total nitrogen in the substrates (C, BC, AC, MC) during vermicomposting process

Parameters	C	BC	AC	MC
Total Organic Carbon (%)				
Day 0	17.14±0.58^{a}	19.52±0.76^{a}	19.83±0.04^{a}	20.37±0.54^{a}
Day 15	15.9±0.12^{b}	19.23±0.3^{ab}	17.87±1.12^{b}	19.05±1.23^{ab}
Day 30	14.89±0.15^{c}	17.56±0.29^{b}	15.1±0.3^{c}	18.06±0.96^{bc}
Day 45	11.2±0.16^{d}	17.9±0.95^{b}	14.92±0.41^{c}	17.49±0.14^{c}
Total Nitrogen (%)				
Day 0	1.26±0.006^{a}	1.52±0.003^{a}	1.82±0.003^{a}	3.08±0.05^{a}
Day 15	1.54±0.06^{b}	1.68±0.06a^{b}	1.82±0.01^{a}	3.11±0.03^{a}
Day 30	1.67±0.04^{c}	1.78±0.006^{b}	1.93±0.005^{ab}	3.23±0.01^{a}
Day 45	1.96±0.05^{d}	2.23±0.003^{c}	2.16±0.001^{b}	3.83±0.28^{b}

Dissimilar alphabets (a, b, c, d) in superscript indicate statistically significant differences ($p<0.05$); C – Cowdung; BC – Bamboo leaf: Cowdung; AC-Acacia leaf: Cowdung; MC- Mikania: Cowdung

decomposition. A significant ($p<0.05$) increase in total nitrogen content was observed from 15th day onwards in C, 30th day onwards in BC and on 45th in AC and MC during the vermicomposting process (Table 2). The maximum increase in total nitrogen content was noticed in C (55 %) followed by BC (47 %), MC (19 %) and AC (18.7 %) on 45th day of vermicomposting (Table 2). Many folds increase in total nitrogen contents during vermicomposting experiments by using *P. excavatus* was reported by previous investigators (Table 4).

Increased nitrogen content in the worm worked waste mixtures were likely due to the addition of nitrogenous excretory substance, mucous (mucoprotein), growth stimulating enzymes and hormones from earthworms (Macci *et al.,* 2010). In addition, the mineralization of protein containing organic matter and the transformation of ammonium nitrogen into nitrate are probably other factors for nitrogen enrichment in the vermicompost (Garg and Gupta, 2011). According to Suther and Sharma (2013), earthworms- microbes mediated nitrogen mineralization is another possible cause of nitrogen enrichment in vermicompost.

A significant ($p<0.05$) rise in available phosphorus was observed in BC, AC and MC from 15th day onwards and in the C from 30th day onwards (Table 3). Maximum increase in available phosphorus was noted in MC (137.25 mg/100g) followed by C (127.65 mg 100g^{-1}), BC (82.00 mg 100g^{-1}) and minimum was recorded in AC (60.7 mg 100 g^{-1}) (Table 3). The results of the present findings corroborate the observation of Chaudhuri *et al.* (2001), who also reported an elevated level of available phosphorus (mg 100g^{-1}) during vermicomposting of aquatic weeds, Trapa bispinosa by *P. excavatus.* Deka *et al.* (2011) recorded 63.4% increase in available phosphorus in the worm worked compost after 105 days of vermicomposting of *Citronella* and cowdung mixtures using same species of earthworm. Examining the phosphorus mineralizing capacity of *P. excavatus, Lampito mauritii, Pontoscolex corethrurus* and *Polypheretima*

Table 3: Day wise changes in Available Phosphorus and Available Potassium in the substrates (C, BC, AC, MC) during vermicomposting process

Parameters	C	BC	AC	MC
Available phosphorus (mg $100g^{-1}$)				
Day 0	147.39±5.08^{a}	48.97±0.8^{a}	26.15±0.17^{a}	163.71±2.5^{a}
Day 15	161.21±5.81^{a}	87.05±0.94^{b}	42.83±1.46^{b}	261.83±2.81^{b}
Day 30	216.61±10.08^{b}	109.65±4.56^{c}	65.48±2.9^{c}	235.47±1.2^{b}
Day 45	275.04±8.08^{c}	130.96±7.37^{D}	86.88±3.1^{d}	300.96±3.04^{c}
Available potassium (mg $100g^{-1}$)				
Day 0	1000.00±9.43^{a}	937.33±7.21^{a}	1087.00±7.21^{a}	5962.00±12.31^{a}
Day 15	1075.00±14.43^{b}	1299.33±5.66^{b}	1475.00±0.00^{b}	2525.00±11.75^{b}
Day 30	1133.33±10.08^{c}	1325.00±11.42^{c}	1512.00±7.21^{c}	8287.00±8.75^{c}
Day 45	1175.00±11.23^{d}	1420.00±12.52^{d}	1589.00±8.3^{c}	7321.33±7.2^{d}

Dissimilar alphabets (a, b, c, d) in superscript indicate statistically significant differences ($p<0.05$); C – Cowdung; BC – Bamboo leaf: Cowdung; AC-Acacia leaf: Cowdung; MC- Mikania: Cowdung

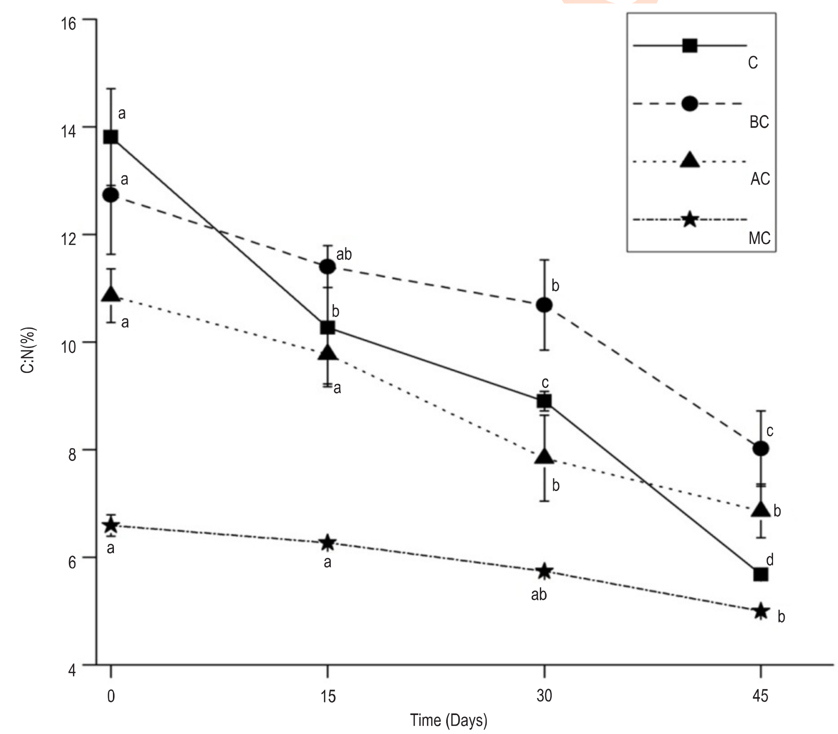

Fig. 1: Day wise variations in C: N ratios of the substrates (C, BC, AC, MC) during vermicomposting process; Dissimilar alphabets (a, b, c, d) in superscript indicate statistically significant differences ($p<0.05$); C – Cowdung; BC – Bamboo leaf: Cowdung; AC- Acacia leaf: Cowdung; MC- Mikania: Cowdung.

elongata in grasslands around Bangalore, India, Krishnamoorthy (1990) reported that *P. excavatus* had the highest capacity for increasing phosphorus availability in soil. He concluded that the rise in the level of available phosphorus content during vermicomposting is probably due to mineralization of phosphorus by the combined action of faecal phosphatases (both acid and alkaline phosphates) of earthworms and microbial activity in the casts. Ghosh *et al.* (1999) recorded higher level of phosphorus conversion from organic to inorganic state, and thus becoming accessible during vermicomposting compared to ordinary composting. According to Vinotha *et al.* (2000) microflora plays an important role in the enhancement of phosphate activity in

Table 4: Comparative studies on nutrient characteristics of worm worked different plant wastes

Plant wastes	Earthworm species involved	Nutrients contents of vermicompost						References
		pH	Organic carbon	Nitrogen	Potassium	Phosphorus	C:N	
Acacia auriculiformis (70%) + Cowdung (30%)	*P. excavatus*	I- 6.3±0.00 F- 6.9±0.11	19.83(%)±0.04 (%) 14.92±0.41 (%)	1.82±0.003 (mg 100g^{-1}) 2.16±0.001 (mg 100g^{-1})	1087±7.21 (mg 100g^{-1}) 1589±8.3 (mg 100g^{-1})	26.15±0.17 (mg 100g^{-1}) 86.88±3.1 (mg 100g^{-1})	10.86±0.5 6.86±0.5	Present study
Bambusa polymorpha (70%) + Cowdung (30%)	*P. excavatus*	I- 6.75±0.003 F- 7.06±0.005	19.52±0.76 (%) 17.9±0.95 (%)	1.52±0.003 (mg 100g^{-1}) 2.23±0.003 (mg 100g^{-1})	937.33±7.21 (mg 100g^{-1}) 1420±12.52 (mg 100g^{-1})	48.97±0.8 (mg 100g^{-1}) 130.96±7.37 (mg 100g^{-1})	12.73±1.1 8.02±0.7	Present study
Mikania micrantha (70%) + Cowdung (30%)	*P. excavatus*	I- 7.63±0.11 F- 6.71±0.005	20.37±0.54 (%) 17.49±0.14 (%)	3.08±0.05 (mg 100g^{-1}) 3.83±0.28 (mg 100g^{-1})	5962±12.31 (mg 100g^{-1}) 7321.33±7.2 (mg 100g^{-1})	163.71±2.5 (mg 100g^{-1}) 300.96±3.04 (mg 100g^{-1})	6.59±0.2 5.00±0.04	Present study
Parthenium (75%) + Cowdung (25%)	*E. fetida*	I- 7.9±0.1 F- 6.9±0.00	742.0±8 (g kg^{-1}) 292.0±12 (g kg^{-1})	7.25±0.08 (g kg^{-1}) 14.2±0.8 (g kg^{-1})	7.6±0.1 (g kg^{-1}) 8.73±0.17 (g kg^{-1})	*4.3±0.1 (g kg^{-1}) *6.2±0.1 (g kg^{-1})	65.10±0.3 20.59±0.3	Yadav and Garg, 2011
Lantana camara (80%) + Cowdung (20%)	*E. fetida*	I- 8.61±0.01 F- 6.26±0.09	702.0±1.15 (g kg^{-1}) 583.0±1.15 (g kg^{-1})	25.67±0.01 (g kg^{-1}) 28.48±0.01 (g kg^{-1})	*6.52±0.018 (g kg^{-1}) *7.8±0.001 (g kg^{-1})	*1.074±0.001 (g kg^{-1}) *5.86±0.001 (g kg^{-1})	20.47±0.004 27.34±0.05	Suther and Sharma, 2013
Pistia (80%) + Cowdung (20%)	*E. fetida*	I- 7.79±0.01 F- 7.69±0.03	459.87±7.93 (g kg^{-1}) 434.3±7.1 (g kg^{-1})	14.6±0.22 (g kg^{-1}) 24.56±1.2 (g kg^{-1})	3.61±0.7 (mg kg^{-1}) 4.45±0.09 (mg kg^{-1})	4.67±0.03 (g kg^{-1}) 6.45±0.06 (g kg^{-1})	31.5±0.23 17.57±0.62	Suther *et al.*, 2017
Eichornia crassipa + Cowdung	*E. fetida*	I- 10.0 F- 8.34	ND	1.22 (%) 8.34 (%)	0.48 (%) 0.68 (%)	0.80 (%) 0.87 (%)	15.7 18.5	Sridevi *et al.*, 2016
Trapa bispinosa	*P. excavatus*	I- 7.9 F- 7.0	ND	1.8 (%) 1.64 (%)	1105.00 (mg 100g^{-1}) 500.00 (mg 100g^{-1})	40 (mg/100g) 100.00 (mg/100g)	ND	Chaudhuri *et al.*, 2001
Pineapple wastes	*E. eugeniae*	I- 4.4±1.3 F- 7.2±0.2	40.5±1.3 (%) 20.3±3.2 (%)	0.78±0.05 (%) 0.29±0.03 (%)	1.43±0.09 (%) 0.46±0.12 (%)	0.2±0.04 (%) 0.38±0.08 (%)	21 12	Mainoo et al., 2009
Kitchen wastes	*P. excavatus*	I- 10±0.003 F- 7.59±0.15	36.8± 0.71 (%) 10.48±0.32 (%)	3.49±0.06 (%) 1.67±0.13 (%)	2.18±0.02 (%) 0.85±0.02 (%)	0.89±0.02 (%) 1.09±0.02 (%)	10.55±0.16 6.41±0.64	Chaudhuri *et al.*, 2000
Pulse straw + Wheat straw + Cowdung (1:2:2 ratio)	*P. sansibaricus*	ND	438.13 (g kg^{-1}) 335.9 (g kg^{-1})	12.96 (g kg^{-1}) 26.61 (g kg^{-1})	*8.98 (g kg^{-1}) *13.29 (g kg^{-1})	*5.91 (g/kg) *9.69 (g/kg)	33.8 13.11	Suthar, 2007
Cowdung + *mixed* liquor suspended solid + leaf (Mango+ *Eucalyptus*) (0:1:3 ratio)	*E. eugeniae*	I- 7.49 F- 7.31	26.9 (%) 22.0 (%)	0.78 (%) 1.36 (%)	0.53 (%) 1.07 (%)	0.74 (%) 1.01 (%)	34.5 16.2	Ponmani *et al.*, 2014
Citronella waste materials + Cowdung (5:1 ratio)	*P. excavatus*	I- 6.8±0.9 F- 6.21±0.9	190.6±1 (g kg^{-1}) 134.7±1.7(g kg^{-1})	4.4±0.5 (g kg^{-1}) 18.2±1.3 (g kg^{-1})	184.2±0.9 (mg kg^{-1}) 736.0±2.6 (mg kg^{-1})	*408.2±1.2 (mg kg^{-1}) *666.9±1 (mg kg^{-1})	43.3 7.4	Deka *et al.*, 2011

* - Available; ND- Not determined; I- Initial; F- Final

earthworm casts. Worm worked substrates had significantly ($p<0.05$) higher concentration of available potassium than the initial levels in all the pots (C, BC, AC, MC) from 15th day onwards and maintained significant increase level of available potassium up to 45th of vermicomposting (Table 3). In the final product of vermicomposting, the maximum increase in available potassium (mg 100g^{-1}) was recorded in MC (1359.33) followed by AC (502.00), BC (482.7) and C (175.00) (Table 3). According to Basker *et al.* (1994) elevated level of cations such as potassium in earthworm casts was due to selective feeding by earthworms on materials enriched in these cations. Rise in available potassium in earthworm processed waste materials was likely due to enhanced microbial and enzyme activities in the gut of earthworms that could have increased the mineralization rate of organic wastes (Tripathi and Bhardwaj, 2004).

In addition, acid production by the microorganisms during the vermicomposting cycle tends to be a primary mechanism for solving insoluble potassium (Suthar, 2007). The results presented are consistent with the studies of Deka *et al.* (2011), Suthar and Sharma (2013), who have demonstrated higher potassium concentration in the end product of vermicomposting. Earthworm can alter the C:N ratio of material that passes through their digestive tract although they have relatively low assimilation efficiencies for both carbon and nitrogen (Edward and Bohlen, 1996). C:N is an essential indicator of the maturation of compost during the vermicomposting process and reflects the organic mineralization and stabilization during decomposition of organic matters (Soobhany *et al.,* 2015). Variations in the C:N ratio with time in different vermibeds during the vermicomposting process are shown in (Fig. 1). C:N ratio in different worm worked substrates (C, BC, AC, MC) reduced significantly ($p<0.05$) from 30th day onwards (Fig. 1). The percentage of decline in C:N ratio was maximum in C (58 %) followed by BC (37 %), AC (36.5 %) and MC (24 %) after 45 days of earthworm activity.

This indicates that among the four different feed substrates, maturation of compost is quickest in C and much later in MC. Chaudhuri *et al.* (2000) also reported a significant reduction in C:N ratios during vermicomposting of kitchen wastes in the presence of *P. excavatus.* The decline in C:N ratios during the vermicomposting process was also reported from several other studies (Table 4). In fact increase in nitrogen and decrease in carbon content during vermicomposting leads to the decrease in C/N ratio (Yadav *et al.,* 2017). The proportion of carbon to nitrogen (C:N ratio) in organic matter added to soil is of importance because net mineralization of this organic matter does not occur unless the C:N ratio is of the order of 20:1 or lower (Edward and Bohlen, 1996). According to Ndegwa and Thompson (2000), increase in the earthworm populations during vermicomposting also lead to decline in C:N ratios. A C:N ratio below 20 is indicative of an advanced degree of stabilization and acceptable maturity while 15 or lower is being favored for use of the compost in agronomy (Morais and Queda, 2003). Likewise, vermicompost obtained in the present experiment were found to meet these requirements thereby indicating a high degree of organic matter stabilization and agronomic potential (Fig. 1). Cowdung mixed either with weed or leaf litter is a much better substrate than only cowdung as substrates for vermicomposting in order to retain more plant available nutrients and desired value of C:N ratio. Among different wastes used, MC is considered to be the most potential waste resource for vermicomposting because of its highest content of plant nutrients (N, P, K), highest EC and low C:N ratio. Addition of carbonaceous substance (straw or leaf litter or sawdust) with MC is recommended to increase its C:N ratio for slow release of nutrients in the field.

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