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Integrated system of managing and utilizing lignocellulosic wastes: composting and vermicomposting with microbial inoculants

K. V. Prashija[1]* and K. Parthasarathi[2]

[1]Ph.D. Research Scholar, Department of Zoology, Annamalai University, Annamalainagar 608002, Tamil Nadu, India. E-mail: kvprashija@gmail.com
[2]Assistant Professor, Department of Zoology, Annamalai University, Annamalainagar 608002, Tamil Nadu, India. E-mail: kpsarathi_2000@rediffmail.com

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Abstract

Integrated system of composting and vermicomposting bring the advantages of both the processes and microbial inoculation additionally improve the properties of final product. Also, this technology is time reducing and environment-friendly method and maximum biotransformation of organic matter can be achieved. In our integrated system of vermicomposting study, the lignocellulosic wastes (50:50%) – cashew leaf litter, cowdung and pressmud have been subjected to microbial inoculant [lignolytic fungi-*Pleurotus platypus* and cellulolytic fungi-*Trichoderma viridae* in alone (500 mg) or combine (250 mg)] followed by composting and vermicomposting for 60 days. The combined inoculation of microbial consortium reduces the pH, organic carbon, C:N ratio, C:P ratio, lignin, cellulose, hemicellulose and phenol and increases nitrogen, phosphorus, potassium, microbial population and activity and humic acid content in the vermicompost than alone and non-inoculated compost and vermicompost. Also better earthworms (*L.mauritii* and *P.excavatus*) activities—biomass, cocoon production, hatchling number and vermicompost recovery were found in the combine inoculated lignocellulosic wastes than alone or non-inoculated. This indicates the efficient role of lignocellulosic microbes in rapid biodegradation of lignocellulosic waste materials and produce agronomic value vermicompost and support earthworm activities.

Keywords: *Lignocellulosic waste, Integrated vermicomposting, Lignocellulosic microbes, Pleurotus platypus, Trichoderma viridae, Lampito mauritii, Perionyx excavatus.*

1. Introduction

In general, composting and vermicomposting are the natural technology of managing and utilizing degradable wastes. Composting is a dynamic procedure in which synergistic action of variety of microorganisms aids in recycling lignocellulosic waste materials by mineralization and humification process. The capacities of microorganisms to degrade complex carbohydrates such as cellulose, hemicellulose and lignin, depend on their ability to produce a battery of enzymes. Its real advantages not only by reducing the volumes of waste but also by recycling nutrients and organic matter and improving soils. Disadvantages associated with thermophilic

* *Corresponding author: K. V. Prashija, Ph.D. Research Scholar, Department of Zoology, Annamalai University, Annamalainagar 608002, Tamil Nadu, India. E-mail: kvprashija@gmail.com*

composting are the long duration process and so that loss of nutrients occurs during the process and frequent turning is needed to maintain aerobic condition (Alidadi *et al*., 2005). Vermicomposting is an earthworm-microbe symbiotic process in which organic waste accelerate organic matter stabilization and gives a product rich in chelating and phytohormonal elements which has high contents of stabilized humus substances (Tomati *et al*., 1995; Edwards and Bohlen, 1996; Ranganathan, 2006; Parthasarathi, 2010; and Patidar *et al*., 2012). The integrated system of composting and vermicomposting with microbial inoculants in recent times consider as a way of achieving stable products (Ndegwa and Thompson, 2001; Tognetti *et al*., 2007; Kumar and Shweta, 2011; Patidar *et al*., 2012 and 2014; and Xu and Li, 2017). This approach brings the advantages of both thermophilic composting and the vermicomposting process and minimize the adverse impact of waste on environment. The decomposition of organic agroindustrial wastes and lignocellulosic wastes through an integrated system of composting and vermicomposting with microbial inoculants have been studied (Dale, 2007; Kumar *et al*., 2010; and Kumar and Shweta, 2011). Table 1 also summarizes the work carried out by different workers to investigate the biodegradation of various organic agroindustrial processing wastes in the integrated system of vermicomposting with various microbial inoculants.

Table 1: Biodegradation of various organic-agroindustrial processing wastes in the integrated system of vermicomposting with microbial inoculants

S. No.	Organic-agroindustrial wastes	Supplement used	Earthworm used	Inoculation used	Time period of degradation (days)	References
1.	Cashew leaf litter	Cowdung and pressmud	*Perionyx excavatus Lampito mauritii*	*Pleurotus platypus*, *Trichoderma viridae*	60	Present study
2.	Coir wastes and sugarcane bagasse	Cowdung	*Eudrilus eugeniae E. fetida*	*T. viridae, Aspergillus niger, Bacillus polymyxa, Phanerochaete chrysosporium,*	45	Krishnan and Manivannan (2017)
3.	Obnoxious weeds (Water hyacinth, parthenium, ipomea, lantana)	Cowdung	*E. fetida*	*T. viridae*	60	Tiwari *et al.* (2017)
4.	Water hyacinth, paddy straw, sawdust	Cowdung	*E. fetida*	*T. viridae, Azotobacter chroococcum, B. polymyxa, Bacillus firmus*	84-112	Das *et al.* (2016)
5.	Sugar-cane waste by-products	Bagasse and Sugarcane trash	*Drawida willsi*	*Pleurotus sajor-caju, T. viridae, A. niger, P.striata*	70	Shweta *et al.* (2010)
6.	Corncob agro-wastes	Cowdung	*E. eugeniae*	*P. sajor-caju*	60	Sakthivigneswari and Annamalai (2016)
7.	Rice straw, distillation waste of geranium	Cowdung	*E. fetida*	*Trichoderma atroviride*	90-110	

Table 1 (Cont.)

S. No.	Organic-agroindustrial wastes	Supplement used	Earthworm used	Inoculation used	Time period of degradation (days)	References
8.	Municipal solid waste	Cowdung	*E. fetida*	*P. sajor-caju, Trichoderma harzianum, A. chroococcum*	30	Maji *et al.* (2015) Singh and Sharma (2003)
9.	Patchouli de-oiled wastes	Cowdung	*E. fetida*	*T. viridae, T. harzianum, A.chroococcum, Pseudomonas monteilii, Bacillus megaterium*	45	Singh *et al.* (2013)
10.	Paddy straw	Cowdung	*E. eugeniae P. excavatus L. mauritii*	*T. viridae*	48	Viji and Neelanarayanan (2013)
11.	Paddy straw	Cowdung	*E. eugeniae*	*T. viridae*	67	Sarangi and Lama (2013)
12.	Sunflower cake	Cattle manure	*E. fetida*	*Burkholderia spp., Burkholderia silvatlantica, Herbaspirillum seropedicae*	120	Busato *et al.* (2012)
13.	Peat manure mixture	Cattle litter manure	*E. fetida*	*T. viridae*	33	Bubina and Tereshchenko (2011)
14.	Timber wastes (Shredded wood chips)	Cowdung	*D. willsi*	*P. chrysosporium, Trichoderma reesei, A. niger, A. chroococcum, Bacillus cereus*	30	Kumar and Shweta (2011)
15.	Sugarcane waste-Bagasse and trash	Pressmud	*D. willsi*	*P. sajor-caju, T. viridae, A. niger, Pseudomonas striatum*	30	Kumar *et al.* (2010)
16.	Kitchen wastes	Cowdung	*E. fetida*	*Trichoderma sp.*	28	Nair and Okamitsu (2010)
17.	Bagasse coil	Cowdung	*E. fetida*	*T. viridae, A. niger, B. megaterium*	63-68	Pramanik (2010)
18.	Paddy straw	Cowdung	*E. fetida*	*Aspergillus awamori*	60	Shukla *et al.* (2009)
19.	Asphaltens from Prestige oil spill	Cowbed and potato peelings	*E. fetida*	*Stenotrophomonas maltophilia, Scedosporium apiospermium*	6 months	Martín-Gil *et al.* (2008)
20.	Aquatic weeds, grasses, municipal solid wastes	Cowdung	*E. fetida*	*T. viridae, B. polymyxa*	70-85	Pramanik *et al.* (2007)

Table 1 (Cont.)

S. No.	Organic-agroindustrial wastes	Supplement used	Earthworm used	Inoculation used	Time period of degradation (days)	References
21.	Wet oil cake	Cattle manure	*E. fetida*	*Pleurotus ostreatus*	6 months	Saavedra *et al.* (2006)
22.	Wood chips, sewage sludge	Cowdung	*E. fetida*	*Pseudomonas spp., Lactobacillus spp., Saccharomyces spp.*	28	Maboeta and Rensburg (2003)
23.	Wheat straw	Cowdung	*E. fetida*	*P. sajor-caju, T. harzianum, A. niger, A. chroococcum*	70	Singh and Sharma (2002)

Sources: Kumar and Shweta (2011); Patidar et al. (2012); Das et al. (2016); Tiwari et al. (2017)

Cellulose, hemicellulose and lignin are constituents of lignocellulosic materials of the leaf litter. It gives rigidity to vascular plants and protects their structural polysaccharides (cellulose and hemicellulose) from attack by other organisms (Singh and Sharma, 2003). Lignin is the most recalcitrant material present in the organic wastes and decomposes only at the later stage of decomposition. The physical barrier by lignin-cellulose encrustation can be degraded by the composting system (Maji *et al*., 2015) with the assistance of a special group of microbes called lignocellulosic microbes (Kumar and Shweta, 2011). Inoculation of suitable cellulolytic and lignolytic microbes has been reported to hasten the rate of composting, which in turn leads to the enrichment of nutrients in the vermicompost (Pramanik *et al*., 2007; Patidar *et al*., 2012; and Das *et al*., 2016). Previous our studies (Parthasarathi *et al*., 2016; and Prashija *et al*., 2017) have shown that cashew leaf litter can be used as feed substrate for epigeic (*Perionyx excavatus*) and anecic (*Lampito mauritii*) earthworms but it could not be used alone as feeding material for earthworms due to its wider C:N ratio (40:1), high levels of cellulose (459 g / Kg), lignin (193 g / Kg) and phenol (68 g / Kg). Geetha and Vijayalakshmi (1995), Parthasarathi (2010) and Patidar *et al*. (2014) state that the optimum C:N ratio for earthworm growth as 30:1. Further, rate of degradation of organic matter depends largely on its chemical composition. Usually organic matter with high N content and narrow C-N ratio undergoes faster decomposition than the one with poor N content (DattaAmlan and Suseela Devi, 2001). So, cashew leaf litter need to be mixed with N and other nutrient rich sources such as cowdung and / pressmud and lignocellulosic microbes in order to overcome the problem of lignocellulosic waste degradation. Already, we proved and established that pressmud as an alternative substrate to CD and as a better N rich substrate for earthworm rearing and vermicomposting process (Parthasarathi, 2010; Prashija and Parthasarathi, 2016; and Parthasarathi and Ranganathan, 2018). Meentemeyer (1978), Kumar *et al*. (2010) and Parthasarathi *et al*.(2016) states that many studies are available on the decomposition of leaf litter with lack of information on the lignin, cellulose, hemicellulose, phenol and humic acid content of the decomposting materials. Therefore, our objectives of the present study is to study the effect of lignolytic and cellulolytic microbial inoculants on nutrient (chemical and biological features) status of vermicomposts prepared from different combination of lignocellulosic wastes and cellulose, hemicellulose, lignin, phenolic and humic acid contents are also analyzed to evaluate the effect of the inoculating lignocellulosic microbes on the activities of both epigeic and anecic earthworms, and quality of the vermicompost.

2. Materials and methods

2.1. Collection of earthworms, experimental substrates and microbial inoculants

Earthworms, *L.mauritii* (Kinberg) and *P.excavatus* (Perrier) were obtained from the breeding stocks, department of Zoology, Annamalai University, Annamalainagar, India. Cowdung (CD) was obtained from Agricultural experimental Farm of Annamalai University, Annamalainagar and pressmud (PM) was collected from E.I.D Parry (I) sugar factory at Nellikuppam, Cuddalore district, Tamilnadu, India. Cashew leaf litter (CLL) were

collected from cashew forest, Mutlur, Cuddalore district, Tamilnadu, India. The lignocellulolytic microbial strains - *Pleurotus platypus* (lignolytic fungi) (Pp) and *Trichoderma viridae* (cellulolytic fungi) (Tv) were obtained from Aduthurai Rice Research Institute, Tanjaure district, Tamilnadu, India and stored in refrigerator.

2.2. Preparation of experimental substrates

Our previous experimental studies clearly proved that 2:2 (1:1) ratio of CD / PM+CLL highly support the growth and reproduction of earthworms, *L.mauritii* and *P.excavatus* during vermicomposting practices and recommended for the production of quality rich vermifertilizer (Parthasarathi *et al*., 2016; and Prashija and Parthasarathi, 2016) and hence these are considered as basal feed substrates. CD / PM alone and each mixed with chopped CLL (3-5 cm) (dry weight) and microbial inoculants in total of 18 vermibeds were prepared in the following manner: (i) CD(1000 g); (ii) CD 500 g + CLL 500 g with *P.excavatus*; (iii) CD 500 g + CLL 500 g + 500 mg Pp with *P.excavatus*; (iv) CD 500 g + CLL 500 g + 500 mg Tv with *P.excavatus*; (v) CD 500 g + CLL 500 g + 250 mg Pp + 250 mg Tv with *P.excavatus*; (vi) PM (1000 g); (vii) PM 500 g + CLL 500 g with *P.excavatus;* (viii) PM 500 g + CLL 500 g + 500 mg Pp with *P.excavatus*; (ix) PM 500 g + CLL 500 g + 500 mg Tv with *P.excavatus*; (x) PM 500 g + CLL 500 g + 250 mg Pp + 250 mg Tv with *P.excavatus*; (xi) CD 500 g + CLL 500g with *L.mauritii*; (xii) CD 500 g + CLL 500 g + 500 mg Pp with *L.mauritii*; (xiii) CD 500 g + CLL 500 g + 500 mg Tv with *L.mauritii*; (xiv) CD 500 g + CLL 500 g + 250 mg Pp + 250 mg Tv with *L.mauritii*; (xv) PM 500 g + CLL 500 g with *L.mauritii;* (xvi) PM 500 g+ CLL 500 g + 500 mg Pp with *L.mauritii;* (xvii) PM 500 g + CLL 500 g + 500 mg Tv with *L.mauritii;* and (xviii) PM 500 g + CLL 500 g + 250 mg Pp + 250mg Tv with *L.mauritii*. The experimental setup (vermibeds) were maintained with 62- 65% moisture, 65% relative humidity (measured by hygrometer) and at a temperature of 30±2°C. In addition, the characteristic features of the raw materials used for experiments are given in the Table 2. The organic substrates served as bedding as well as food material for earthworms. The feed mixture was transferred to separate plastic troughs (40 cm diameter x 15 cm depth) and to this above said preparations of lignocellulosic fungi were added. Experimental bedding was kept in triplicate for each vermibed with earthworms and same another triplicate for each vermibed without earthworm as control.

Table 2: Characteristic features of the raw materials used for experiments (*n* = 6)

Parameters	Lignocellulosic wastes		
	CD	PM	CLL
pH	8.03	7.85	6.13
OC (%)	27.9	39.06	42.79
N (%)	1.09	2.02	1.07
P (%)	0.50	1.99	0.37
K (%)	0.82	0.58	0.28
C:N ratio	26:1	19:1	40:1
C:P ratio	56:1	20:1	116:1
Total microbial population (CFU x 10^6 g^{-1})	264	520	88
Dehydrogenase activity (μlH / 5 g substrate)	4.35	7.76	1.32
Lignin (mg / g)	22	41	193
Cellulose (mg / g)	86	153	459
Hemicellulose (mg / g)	14	26	46
Phenol (mg / 100 g)	29	44	68
Humic acid (mg / 5 g)	6.06	21.36	0.42

Note: CD - cowdung; PM - pressmud; CLL - cashew leaf litter

2.3. Earthworm inoculation and their activity

Fifteen grams of sexually immature, preclitellate *P.excavatus* (15-18 days old) (±34-36 numbers) and *L.mauritii* (30-32 days old) (±22-25 numbers) were inoculated into each vermibeds separately, each vermibed containing 1 kg of basal feed substrate of different proportions (initial 0-day) (Parthasarathi, 2007a and b). Six replicates for each vermibed were maintained up to 60 days. The worms were not fed with additional basal feed substrates 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 and b). The vermifertilizer was collected on the 60th day by hand sorting (Parthasarathi, 2004), weighed, and used for determining various quality parameters.

2.4. Quality analysis of vermifertilizer

The nutrient contents of the substrates- initial (0-day), worm unworked normal compost and worm worked vermicompost were analyzed by using standard methods: pH (*ISI Bulletin*, 1982), Organic carbon (Walkley and Black, 1934), total Nitrogen (Jackson, 1962), phosphorus (Olsen *et al*., 1954), potassium (Stanford and English, 1949), total microbial population (Baron *et al*., 1994), dehydrogenase activity (Pepper *et al*., 1995), lignin, cellulose, hemicellulose (Ververis *et al*., 2007), phenol (Dolatto *et al*., 2012) and humic acid content (HA) (Valdrighi *et al*., 1996). 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.

2.5. 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).

3. Results

Data in the Tables 3 and 4 reveal a significant ($p < 0.05$) changes in the chemical and biological parameters of the vermicompost from all vermibeds during composting and vermicomposting with microbial inoculants. As

Table 3: Chemical composition of vermifertilizer obtained through integrated system of vermicomposting lignocellulosic wastes (n=6; $\bar{X}$)

Parameters		Vermibeds									
		100% CD	50% CD+ 50% CLL	50% CD + 50% CLL+ 500 mg Pp	50% CD + 50% CLL + 500 mg Tv	50% CD + 50% CLL +250 mg Pp + 250 mg Tv	100% PM	50% PM+ 50% CLL	50% PM + 50% CLL+ 500 mg Pp	50% PM + 50% CLL + 500 mg Tv	50% PM + 50% CLL + 250 mg Pp + 250 mg Tv
pH											
OD		8.03^{ab}	10.52^{a}	10.55^{a}	10.56^{ab}	10.58^{a}	7.85^{a}	10.41^{ab}	10.38^{abc}	10.36^{ab}	10.31^{abc}
WU		7.64^{abc}	9.68^{ab}	10.12^{bc}	10.14^{abc}	10.06^{a}	7.55^{ab}	10.22^{a}	10.18^{ab}	10.20^{b}	10.10^{bc}
WW	A	7.05^{b}	7.02^{abc}	6.91^{abc}	6.82^{ab}	6.76^{ab}	7.01^{ab}	7.06^{bc}	7.16^{a}	7.14^{bc}	6.88^{a}
	B	7.02^{a}	7.00^{bc}	6.95^{bc}	6.86^{a}	6.72^{abc}	6.99^{ab}	7.00^{a}	7.13^{a}	7.10^{abc}	6.93^{a}
Organic carbon (%)											
OD		27.9^{ab}	38.8^{ac}	38.6^{ab}	38.2^{ab}	38.0^{bc}	39.06^{abc}	46.3^{ab}	46.6^{bc}	46.0^{b}	46.4^{ab}
WU		21.2^{abc}	29.3^{bc}	33.2^{abc}	32.6^{a}	32.0^{ab}	30.11^{ab}	36.3^{ac}	35.2^{abc}	34.6^{b}	30.5^{bc}
WW	A	16.6^{b}	19.4^{a}	15.5^{bc}	15.2^{a}	14.2^{bc}	22.4^{ac}	17.5^{bc}	16.3^{a}	18.2^{b}	14.2^{a}
	B	16.0^{a}	18.2^{b}	14.6^{a}	14.2^{a}	13.0^{ab}	21.5^{ab}	16.8^{a}	15.2^{ab}	17.7^{a}	13.8^{ab}

Table 3 (Cont.)

Parameters		Vermibeds									
		100% CD	50% CD+ 50% CLL	50% CD + 50% CLL+ 500 mg Pp	50% CD + 50% CLL + 500 mg Tv	50% CD + 50% CLL +250 mg Pp + 250 mg Tv	100% PM	50% PM + 50% CLL	50% PM + 50% CLL+ 500 mg Pp	50% PM + 50% CLL + 500 mg Tv	50% PM + 50% CLL +250 mg Pp + 250 mg Tv
Nitrogen (%)											
OD		1.09^{abc}	1.58^{bc}	1.55^{ab}	1.56^{bc}	1.54^{bc}	2.02^{ac}	2.34^{a}	2.36^{a}	2.34^{ab}	2.33^{abc}
WU		1.27^{a}	1.81^{ab}	1.84^{a}	1.83^{bc}	1.86^{ab}	2.22^{ab}	2.48^{b}	2.46^{ab}	2.44^{ab}	2.66^{ab}
WW	A	1.86^{abc}	2.49^{abc}	2.57^{bc}	2.55^{bc}	3.06^{bc}	3.46^{ab}	3.48^{b}	3.54^{a}	3.56^{a}	3.72^{a}
	B	1.93^{a}	2.55^{ac}	2.60^{ac}	2.64^{abc}	3.18^{ab}	3.50^{a}	3.59^{ab}	3.66^{a}	3.70^{a}	3.77^{b}
Phosphorus (%)											
OD		0.50^{b}	0.76^{bc}	0.78^{bc}	0.79^{ab}	0.80^{ac}	1.91^{a}	1.54^{a}	1.60^{ab}	1.64^{ab}	1.70^{ab}
WU		0.78^{a}	1.16^{a}	1.26^{ac}	1.29^{bc}	1.31^{ab}	2.22^{ab}	1.78^{a}	1.83^{abc}	1.85^{abc}	1.88^{abc}
WW	A	1.06^{a}	1.42^{b}	1.64^{ab}	1.76^{ab}	1.85^{abc}	2.46^{ab}	2.91^{ab}	3.18^{ab}	3.30^{bc}	3.42^{ab}
	B	1.12^{abc}	1.56^{ab}	1.71^{a}	1.78^{a}	1.91^{ac}	2.70^{a}	2.98^{a}	3.26^{ab}	3.36^{ab}	3.48^{bc}
Potassium (%)											
OD		0.83^{ab}	0.64^{bc}	0.66^{ab}	0.68^{ab}	0.69^{bc}	0.58^{ab}	0.71^{ab}	0.73^{a}	0.72^{a}	0.75^{ab}
WU		0.91^{ab}	0.79^{a}	0.84^{ac}	0.86^{abc}	0.88^{ab}	0.66^{bc}	0.78^{a}	0.86^{a}	0.90^{a}	0.92^{a}
WW	A	1.02^{a}	1.26^{ab}	1.38^{abc}	1.43^{a}	1.52^{a}	1.44^{b}	1.82^{ab}	2.31^{abc}	2.45^{bc}	2.66^{ab}
	B	1.10^{a}	1.30^{abc}	1.41^{ab}	1.46^{ab}	1.55^{abc}	1.52^{c}	1.91^{a}	2.44^{a}	2.54^{ab}	2.74^{a}
C:N ratio											
OD		26:1^{abc}	25:1^{bc}	25:1^{ab}	24:1^{a}	25:1^{bc}	20:1^{a}	30:1^{a}	29:1^{abc}	28:1^{a}	27:1^{abc}
WU		17:1^{ab}	16:1^{abc}	18:1^{a}	18:1^{a}	17:1^{abc}	14:1^{bc}	20:1^{a}	19:1^{ab}	19:1^{ab}	16:1^{ab}
WW	A	9:1^{bc}	8:1^{ab}	6:1^{a}	6:1^{a}	5:1^{bc}	9:1^{ab}	6:1^{a}	5:1^{ab}	6:1^{abc}	4:1^{a}
	B	8:1^{ac}	7:1^{a}	6:1^{ab}	5:1^{ab}	4:1^{ab}	8:1^{ab}	6:1^{ab}	5:1^{abc}	5:1^{a}	4:1^{ab}
C:P ratio											
OD		56:1^{bc}	51:1^{bc}	49:1^{bc}	48:1^{a}	48:1^{a}	67:1^{a}	65:1^{abc}	64:1^{b}	64:1^{b}	62:1^{a}
WU		27:1^{abc}	25:1^{abc}	26:1^{b}	25:1^{bc}	24:1^{b}	46:1^{ab}	47:1^{abc}	41:1^{a}	38:1^{a}	33:1^{b}
WW	A	16:1^{ab}	14:1^{a}	11:1^{c}	9:1^{ac}	8:1^{b}	16:1^{bc}	10:1^{abc}	7:1^{ab}	7:1^{a}	5:1^{ab}
	B	14:1^{a}	12:1^{bc}	9:1^{b}	8:1^{a}	7:1^{a}	14:1^{ab}	9:1^{a}	6:1^{ab}	7:1^{ab}	5:1^{abc}

ANOVA

Parameters	pH	Organic carbon (%)	Nitrogen (%)	Phosphorus (%)	Potassium (%)	C:N ratio	C:P ratio
Substrates							
Sum of squares	9.78	261.14	43.89	15.33	3.15	35.63	720.5
Mean of squares	1.09	29.02	4.87	1.70	0.34	3.96	80.06
F-value	2.69	2.34	0.97	21.11	3.44	0.96	2.69

Table 3 (Cont.)

Parameters	**pH**	**Organic carbon (%)**	**Nitrogen (%)**	**Phosphorus (%)**	**Potassium (%)**	**C:N ratio**	**C:P ratio**
P-value	0.022	0.04	0.48	0.000	0.006	0.49	0.023
Treatments							
Sum of squares	78.87	4226.02	8.61	10.08	9.99	2781.07	15609
Mean of squares	26.29	1408.67	2.87	3.36	3.33	927.02	5203
F-value	65.13	113.63	0.57	41.64	32.79	224.13	174.62
P-value	0.000	0.000	0.64	0.000	0.000	0.000	0.000

Note: Mean value followed by different letters is statistically different (ANOVA; Duncan multiple - ranged test, $P < 0.05$), Pp – *Pleurotus platypus,* Tv – *Trichoderma viridae,* CD – Cowdung, PM – Pressmud, CLL – Cashew leaf litter, A-*Perionyx excavatus*, B-*Lampito mauritii,* OD – chemical composition of raw materials used in different vermibed (initial 0-day); WU – chemical composition of compost proceed without earthworms (normal compost); WW – chemical composition of compost proceed with *P. excavatus* and/*L. mauritii* (vermicompost).

Table 4: Biological composition of vermifertilizer obtained through integrated system of vermicomposting lignocellulosic wastes (n=6; $\bar{X}$)

Parameters		**Vermibeds**									
		100% CD	**50% CD+ 50% CLL**	**50% CD + 50% CLL+ 500 mg Pp**	**50% CD + 50% CLL + 500 mg Tv**	**50% CD + 50% CLL +250 mg Pp + 250 mg Tv**	**100% PM**	**50% PM+ 50% CLL**	**50% PM + 50% CLL+ 500 mg Pp**	**50% PM + 50% CLL + 500 mg Tv**	**50% PM+ 50% CLL +250 mg Pp + 250 mg Tv**
Total microbial population (CFUx10^{6}g^{-1})											
OD		264^{ab}	291^{ab}	296^{a}	293^{ab}	294^{a}	526^{a}	542^{ab}	556^{a}	564^{a}	578^{b}
WU		316^{a}	386^{abc}	392^{ab}	396^{ab}	412^{bc}	583^{bc}	596^{bc}	613^{a}	619^{a}	628^{bc}
WW	A	418^{abc}	468^{ab}	484^{abc}	491^{bc}	525^{ab}	679^{a}	698^{a}	706^{ab}	718^{b}	731^{a}
	B	461^{ab}	501^{ac}	495^{bc}	502^{b}	534^{ab}	693^{ab}	714^{ab}	731^{a}	742^{ab}	766^{ab}
Dehydrogenase activity*											
OD		4.35^{ab}	5.13^{abc}	5.16^{ab}	5.18^{c}	5.20^{a}	7.76^{a}	7.79^{ab}	7.81^{ab}	7.83^{a}	7.85^{a}
WU		5.10^{a}	6.02^{ab}	5.67^{bc}	5.73^{ab}	5.81^{ab}	7.81^{abc}	7.86^{bc}	7.91^{a}	7.94^{ab}	7.98^{bc}
WW	A	6.33^{bc}	7.10^{ab}	7.55^{ab}	7.67^{ab}	7.64^{a}	8.11^{bc}	8.56^{a}	8.61^{ab}	8.65^{bc}	8.72^{a}
	B	6.45^{a}	7.28^{bc}	7.65^{ab}	7.81^{bc}	7.86^{bc}	8.45^{ab}	8.83^{ab}	8.86^{b}	8.90^{a}	8.98^{ab}
Lignin (mg/g)											
OD		22.0^{a}	95.5^{abc}	95.7^{b}	95.8^{a}	96.02^{a}	41.5^{a}	135.3^{abc}	135.5^{a}	135.4^{ab}	135.7^{a}
WU		19.5^{b}	92.3^{ab}	90.11^{a}	92.26^{ab}	92.35^{ab}	36.2^{ab}	122.1^{ab}	102.6^{ab}	116.3^{a}	94.5^{a}
WW	A	10.4^{abc}	71.1^{ab}	63.17^{ab}	66.13^{a}	61.30^{a}	31.1^{bc}	81.5^{a}	74.8^{a}	78.3^{ab}	70.2^{ab}
	B	9.5^{a}	66.3^{bc}	61.10^{abc}	64.21^{b}	60.11^{ab}	30.4^{ab}	80.2^{ab}	72.5^{a}	76.6^{a}	69.2^{a}

Table 4 (Cont.)

Parameters		Vermibeds									
		100% CD	50% CD+ 50% CLL	50% CD + 50% CLL+ 500 mg Pp	50% CD + 50% CLL + 500 mg Tv	50% CD + 50% CLL +250 mg Pp + 250 mg Tv	100% PM	50% PM+ 50% CLL	50% PM + 50% CLL+ 500 mg Pp	50% PM + 50% CLL + 500 mg Tv	50% PM + 50% CLL +250 mg Pp + 250 mg Tv
Cellulose (mg/g)											
OD		86.0^{ab}	256.5^{abc}	256.7^{a}	257.3^{ab}	257.6^{abc}	153.3^{a}	416.5^{abc}	414.2^{b}	412.5^{ab}	410.6^{ab}
WU		78.0^{a}	237.6^{bc}	236.1^{ab}	221.5^{a}	216.3^{a}	142.5^{ab}	405.3^{a}	395.6^{ab}	388.3^{bc}	370.3^{c}
WW	A	64.0^{bc}	166.7^{bc}	142.3^{ab}	114.6^{ab}	103.2^{ab}	106.3^{a}	172.4^{b}	170.2^{a}	151.4^{ab}	142.4^{ab}
	B	58.2^{a}	155.2^{ab}	140.5^{b}	110.3^{abc}	98.6^{a}	98.5^{ab}	161.3^{a}	168.6^{abc}	149.2^{bc}	140.8^{a}
Hemicellulose (mg/g)											
OD		14.0^{ab}	28.2^{b}	28.5^{a}	28.1^{ab}	28.4^{ab}	26.3^{ab}	39.6^{ab}	39.5^{a}	39.7^{a}	39.6^{bc}
WU		11.8^{abc}	24.5^{b}	23.2^{ab}	21.4^{a}	20.3^{a}	23.8^{a}	34.5^{a}	33.2^{ab}	32.4^{bc}	31.6^{a}
WW	A	8.5^{ab}	13.3^{a}	11.4^{a}	10.2^{ab}	8.8^{bc}	19.4^{a}	20.3^{ab}	17.6^{abc}	14.5^{a}	11.4^{bc}
	B	7.9^{bc}	11.6^{b}	10.8^{ab}	9.4^{a}	8.2^{a}	18.5^{ab}	18.2^{bc}	17.0^{ab}	13.2^{ab}	10.3^{ab}
Phenol (mg/100 g)											
OD		29.0^{ab}	49.1^{a}	49.3^{a}	49.5^{abc}	49.5^{ab}	49.6^{b}	44.2^{ab}	66.7^{bc}	66.5^{a}	66.7^{a}
WU		24.2^{bc}	41.7^{ab}	39.5^{ab}	38.6^{bc}	38.6^{a}	38.2^{a}	41.6^{a}	54.2^{a}	53.5^{bc}	50.6^{a}
WW	A	18.5^{ac}	26.2^{abc}	25.3^{a}	25.7^{a}	25.7^{abc}	23.3^{a}	20.5^{a}	23.7^{ab}	22.4^{a}	20.3^{bc}
	B	17.2^{bc}	24.6^{abc}	24.4^{ab}	24.4^{ab}	24.2^{bc}	22.5^{ab}	19.2^{ab}	22.2^{a}	21.5^{bc}	19.5^{ab}
Humic acid (mg/5 g)											
OD		6.06^{ab}	3.68^{ab}	3.69^{a}	3.71^{a}	3.75^{a}	21.36^{a}	18.4^{ab}	18.8^{ab}	19.2^{a}	19.6^{a}
WU		7.15^{abc}	4.42^{a}	4.55^{ab}	4.58^{bc}	4.66^{b}	23.21^{ab}	23.5^{a}	20.3^{abc}	20.8^{ab}	20.10^{bc}
WW	A	8.18^{ac}	5.89^{bc}	6.02^{a}	6.06^{a}	6.12^{b}	26.18^{a}	28.6^{a}	29.5^{a}	29.8^{bc}	30.12^{a}
	B	9.12^{bc}	6.04^{ab}	6.16^{ab}	6.23^{ab}	6.50^{a}	27.23^{a}	30.2^{bc}	30.6^{ab}	31.5^{a}	32.22^{ab}

ANOVA

Parameters	pH	Total Microbial Population	Dehydrogenase Activity	Lignin	Cellulose	Hemicellulose Phenol	Humic Acid
Substrates							
Sum of squares	587377.4	40.55	30360.7	195632.1	1035.23	1112.52	3799.02
Mean of squares	65264.16	4.51	3373.41	21736.9	115.03	123.61	422.11
F-value	342.40	26.65	32.22	8.25	8.20	3.35	68.43
P-value	0.000	0.000	0.000	0.000	0.000	0.007	0.000

Table 4 (Cont.)

Parameters	pH	Total Microbial Population	Dehydrogenase Activity	Lignin	Cellulose	Hemicellulose Phenol	Humic Acid
Treatments							
Sum of squares	241594.1	20.70	11378.04	227475	2530.80	6491.35	322.27
Mean of squares	80531.37	6.90	3792.68	75824.99	843.60	2163.79	107.43
F-value	422.50	40.82	36.22	28.79	60.12	58.72	17.41
p-Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Mean value followed by different letters is statistically different (ANOVA; Duncan multiple - ranged test, $P < 0.05$), Pp – *Pleurotus platypus,* Tv – *Trichoderma viridae*, CD – Cowdung, PM – Pressmud, CLL – Cashew leaf litter, A- *Perionyx excavatus*, B – *Lampito mauritii,* OD – chemical composition of raw materials used in different vermibed (initial 0-day); WU – chemical composition of compost proceed without earthworms (normal compost); WW – chemical composition of compost proceed with *P. excavatus* and/*L. mauritii* (vermicompost); * – μl H/5 g substrate.

compared to initial substrates, worm unworked compost values, the vermicompost from 250 mg *P.platypus* and 250 mg *T.viridae* mixed inoculant vermibeds show significant ($p < 0.05$) reduction in pH, OC, C-N ratio, C-P ratio, lignin, cellulose, hemicellulose and phenol value and increment in the N, P, K, total microbial population, dehydrogenase activity and humic acid content than the *T.viridae* and *P.platypus* alone inoculant vermibeds and without microbial inoculant vermibeds. During the integrated system of vermicomposting lignocellulosic wastes in all vermibeds, the activity of both earthworms – *P.excavatus* and *L.mauritii* such as biomass, cocoon production, hatchling number and vermicompost recovery are presented in the Table 5 during the 60 days of integrated system of vermicomposting periods, no mortality of both worms are found. In overall, after 60 days, a pronounced increase in the biomass, cocoon production, hatchling number and vermicompost recovery of both worms are found in all vermibeds, especially more in the 250 mg mixed inoculation of *P.platypus* and *T.viridae* followed by *T.viridae* alone, *P.platypus* alone inoculant and than without microbial inoculant substrates. In the present observation, 250 mg *T.viridae* and 250 mg *P.platypus* mixed inoculants in the 50% CD / PM+50% CLL vermibed is found to have prolonged and sustainable earthworm activity and produce nutrient quality vermicompost.

Table 5: Activity of earthworms (*P. excavatus* and *L. mauritii*) during integrated system of vermicomposting lignocellulosic wastes (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	A	15.5^{ab}	38.7^{ab}	0	148.6^{ab}	0	224.6^{a}	0	668.4^{ab}
	B	15.2^{a}	45.2^{a}	0	36.8^{a}	0	58.7^{b}	0	680.2^{a}
50% CD + 50% CLL	A	15.4^{a}	37.5^{b}	0	141.6^{a}	0	206.7^{ab}	0	656.6^{ab}
	B	15.2^{ab}	44.0^{a}	0	42.5^{ab}	0	56.2^{a}	0	653.5^{a}
50% CD + 50% CLL	A	15.4^{a}	36.2^{a}	0	140.7^{a}	0	208.2^{a}	0	640.2^{ab}
+ 500 mg Pp	B	15.2^{ab}	42.3^{ab}	0	41.5^{ab}	0	57.5^{ab}	0	655.4^{a}
50% CD + 50% CLL	A	15.5^{a}	37.4^{a}	0	142.3^{a}	0	207.3^{a}	0	638.6^{ab}

Table 5 (Cont.)

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)
+ 500 mg Tv	B	15.4^{ab}	42.2^{ab}	0	42.6^{b}	0	57.2^{ab}	0	654.4^{a}
50% CD + 50% CLL	A	15.4^{a}	39.5^{a}	0	150.5^{b}	0	232.8^{a}	0	673.8^{a}
+250 mg Pp + 250 mg Tv	B	15.2^{ab}	46.4^{a}	0	45.3^{a}	0	60.3^{ab}	0	686.5^{ab}
100% PM	A	15.3^{a}	40.7^{ab}	0	167.2^{a}	0	234.6^{bc}	0	681.8^{a}
	B	15.6^{a}	50.6^{a}	0	46.5^{ab}	0	66.2^{a}	0	701.5^{ab}
50% PM + 50% CLL	A	15.4^{a}	38.2^{a}	0	158.5^{a}	0	218.5^{a}	0	674.0^{a}
	B	15.5^{ab}	41.5^{a}	0	42.6^{ab}	0	56.3^{ab}	0	685.1^{a}
50% PM + 50% CLL	A	15.3^{ab}	38.8^{ab}	0	159.8^{a}	0	220.3^{bc}	0	675.5^{a}
+500 mg Pp	B	15.6^{ab}	39.6^{a}	0	43.4^{a}	0	57.2^{ab}	0	687.3^{a}
50% PM + 50% CLL	A	15.4^{ab}	40.2^{a}	0	160.4^{ab}	0	221.6^{a}	0	676.2^{ab}
+ 500 mg Tv	B	15.3^{a}	47.2^{b}	0	44.2^{a}	0	58.6^{ab}	0	689.5^{a}
50% PM +50% CLL	A	15.2^{a}	43.5^{b}	0	169.7^{a}	0	238.8^{a}	0	691.3^{a}
+250 mg Pp + 250 mg Tv	B	15.1^{b}	50.6^{a}	0	51.2^{ab}	0	70.5^{b}	0	722.5^{ab}

ANOVA

Parameters	Biomass (g)	Cocoon production (number)	Hatchling number	Vermicompost recovery (g)
Substrates				
Sum of squares	7107.56	97604.52	197697.7	4551054
Mean of squares	7107.55	97604.52	197697.7	4551054
F-value	775.74	59.87	57.01	21394.67
P-value	0.000	0.000	0.000	0.000
Treatments				
Sum of squares	165.05	30972.56	65890.54	4041.66
Mean of squares	8.69	1630.13	3467.92	212.72
F-value	0.95	1	1	1
P-value	0.54	0.5	0.5	0.5

Note: Mean value followed by different letters is statistically different (ANOVA; Duncan multiple-ranged test, $P < 0.05$), Pp – *Pleurotus platypus,* Tv – *Trichoderma viridae,* CD – Cowdung, PM – Pressmud, CLL – Cashew leaf litter, A – *Perionyx excavatus*, B – *Lampito mauritii,* OD – chemical composition of raw materials used in different vermibed (initial 0-day); WU – chemical composition of compost proceed without earthworms (normal compost); WW – chemical composition of compost proceed with *P. excavatus* and/*L. mauritii* (vermicompost).

4. Discussion

Combine technology of composting and vermicomposting with microbial inoculants is time reducing and environmental-friendly method and maximum biotransformation of organic matter can be achieved (Patidar *et al*., 2012 and 2014). Biodegradation of lignocellulosic wastes through an integrated system of composting with bioinoculants and vermicomposting have been studied (Maboeta and Rensburg, 2003; Valaskora and Baldrian, 2006; Dale, 2007; Kumar *et al*., 2010; and Kumar and Shweta, 2011). Pramanik *et al*. (2007) revealed that inoculation of microorganisms significantly influenced chemical and biochemical properties of organic substances during vermicomposting. Decomposition of organic matter leads to formation of ammonium ions (NH_4^+) and humic acids (Edwards and Bohlen, 1996; Ranganathan, 2006; and Parthasarathi, 2010). These two components have exactly opposite effect on the pH. In the present study, the pH of the vermicompost from the alone or combined microbial inoculated vermibeds initially has decreased and later remained constant near towards neutrality as compared to compost and vermicompost. The decreasing pH value are due to rapid decomposition of protein and the elimination of CO_2 and the remained constant pH value are due to the acids produced by microorganisms during vermicomposting lignocellulosic wastes were utilized by them. Also, presence of carboxylic and phenolic groups in humic acids caused lowering of pH while ammonium ions increased the pH of the system. Combined effect of these two oppositely charged ions actually regulates the pH of vermicompost leading to a shift of pH towards neutrality (Pramanik *et al*., 2007; and Busato *et al*., 2012).

As compared to compost and vermicompost, in the present study, the OC content was lower in the vermicompost obtained from alone or combine microbial inoculated vermibeds. Such lowering OC content indicating higher mineralization of lignocellulosic wastes and loss of OC as CO_2 through biological mutuality during vermicomposting. Better mineralization of lignocellulosic wastes might have followed higher synthesis or polycondensation during the vermicomposting process because of addition of lignocellulosic microbes in our study. Kausar *et al*. (2010) who reported enhanced carbon mineralization by lignocellulolytic fungal consortium during the composting of rice straw. Similar results were also observed during vermicomposting of paper mill and dairy sludges (Elvira *et al*., 1998). Also, decrease of OC during vermicomposting of crop residue (Singh and Sharma, 2002), bagasse and coir wastes (Pramanik, 2010), sugarcane wastes (Kumar *et al*., 2010) and timber wastes (Kumar and Shweta, 2011) with microbial inoculants. The conversion of some part of organic functions of lignocellulosic wastes into worm biomass can also reduce the OC loss from the vermicompost.

At the end of integrated system of vermicomposting lignocellulosic wastes in the present study, the macronutrient contents (NPK) were increased in the vermicompost of alone / combine microbial inoculant than non-inoculated compost and vermicompost. This indicates a positive effect of microbial inoculants for the degradation of OC and N, which led to the accumulation of higher content of total and available NPK in the end compost product. This agrees with the findings of Pramanik *et al*.(2007), who observed an increase in the content of total NPK in the vermicompost produced using inoculation of the organic wastes with lignolytic fungi (*T.viridae* and *Phanerochaete chrysosporium*). The increase of total N might be due to the formation of new cell structure, enzymes, hormones and nitrification by the microorganisms (Zhu, 2007; and Parthasarathi, 2010). The earthworms also enhance the N contents by adding their excretory products, mucus, body fluid, enzymes and even through decaying tissues of dead worms in the vermibeds (Edwards and Bohlen, 1996; Ranganathan, 2006; and Parthasarathi, 2010). Acid production during microbial decomposition of lignocellulosic wastes is the major mechanism for solubilization of insoluble phosphorous and potassium. Also, the presence of large number of microbes in the gut of both earthworms (Parhtasarathi and Ranganathan, 1999; Parthasarathi *et al*., 2007; and Parthasarathi, 2010) might play an important role in increasing P and K content in the process of vermicomposting lignocellulosic wastes. Similar enhancement of PK contents were observed in the vermicompost produced using inoculation of *T.viridae* with peat manure (Bubina and Tereshchenko, 2011) and they concluded that the PK contents might increase due to production of acids and enzymatic activity of microorganisms in the organic substrate and earthworm digestive tract. Microbial enzyme activity also contributes to increase the mineral nutrients in the vermicasts through nitrification, phosphate solubilization and mineralization (Edwards and Bohlen, 1996; Elvira *et al*., 1998; Parthasarathi and Ranganathan, 1999; Ranganathan, 2006; Parthasarathi, 2010; and Prashija and Parthasarathi, 2016).

The C / N ratio is a reliable indicator in composting process and is used as an index of compost maturity. The changes in the C / N and C / P ratios of the substrate reflects the organic matter degradation and stabilization during integrated system of vermicomposting lignocellulosic wastes. In the present study, the fungal consortium (alone / combine) was found to reduce the C / N and C / P ratios significantly in the vermicompost compared to

the non-inoculated compost, vermicompost and initial substrates (lignocellulosic wastes). This indicates the inoculated microbial consortium mineralizes the lignocellulosic wastes of high C/N and C/P ratios and promotes the composting process. This is in accordance with the findings of Nair and Okamitsu (2010) and Sakthivigneswari and Annamalai (2016) who reported a drastic reduction in C/N and C/P ratios of vermicompost produced from kitchen wastes using *Trichoderma spp*. and corncob agro wastes using *Pleurotus sajor-caju*, respectively. A C/N ratio less than or equal to 20 is considered as satisfactory value for maturity when the initial value of composting substrates in between 25 and 30 (Goyal *et al*., 2005). For effective biodegradation by earthworm and microflora the starting C/N ratio of substrate should be in the range of 25-30 and for final product to be stabilized and matured it should be below 20 (Patidar *et al*., 2014). In our integrated system of vermicomposting lignocellulosic wastes, the C/N ratio of vermicompost (both in inoculated and non-inoculated) is (minimum 4 and maximum 9), indicating it is more sufficiently mature for field application. Finally results of the present study revealed that incorporation of lignocellulolytic consortiums- *P.platypus* and *T.viridae* could be an efficient way to achieve the rapid biodegradation of lignocellulosic waste materials and produce agronomic value added vermicompost.

Inoculation of microorganisms with earthworms accelerated decomposition process of lignocellulosic wastes and produced highest nutrient content of vermicompost. Lignocellulosic degraders have an advantage in the composting of lignocellulosic wastes because they are filamentous and they have the ability to produce prolific spores, which can invade substrates quickly (Kausar *et al*., 2010). The capacity of microorganisms to assimilate organic matter depends on their ability to produce the enzymes needed for degradation of the substrate components, i.e., cellulose, hemicellulose and lignin. The production of cellulose, hemicellulose and lignin degrading enzymes by the inoculated microbes during predecomposition might have accelerates the decomposition process (Singh and Nain, 2014; and Maji *et al*., 2015). In the present study of integrated system of vermicomposting lignocellulosic wastes, maximum reduction of cellulose, hemicellulose, lignin and phenolic contents in the vermicompost obtained from the alone or combine microbial inoculated vermibeds than compost and vermicompost from non-inoculated vermibeds. This could be due to combined activity of microflora present in the gut of both earthworms and inoculated lignocellulolytic fungi - *T.viridae* and *P.platypus* and they might have intensified cellulolysis and lignolysis. The lignocellulolytic fungi - *P.platypus* and *T.viridae* could render better composting of lignocellulosic wastes like cashew leaf litter, cowdung and pressmud and play a pivotal role in lignocellulosic degradation.

Previous our studies (Parthasarathi and Ranganathan, 1999, 2000; Parthasarathi, 2007b and 2010; Parthasarathi *et al*., 2007, 2016; and Prashija *et al*., 2017) have reported increased microbial population and microbial-enzyme activities in the vermicompost. In the present integrated system of vermicomposting lignocellulosic wastes, increased microbial population and activity are found in the vermicompost obtained from combine or alone inoculated vermibeds than compost and vermicompost of non-inoculated vermibeds. This is due to the multiplication of surviving microorganisms in the lignocellulosic wastes and inoculated microbes during passage through the guts of both earthworms are voided along with vermicompost. Similar enhanced microbial population and activity were reported in the vermicompost obtained from bagasse and coir wastes using *T.viridae*, *A.niger* and *Bacillus megaterium* (Pramanik, 2010) and sunflower cake and cattle manure using *Burkholderia silvatlantica* and *Herbaspirillum seropedicae* (Busato *et al*., 2012) inoculants, respectively. During vermicomposting, earthworms ingest microorganisms, with organic substrates but not all the microorganisms are killed during gut passage. In fact, under favorable condition of earthworm guts, spore germination was facilitated. This was probably responsible for increasing microbial population. The lignin (main substrate for HA) degrading microbes improve the content of HA and accelerate the process of composting/vermicomposting. The integrated system of vermicomposting lignocellulosic wastes in the present study, *T.viridae* and *P.platypus* alone/combine inoculant exhibits both celluloxylanolytic and lignolytic activities, they may act by degrading lignin as well as celluloxylans of the lignocellulosic wastes, thus producing highest amount of HA in the vermicompost than non-inoculated compost and vermicompost. Our findings are in close conformity with the findings of Pramanik *et al*. (2007) and Maji *et al*. (2015) who reported an enhancement of HA content in the compost/vermicompost obtained from biodegradable organic wastes and agroindustrial wastes using lignolytic fungi (*T.viridae* and *P.chrysosporium*), nitrogen fixing bacteria (*Bacillus polymyxa*) and *Trichoderma atroviride* inoculants, respectively. Higher amount of microbial population and activity in the substrates and gut of earthworms also support the enhanced formation of HA in the vermicompost (Edwards and Bohlen, 1996; Ranganathan, 2006; and Parthasarathi, 2010).

There was no mortality of both species of earthworms, in the present study, in all microbial inoculated vermibeds indicating good association with inoculated microbes. This phenomenon has also been reported by Maboeta and Rensburg (2003); Kumar *et al*. (2010); Nair and Okamitsu (2010) and Kumar and Shweta (2011). In the present study, the growth and reproduction (cocoon production and hatchling number) and vermicompost recovery of both worms increased when *T.viridae* and *P.platypus* alone or in combine inoculated lignocellulosic wastes vermibeds during vermicomposting process. The reason of high reproductive rates could be due to better microbial activity and a better substrate with microbes as protein food for the worms to reproduce (Parthasarathi, 2010). These findings agreed with the observation of Aira *et al*. (2007) who reported that microbial biomass and activity of *Azotobacter spp*. strongly affects not the size of the earthworm populations but also their growth and reproduction. Flack and Hartenstein (1984) obtained similar results in regard to *Azotobacter* on earthworms. Various studies have shown that earthworm utilize microorganisms in their substrates as a food source and can digest them selectively (Edwards and Bohlen, 1996; Parthasarathi *et al*., 1997, 1998, 2007; Ranganathan and Parthasarathi, 1999; Parthasarathi and Ranganathan, 2000; Curry and Schmidt, 2007; and Parthasarathi, 2010). In general, the number of earthworms in a system was found to be inversely proportional to C / N ratio (Ndegwa and Thompson, 2001; and Aira *et al*., 2006). The increase in growth and reproduction of *P.excavatus* and *L.mauritii* in the present study, may also be attributed to a low C / N ratio of predecomposted lignocellulosic wastes and positive role of microbial inoculants used in the present study.

Our present findings suggests a dual role of inoculated microbes as food material for earthworms and as enrichment of the substrates for more vermicompost production with nutritive value during integrated system of vermicomposting lignocellulosic wastes. Maximum vermicompost recovery was found in the combined (*T.viridae* and *P.platypus*) or alone microbial inoculated vermibed than non-inoculated composting and vermicomposting vermibeds. Similar findings were reported by Nair and Okamitsu (2010), Kumar *et al*. (2010) and Kumar and Shweta (2011) in the composting and vermicomposting of kitchen wastes, sugarcane wastes and wood wastes with microbial inoculants, respectively.

5. Conclusion

Finally our present study proved beyond doubt that cashew leaf litter can be served as feed stock for indigenous earthworms - *P. excavatus* and *L. mauritii* and converted into nutrients and microbial rich organic manure by the action of both earthworm species and inoculated lignocellulolytic microbes. Also our study paves a way for effective utilization of cashew leaf litter using indigenous earthworms and inoculated lignocellulolytic microbes and lays foundation for the further planning of large scale integrated system of vermicomposting programs with other species of earthworms and microbes.

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