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

K. V. Prashija* and K. Parthasarathi2

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

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, hatching 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...
composting are a 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 accelerates 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         | Perionyx excavatus | Pleurotus platypus, Trichoderma viridae          | 60                               | Present study                  |
| 2.    | Coir wastes and sugarcane bagasse   | Cowdung         | Eudrilus eugenia | T. viridae, Aspergillus niger, Bacillus polymyxa, F. chrysosporium | 45                               | Krishnan and Manivannan (2017) |
| 3.    | Obnoxious weeds                     | 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, B. firmus | 84-112                           | Das et al. (2016)              |
| 5.    | Sugar-cane waste by-products        | Bagasse          | D. willsi      | Pleurotus sajor-caju, T. viridae, A. niger, P. striata | 70                               | Shweta et al. (2010)           |
| 6.    | Corn cob agro-wastes               | Cowdung         | E. eugenia     | P. sajor-caju                                        | 60                               | Sakhivigneswari and Annamalai (2016) |
| 7.    | Rice straw, distillation waste of geranium | Cowdung | E. fetida | Trichoderma atrobradea                              | 90-110                           |                                |
| 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, T. viridae, T. harzianum, A. chroococcum, Pseudomonas monteillii, Bacillus megaterium | 30                               | Maji et al. (2015) Singh and Sharma (2003)                                   |
| 9.    | Patchouli de-oiled wastes                   | Cowdung         | E. fetida                         | T. viridae, T. harzianum, A.chroococcum, Pseudomonas monteillii, Bacillus megaterium | 45                               | Singh et al. (2013)                                                          |
| 10.   | Paddy straw                                | Cowdung         | E. eugeniae, P. excavatus, L. mauritii | T. viridae                                                                      | 48                               | Vijji and Neeanalarayan (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 striatium                      | 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 apiospermum                      | 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 (Lamptimaurin) 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 cow dung 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). Meinerteyer (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 microbe 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 vermicompost (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 500 g 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 + 250 mg 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.

| 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  | 264                     | 520                     | 88                       |
| Dehydrogenase activity      | 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, predilettate *P. excavatus* (15-18 days old) (±34-36 numbers) and *L. mauritii* (30-32 days old) (±22-25 numbers) were inoculated into each vermibed 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 vermi fertilizer was collected on the 60th day by hand sorting (Parthasarathi, 2004), weighed, and used for determining various quality parameters.

2.4. Quality analysis of vermi fertilizer

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 (Verversis et al., 2007), phenol (Dolatto et al., 2012) and humic acid content (HA) (Valdighi 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

| Parameters | 100% CD | 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 + 500 mg Pp | 50% PM + 50% CLL + 500 mg Tv | 50% PM + 50% CLL + 250 mg Pp + 250 mg Tv |
|------------|--------|-----------------------------|-----------------------------|--------------------------------|--------|----------------------------|-----------------------------|--------------------------------|
| pH         |        |                             |                             |                                |        |                            |                             |                                |
| OD         | 8.03bc | 10.52a                      | 10.55bc                     | 10.56bc                        | 7.85a  | 10.41ab                    | 10.38bc                     | 10.36a                         |
| WU         | 7.64abc| 9.68ab                      | 10.12bc                     | 10.14bc                        | 10.06bc| 7.55ab                     | 10.22a                      | 10.18ab                        |
| WW A       | 7.05a  | 7.024bc                     | 6.91bc                      | 6.82bc                         | 6.76ae | 7.01ab                     | 7.06bc                      | 7.16a                          |
| WW B       | 7.02a  | 7.000bc                     | 6.95bc                      | 6.86b                          | 6.72ae | 6.99ae                     | 7.00a                       | 7.13a                          |
| Organic carbon (%) |       |                             |                             |                                | 7.00a  | 7.13a                       | 7.10bc                      | 6.88e                          |
| OD         | 27.9bc | 38.8bc                      | 38.6bc                      | 38.2bc                         | 38.0bc | 39.06bc                     | 46.3bc                      | 46.6bc                         |
| WU         | 21.24bc| 29.3bc                      | 33.2bc                      | 32.6bc                         | 32.0bc | 30.11bc                     | 36.3bc                      | 35.2bc                         |
| WW A       | 16.6a  | 19.4ab                      | 15.5bc                      | 15.2bc                         | 14.2bc | 22.4bc                      | 17.5bc                      | 16.3a                          |
| WW B       | 16.0a  | 18.2bc                      | 14.6b                       | 14.2b                          | 13.0a  | 21.5bc                      | 16.8a                       | 15.2bc                         |

Table 3: Chemical composition of vermi fertilizer obtained through integrated system of vermicomposting lignocellulosic wastes (n=6; X)
Table 3 (Cont.)

| Parameters | 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 |
|------------|---------|------------------|-------------------------------|-------------------------------|-----------------------------------------------|---------|------------------|-------------------------------|-------------------------------|-----------------------------------------------|
| **Vermibeds** |         |                  |                               |                               |                                               |         |                  |                               |                               |                                               |
| **Nitrogen (%)** |         |                  |                               |                               |                                               |         |                  |                               |                               |                                               |
| OD         | 1.09abc | 1.58bc           | 1.55abc                       | 1.56abc                       | 1.54abc                                       | 2.02a   | 2.34abc          | 2.36a                         | 2.36abc                      | 2.34abc                                       |
| WU         | 1.27a   | 1.81abc          | 1.84a                         | 1.83abc                       | 1.86abc                                       | 2.22abc | 2.48a            | 2.46abc                      | 2.44abc                      | 2.66abc                                       |
| WW A       | 1.86abc | 2.49abc          | 2.57c                         | 2.55c                         | 3.06c                                         | 3.46d   | 3.48c            | 3.54a                         | 3.56a                         | 3.72a                                          |
| B          | 1.93a   | 2.55a            | 2.60a                         | 2.64abc                       | 3.18ab                                        | 3.59ab  | 3.66a            | 3.70a                         | 3.77a                         |                                               |
| **Phosphorus (%)** |         |                  |                               |                               |                                               |         |                  |                               |                               |                                               |
| OD         | 0.50b   | 0.76a            | 0.78c                         | 0.79ab                        | 0.80abc                                       | 1.91a   | 1.54a            | 1.60a                         | 1.64ab                       | 1.70ab                                       |
| WU         | 0.78a   | 1.16a            | 1.26c                         | 1.29a                         | 1.31ab                                        | 2.22abc | 1.78a            | 1.83bc                       | 1.85bc                       | 1.89abc                                       |
| WW A       | 1.06a   | 1.42a            | 1.64ab                        | 1.76ab                        | 1.85abc                                       | 2.46abc | 2.91ab           | 3.18a                         | 3.30c                         | 3.42abc                                       |
| B          | 1.12abc | 1.56bc           | 1.71a                         | 1.78a                         | 1.91a                                         | 2.70a   | 2.98a            | 3.26a                         | 3.36b                         | 3.48bc                                       |
| **Potassium (%)** |         |                  |                               |                               |                                               |         |                  |                               |                               |                                               |
| OD         | 0.83bc  | 0.64a            | 0.66ab                        | 0.68bc                        | 0.69bc                                        | 0.58a   | 0.71a            | 0.73a                         | 0.72a                         | 0.75ab                                       |
| WU         | 0.91ab  | 0.79a            | 0.84a                         | 0.86ab                        | 0.88bc                                        | 0.78a   | 0.86a            | 0.90a                         | 0.92a                         |                                               |
| WW A       | 1.02a   | 1.26c            | 1.38bc                        | 1.43a                         | 1.52a                                         | 1.44a   | 1.82ab           | 2.31abc                       | 2.45bc                       | 2.66abc                                       |
| B          | 1.10a   | 1.30abc          | 1.41ab                        | 1.46bc                        | 1.55abc                                       | 1.52a   | 1.91a            | 2.44a                         | 2.54ab                       | 2.74a                                          |
| **C:N ratio** |         |                  |                               |                               |                                               |         |                  |                               |                               |                                               |
| OD         | 26.1abc | 25.1a            | 25.1ab                        | 24.1a                         | 25.1bc                                        | 20.1a   | 30.1a            | 29.1abc                       | 28.1a                         | 27.1abc                                       |
| WU         | 17.1abc | 16.1abc          | 18.1a                         | 18.1a                         | 17.1abc                                       | 20.1a   | 19.1abc          | 19.1abc                       | 16.1abc                      |                                               |
| WW A       | 9.1bc   | 8.1a             | 6.1a                          | 6.1a                          | 5.1bc                                         | 9.1bc   | 6.1a             | 5.1bc                         | 6.1bc                         | 4.1a                                          |
| B          | 8.1bc   | 7.1a             | 6.1a                          | 5.1bc                         | 4.1b                                          | 8.1ab   | 6.1ab            | 5.1ab                         | 5.1ab                         | 4.1ac                                         |
| **C:P ratio** |         |                  |                               |                               |                                               |         |                  |                               |                               |                                               |
| OD         | 56.1bc  | 51.1bc           | 49.1bc                        | 48.1a                         | 48.1a                                         | 67.1a   | 65.1bc           | 64.1b                         | 64.1b                         | 62.1a                                          |
| WU         | 27.1abc | 25.1abc          | 26.1b                         | 25.1bc                        | 24.1b                                         | 46.1ab  | 47.1bc           | 41.1a                         | 38.1a                         | 33.1bc                                         |
| WW A       | 16.1ab  | 14.1a            | 11.1c                         | 9.1bc                         | 8.1b                                          | 16.1bc  | 10.1bc           | 7.1a                          | 7.1a                          | 5.1ab                                          |
| B          | 14.1a   | 12.1bc           | 9.1b                          | 8.1a                          | 7.1a                                          | 14.1ab  | 9.1a             | 6.1ab                         | 7.1ab                         | 5.1ac                                          |

**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 vermbed (initial 0-day); WU – chemical composition of compost proceed without earthworms (normal compost); WW – chemical composition of compost proceed with *P. excavatus* and/or *L. mauritii* (vermicompost).

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

| Parameters | 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                           | 528^a   | 542^a           | 556^a                       | 564^a                       | 578^a                           |
| WU         | 316^c   | 396^bc           | 392^b                       | 396^b                       | 412^c                           | 583^c   | 596^c           | 613^a                       | 619^a                       | 628^c                           |
| WW A       | 418^bc  | 468^ab           | 484^bc                      | 491^c                       | 525^a                           | 679^a   | 698^a           | 706^b                       | 718^c                       | 731^a                           |
| B          | 461^ab  | 501^bc           | 495^c                       | 502^b                       | 534^ab                           | 693^a   | 714^a           | 731^a                       | 742^b                       | 766^b                           |
| Dehydrogenase activity* |         |                  |                             |                             |                                 |         |
| OD         | 4.35^ab | 5.13^bc          | 5.16^bc                     | 5.18^b                      | 5.20^a                           | 7.76^a  | 7.79^b          | 7.81^a                       | 7.83^a                       | 7.85^a                           |
| WU         | 5.10^a  | 6.02^ab          | 5.67^c                      | 5.73^a                      | 5.81^b                           | 7.82^c  | 7.86^b          | 7.91^c                       | 7.94^a                       | 7.98^b                           |
| WW A       | 6.33^c  | 7.10^ab          | 7.55^b                      | 7.67^a                      | 7.64^c                           | 8.11^c  | 8.56^a          | 8.61^b                       | 8.65^b                       | 8.72^a                           |
| B          | 6.45^a  | 7.28^bc          | 7.65^a                      | 7.81^c                      | 7.86^c                           | 8.45^a  | 8.83^b          | 8.86^b                       | 8.90^a                       | 8.98^b                           |
| Lignin (mg/g) |        |                  |                             |                             |                                 |         |
| OD         | 22.0^a  | 95.5^bc          | 95.7^a                      | 95.8^a                      | 96.02^a                          | 41.5^a  | 135.3^bc        | 135.5^a                      | 135.4^bc                     | 135.7^a                          |
| WU         | 19.5^a  | 92.3^bc          | 90.1^a                      | 92.26^a                     | 92.35^a                          | 36.2^a  | 122.1^b         | 120.6^b                      | 121.6^b                     | 116.3^a                          |
| WW A       | 10.4^bc | 71.1^ab          | 63.17^a                     | 66.13^c                     | 61.30^a                          | 14.3^a  | 18.5^a          | 11.2^a                       | 17.5^a                       | 70.2^a                           |
| B          | 9.5^a   | 66.3^bc          | 61.10^bc                    | 64.21^b                     | 60.11^a                          | 30.4^a  | 80.2^a          | 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% PM + 50% CLL + 250 mg Pp + 250 mg Tv |
|            |            |                | 256.5\textsuperscript{abc} | 257.6\textsuperscript{abc} | 257.3\textsuperscript{a} |
|            |            |                | 257.6\textsuperscript{abc} | 257.6\textsuperscript{abc} | 257.3\textsuperscript{a} |
| Cellulose (mg/g) |            |                | 153.3\textsuperscript{a} | 257.6\textsuperscript{abc} | 257.3\textsuperscript{a} |
|            |            |                | 30360.7 | 405.3\textsuperscript{a} | 142.5\textsuperscript{ab} |
|            |            |                | 195632.1 | 395.6\textsuperscript{ab} | 388.3\textsuperscript{bc} |
|            |            |                | 1112.52 | 388.3\textsuperscript{bc} | 370.3\textsuperscript{c} |
|            |            |                | 3799.02 | 170.2\textsuperscript{a} | 170.2\textsuperscript{a} |
|            |            |                | 149.2\textsuperscript{bc} | 151.4\textsuperscript{ab} | 142.4\textsuperscript{ab} |
|            |            |                | 140.8\textsuperscript{a} | 140.8\textsuperscript{a} | 140.8\textsuperscript{a} |
| Hemicellulose (mg/g) |            |                | 98.5\textsuperscript{ab} | 98.5\textsuperscript{ab} | 98.5\textsuperscript{ab} |
|            |            |                | 161.3\textsuperscript{a} | 161.3\textsuperscript{a} | 161.3\textsuperscript{a} |
|            |            |                | 168.6\textsuperscript{abc} | 149.2\textsuperscript{bc} | 140.8\textsuperscript{a} |
| Phenol (mg/100 g) |            |                | 100% | 100% | 100% |
|            |            |                | 50% | 50% | 50% |
|            |            |                | PM | PM | PM |
|            |            |                | CLL | CLL | CLL |
|            |            |                | +250 mg | +250 mg | +250 mg |
|            |            |                | 6.06 | 6.06 | 6.06 |
|            |            |                | 3.71 | 3.71 | 3.71 |
|            |            |                | 3.75 | 3.75 | 3.75 |
|            |            |                | 21.36 | 21.36 | 21.36 |
|            |            |                | 18.4\textsuperscript{a} | 18.4\textsuperscript{a} | 18.4\textsuperscript{a} |
|            |            |                | 18.8\textsuperscript{a} | 18.8\textsuperscript{a} | 18.8\textsuperscript{a} |
|            |            |                | 19.2\textsuperscript{a} | 19.2\textsuperscript{a} | 19.2\textsuperscript{a} |
| Humic acid (mg/5 g) |            |                | 6.06\textsuperscript{a} | 6.06\textsuperscript{a} | 6.06\textsuperscript{a} |
|            |            |                | 3.68 | 3.68 | 3.68 |
|            |            |                | 3.69 | 3.69 | 3.69 |
|            |            |                | 3.71 | 3.71 | 3.71 |
|            |            |                | 3.75 | 3.75 | 3.75 |
|            |            |                | 21.36 | 21.36 | 21.36 |
|            |            |                | 18.4\textsuperscript{a} | 18.4\textsuperscript{a} | 18.4\textsuperscript{a} |
|            |            |                | 18.8\textsuperscript{a} | 18.8\textsuperscript{a} | 18.8\textsuperscript{a} |
|            |            |                | 19.2\textsuperscript{a} | 19.2\textsuperscript{a} | 19.2\textsuperscript{a} |
|            |            |                | 6.06\textsuperscript{a} | 6.06\textsuperscript{a} | 6.06\textsuperscript{a} |
|            |            |                | 3.68 | 3.68 | 3.68 |
|            |            |                | 3.69 | 3.69 | 3.69 |
|            |            |                | 3.71 | 3.71 | 3.71 |
|            |            |                | 3.75 | 3.75 | 3.75 |
|            |            |                | 21.36 | 21.36 | 21.36 |
|            |            |                | 18.4\textsuperscript{a} | 18.4\textsuperscript{a} | 18.4\textsuperscript{a} |
|            |            |                | 18.8\textsuperscript{a} | 18.8\textsuperscript{a} | 18.8\textsuperscript{a} |
|            |            |                | 19.2\textsuperscript{a} | 19.2\textsuperscript{a} | 19.2\textsuperscript{a} |

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 |
compared to initial substrates, worm unworked compost values, the vermicompost from 250 mg \textit{P. platypus} and 250 mg \textit{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 \textit{T. viridae} and \textit{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 – \textit{P. excavatus} and \textit{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 \textit{P. platypus} and \textit{T. viridae} followed by \textit{T. viridae} alone, \textit{P. platypus} alone inoculant and than without microbial inoculant substrates. In the present observation, 250 mg \textit{T. viridae} and 250 mg \textit{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.

| 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Note: Mean value followed by different letters is statistically different (ANOVA; Duncan multiple - ranged test, \( p < 0.05 \)), \textit{Pp} – \textit{Pleurotus platypus}, \textit{Tv} – \textit{Trichoderma viridae}, CD – Cowdung, PM – Pressmud, CLL – Cashew leaf litter, A- \textit{Perionyx excavatus}, B – \textit{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 \textit{P. excavatus} and \textit{L. mauritii} (vermicompost); * – \( \mu \) H/5 g substrate.

Table 5: Activity of earthworms (\textit{P. excavatus} and \textit{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\textsuperscript{ab} | 38.7\textsuperscript{ab} | 0 | 148.6\textsuperscript{ab} | 0 | 224.6\textsuperscript{a} | 0 | 668.4\textsuperscript{ab} |
| B | 15.2\textsuperscript{a} | 45.2\textsuperscript{a} | 0 | 36.8\textsuperscript{a} | 0 | 58.7\textsuperscript{a} | 0 | 680.2\textsuperscript{a} |
| 50% CD + 50% CLL A | 15.4\textsuperscript{a} | 37.5\textsuperscript{a} | 0 | 141.6\textsuperscript{a} | 0 | 206.7\textsuperscript{a} | 0 | 656.6\textsuperscript{a} |
| B | 15.2\textsuperscript{a} | 44.0\textsuperscript{a} | 0 | 42.5\textsuperscript{a} | 0 | 56.2\textsuperscript{a} | 0 | 653.5\textsuperscript{a} |
| 50% CD + 50% CLL A | 15.4\textsuperscript{a} | 36.2\textsuperscript{a} | 0 | 140.7\textsuperscript{a} | 0 | 208.2\textsuperscript{a} | 0 | 640.2\textsuperscript{a} |
| + 500 mg Pp B | 15.2\textsuperscript{a} | 42.3\textsuperscript{a} | 0 | 41.5\textsuperscript{a} | 0 | 57.5\textsuperscript{a} | 0 | 655.4\textsuperscript{a} |
| 50% CD + 50% CLL A | 15.5\textsuperscript{a} | 37.4\textsuperscript{a} | 0 | 142.3\textsuperscript{a} | 0 | 207.3\textsuperscript{a} | 0 | 638.6\textsuperscript{a} |
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) |
| + 500 mg Tv                                    | B           | 15.4ab                     | 42.2ab           | 0                         | 42.6a          | 0                       | 57.2ab | 0                       | 654.4a |
| 50% CD + 50% CLL                               | A           | 15.4a                      | 39.5a            | 0                         | 150.5b         | 0                       | 232.8a | 0                       | 673.8a |
| +250 mg Pp + 250 mg Tv                         | B           | 15.2ab                     | 46.4a            | 0                         | 45.3b          | 0                       | 60.3ab | 0                       | 686.5ab|
| 100% PM                                        | A           | 15.3ab                     | 40.7ab           | 0                         | 167.2b         | 0                       | 234.6bc| 0                       | 681.8b |
|                                                | B           | 15.6a                      | 50.6a            | 0                         | 46.5ab         | 0                       | 66.2a  | 0                       | 701.5ab|
| 50% PM + 50% CLL                               | A           | 15.4a                      | 38.2a            | 0                         | 158.5a         | 0                       | 218.5a | 0                       | 674.0a |
|                                                | B           | 15.5ab                     | 41.5a            | 0                         | 42.6ab         | 0                       | 56.3ab | 0                       | 685.1a |
| 50% PM + 50% CLL                               | A           | 15.3ab                     | 38.8ab           | 0                         | 159.8a         | 0                       | 220.3bc| 0                       | 675.5a |
| +500 mg Pp                                     | B           | 15.6a                      | 39.6a            | 0                         | 43.4a          | 0                       | 57.2ab | 0                       | 687.3a |
| 50% PM + 50% CLL                               | A           | 15.4ab                     | 40.2a            | 0                         | 160.4ab        | 0                       | 221.6a | 0                       | 676.2ab|
| + 500 mg Tv                                    | B           | 15.3a                      | 47.2a            | 0                         | 44.2a          | 0                       | 58.6a  | 0                       | 689.5a |
| 50% PM +50% CLL                                | A           | 15.2a                      | 43.5a            | 0                         | 169.7a         | 0                       | 238.8a | 0                       | 691.3a |
| +250 mg Pp + 250 mg Tv                         | B           | 15.1bc                     | 50.6a            | 0                         | 51.2ab         | 0                       | 70.5a  | 0                       | 722.5ab|

**ANOVA**

| Parameters                                      | Biomass (g) | Cocoon production (number) | Hatchling number | Vermicompost recovery (g) |
|------------------------------------------------|-------------|----------------------------|------------------|---------------------------|
| **Substrates**                                 |             |                            |                  |                           |
| Sum of squares                                 | 7107.56     |                            |                  |                           |
| Mean of squares                                | 7107.55     |                            |                  |                           |
| F-value                                        | 775.74      |                            |                  |                           |
| P-value                                        | 0.000       |                            |                  |                           |
| **Treatments**                                 |             |                            |                  |                           |
| Sum of squares                                 | 165.05      |                            |                  |                           |
| Mean of squares                                | 8.69        |                            |                  |                           |
| F-value                                        | 0.95        |                            |                  |                           |
| P-value                                        | 0.54        |                            |                  |                           |

**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 – *Lamprota 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/ or *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 (N\textsubscript{H}_4\textsuperscript{+}) 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\textsubscript{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\textsubscript{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. Kaur 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 or 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 (\textit{T. viridae} and \textit{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). Acd 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 (Parthasarathi 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 \textit{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, 2010).

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 Saktivigneswari 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 corn cob 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 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 celluloyxans 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 lignocelulolytic microbes and lays foundation for the further planning of large scale integrated system of vermicomposting programs with other species of earthworms and microbes.

Acknowledgment

Authors are grateful to authorities of Annamalai University for providing facilities, and DST-SERB (SB/ SO/ A S-082/ 2013), New Delhi for financial assistance to conduct this research work.

References

Aira, M., Monroy, F. and Domínguez, J. (2006). C to N ratio strongly affects population structure of Eisenia fetida in vermicomposting systems. European J. Soil Biol. 425, 127-S131. https://doi.org/10.1016/j.ejsobi.2006.07.039

Aira, M., Monroy, F. and Dominquez, J. (2007). Earthworms strongly modify microbial biomass and activity triggering enzymatic activities during vermicomposting independently of the application rates of pig slurry. Sci.Total Env. 385, 252-261.

Alidadi, H., Parvaresh, A. R., Shahnamsouri, M. R. and Pournaghodas, H. (2005). Combined compost and vermicomposting process in the treatment and bioconversion of sludge. Innnian J. Env. Health, Sci. Eng. 2(4), 251-254. http:// dx.doi.org/10.1016/j.scitotenv.2007.06.031

Baron, I. E., Peterson, R. L. and Finegold, M. S. (1994). Cultivation and Isolation of Viable Pathogen in: Diagnostic Microbiology. 9th Edition, Chapter 1, pp. 79-96. Mosby, London.

Bubina, A. B. and Tereshchenko, N. N. (2011). Effect of Trichoderma viride introduction on the technological parameters of vermicultivation and vermicompost quality. Appl. Biochem. Microbiol. 47(7), 695. https://doi.org/10.1134/S0003683811070027
Busato, J. G., Lima, L. S., Aguiar, N. O., Canellas, L. P. and Olivares, F. L. (2012). Changes in labile phosphorus forms during maturation of vermicompost enriched with phosphorus-solubilizing and diazotrophic bacteria. *Bioresour. Tech.* **110**, 390-395. https://doi.org/10.1016/j.biortech.2012.01.126

Curry, J. P. and Schmidt, O. (2007). The feeding ecology of earthworms—a review. *Pedobiologia.* **50**(6), 463-477. https://doi.org/10.1016/ j.pedobi.2006.09.001

Dale, P. (2007). Isolation of cellulolytic fungi from waste paper gradual recycling materials. *Ekologia.* **53**(4), 11-18.

Das, D., Bhattacharya, P., Ghosh, B. C. and Banik, P. (2016). Bioconversion and biodynamics of *Eisenia fetida* in different organic wastes through microbially enriched vermicomposting technologies. *Ecol. Eng.* **86**, 154-161. https://doi.org/10.1016/j.ecoleng.2015.11.012

Datta Amlan and Suseela Devi, L. (2001). Effect of organic and inorganic amendments on CO$_2$ evolution and rate of decomposition of coir dust. *J. Trop. Agric.* **39**, 184-185.

Dolatto, R. G., Messerschmidt, I., Pereira, B. F., Silveira, C. A. and Abate, G. (2012). Determination of phenol and o-cresol in soil extracts by flow injection analysis with spectrophotometric detection. *J. Brazilian Chem. Soc.* **23**(5), 970-976. http://dx.doi.org/10.1590/ S0103-50532012000500025

Edwards, C. A. and Bohlen, P. J. (1996). *Biology and Ecology of Earthworms.* 3rd ed.). Chapman and Hall, London, UK.

Elvira, C., Sampredo, L., Benitez, E. and Nogales, R. (1998). Vermicomposting of sludges from paper mill and dairy industries with *Eisenia andrei*: a pilot-scale study. *Bioresour. Tech.* **63**(3), 205-211. https://doi.org/10.1016/S0960-8524(97)00145-4

Flack, F. M. and Hartenstein, R. (1984). Growth of the earthworms, *Eisenia fetida* on microorganisms and cellulose. *Soil Biol. Biochem.* **16**(5), 491-495. http://dx.doi.org/10.1016/0038-0717(84)90057-9

Geetha, R and Vijayalakshmi, G. S. (1995). *Eisenia fetida* an ideal species for vermicompost production utilizing biogas plant slurry as its growth medium. *Nat. Symp. Org. Farming*, Madurai, 170.

Goyal, S., Dhull, S. K. and Kapoor, K. K. (2005). Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. *Bioresour. Tech.* **96**, 1584-1591. https://doi.org/10.1016/j.biortech.2004.12.012

Jackson, M. L. (1962). *Soil Chemical Analysis*. Asia Publishing House, Bombay.

Kausar, H., Sariah, M., Saud, H. M., Alam, M. Z. and Ismail, M. R. (2010). Development of compatible lignocellulolytic fungal consortium for rapid composting of rice straw. *Int. Biodet. Biodeg.* **64**(7), 594-600. https://doi.org/10.1016/j.ibiod.2010.06.012

Krishnan, J. R. and Manivannan, S. (2017). Influence of lignocellulolytic fungus and earthworms on microbial activity during bioconversion of Lignocellulosic organic biomass coir waste. *Int. J. Biol. Res.* **2**(4), 110-114.

Kumar, R. and Shweta. (2011). Enhancement of wood waste decomposition by microbial inoculation prior to vermicomposting. *Bioresour. Tech.* **102**(2), 1475-1480. https://doi.org/10.1016/j.biortech.2010.09.090

Kumar, R., Verma, D., Singh, B. L. and Kumar, U. (2010). Composting of sugar-cane waste by-products through treatment with microorganisms and subsequent vermicomposting. *Bioresour. Tech.* **101**(17), 6707-6711. https://doi.org/10.1016/j.biortech.2010.03.111

Maboeta, M. S. and Van Rensburg, L. (2003). Vermicomposting of industrially produced woodchips and sewage sludge utilizing *Eisenia fetida*. *Ecotox. Env Safety.* **56**(2), 265-270. https://doi.org/10.1016/S0147-6513(02)00101-X

Maji, D., Singh, M., Waenik, K., Chanotiya, C. S. and Kalra, A. (2015). Therole of a novel fungal strain *Trichoderma atroviride* RVF3 in improving humic acid content in mature compost and vermicompost via lignolytic and celluloxylanolytic activities. *J. Appl. Microbiol.* **119**(6), 1584-1596. https://doi.org/10.1111/jam.12954

Martín-Gil, J., Gómez-Sobrino, E., Correa-Guimaraes, A., Hernández-Navarro, S., Sánchez-Bácones, M. and del Carmen Ramos-Sánchez, M. (2008). Composting and vermicomposting experiences in the treatment
and bioconversion of asphaltens from the Prestige oil spill. *Bioresour. Tech.* 99(6), 1821-1829. https://doi.org/10.1016/j.biortech.2007.03.031

Meentemeyer, V. (1978). Macroclimate and lignin control of litter decomposition rates. *Ecology.* 59, 465-472. http://dx.doi.org/10.2307/1936576

Nair, J. and Okamitsu, K. (2010). Microbial inoculants for small scale composting of putrescible kitchen wastes. *Waste Manage.* 30(6), 977-982. https://doi.org/10.1016/j.wasman.2010.02.016

Ndewa, P. M. and Thompson, S. A. (2001). Integrating composting and vermicomposting in the treatment and bioconversion of biosolids. *Bioresour. Tech.* 76(2), 107-112. https://doi.org/10.1016/S0960-8524(00)00104-8

Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A. (1954). Estimation of available phosphorus in soil by extraction with sodium bicarbonate. USDA, Circ. No. 939.

Parthasarathi, K. and Ranganathan, L. S. (2000). Aging effect on enzyme activities in pressmud vermicasts of *Lampito mauritii* (Kinberg) and *Eudrilus eugeniae* (Kinberg). *Biol. Fertil. Soils.* 30(4), 347-350. https://doi.org/10.1007/s003740050014

Parthasarathi, K. and Ranganathan, L. S. (1999). Longevity of microbial and enzyme activity and their influence on NPK content in pressmud vermicasts. *Eur. J. Soil Biol.* 35, 107-113.

Parthasarathi, K. (2010). *Earthworms – Life cycle, Compost and Therapy.* Lap Lambert Academic Publishing AG & Co., Germany.

Parthasarathi, K., Ranganathan, L. S. and Anandi, V. (1998). Predation of bacteria by *Lampito mauritii* (Kinberg) and *Eudrilus eugeniae* (Kinberg) reared in different substrates. *Trop. Agric. Res. Extension,* 1 (2). 143-148.

Parthasarathi, K. (2007a). *Lifecycle of Lampito mauritii* (Kinberg) in comparison with *Eudrilus eugeniae* (Kinberg) cultured on different substrates. *J. Env. Biol.* 28(4), 803-812.

Parthasarathi, K. (2007b). Influence of moisture on the activity of *Perionyx excavatus* (Perrier) and microbial – nutrient dynamics of pressmud vermicompost. *Iran. J. Env. Health Sci. Eng.* 4(3), 147-156.

Parthasarathi, K. (2004). Vermicompost produced by four species of earthworms from sugar mill wastes (pressmud). *National J. Life Sci.* 1(1), 41-46.

Parthasarathi, K., Anandi, V. and Ranganathan, L. S. (1997). Fungal flora of gut and cast in *Eudrilus eugeniae* with various rearing media. *GEOBIOS-JODHPUR.* 24, 161-166.

Parthasarathi, K., Balamurugan, M., Prashija, K. V., Janyanti, L. and Basha, S. A. (2016). Potential of *Perionyx excavatus* (Perrier) in lignocellulosic solid waste management and quality vermi fertilizer production for soil health. *Int. J. Recycl. Org. Waste Agric.* 5, 65-86. https://doi.org/10.1007/s40093-016-0118-6

Parthasarathi, K., Ranganathan, L. S., Anandi, V. and Zeyer, J. (2007). Diversity of microflora in the gut and casts of tropical composting earthworms reared on different substrates. *J. Env. Biol.* 28(1), 87-97.

Parthasarathi, K. and Ranganathan, L. S. (2018). Pressmud: A rich source of organic manure. Chapter 5, pp 53-65, in *Organic Manure- Sources, Preparation and Usage in Farming Lands.* (Eds. S.M. Singh), Siya Publishing House, New Delhi.

Patidar, A., Gupta, R. and Tiwari, A. (2012). Enhancement of bio-degradation of bio-solids via microbial inoculation in integrated composting and vermicomposting technology. *Scient. Reports.* 1(5), 1-4. http://dx.doi.org/10.4172/scientificreports.273

Patidar, A., Gupta, R. and Tiwari, A. (2014). Integrated composting and vermicomposting: a boon to industry for waste clearance. *Int. J. Env. Waste Manage.* 13(3), 274-290. https://doi.org/10.1504/IJEWM.2014.059933

Pepper, I. L., Gerba, C. P. and Brendecke, J. W. (1995). Dehydrogenase activity of soils. *Environmental Microbiology: A Laboratory Manual.* Academic Press, New York.

Pramanik, P. (2010). Changes in microbial properties and nutrient dynamics in bagasse and coir during vermicomposting: quantification of fungal biomass through ergosterol estimation in vermicompost. *Waste Manage.* 30(5), 787-791. https://doi.org/10.1016/j.wasman.2009.12.007
Pramanik, P., Ghosh, G. K., Ghosal, P. K. and Banik, P. (2007). Changes in organic - C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. Bioresour. Tech. 98(13), 2485-2494. https://doi.org/10.1016/j.biortech.2006.09.017

Prashija, K. V. and Parthasarathi, K. (2016). Management of agroindustrial lignocellulosic wastes through vermitechnology and production of agronomic valid vermicompost. Int. J. Biotech. Wellness Ind. 5, 153-167.

Prashija, K. V., Basha, S. A. and Parthasarathi, K. (2017). Lampito Mauritii (Kinberg) - A potential indigenous earthworm for vermicomposting lignocellulosic waste resources. Int. J. Modern Res. Reviews. 5(10), 1639-1646.

Ranganathan, L. S. (2006). Vermibiotechnology - From Soil Health to Human Health. Agrobios, Jodhpur, India.

Saavedra, M., Benitez, E., Cifuentes, C. and Nogales, R. (2006). Enzyme activities and chemical changes in wet olive cake after treatment with Pleurotus ostreatus or Eisenia fetida. Biodegradation. 17(1), 93-102. https://doi.org/10.1007/s10532-005-4216-9

Sakthivigneswari, G. and Annamalai, V. (2016). Effect of different bio-composting techniques on physico-chemical changes in Corncob. South Indian J. Biol. Sci. 2(1), 61-65.

Shukla, L., Tyagi, S. P. and Kumar, J. (2009). Carbon nitrogen and phosphorus dynamics during vermicomposting of paddy straw inoculated with lignocellulolytic fungi. Indian J. Agric. Sci. 83(4), 420-425.

Singh, A. and Sharma, S. (2003). Effect of microbial inocula on mixed solid waste composting, vermicomposting and plant response. Compost Sci. Utilization. 11(3), 190-199. https://doi.org/10.1080/1065657X.2003.10702127

Singh, R., Singh, R., Soni, S. K., Singh, S. P., Chauhan, U. K. and Kalra, A. (2013). Vermicompost from biodegraded distillation waste improves soil properties and essential oil yield of Pogostemon cablin (patchouli) Benth. Appl. Soil Ecol. 70, 48-56. https://doi.org/10.1016/j.apsicol.2013.04.007

Singh, S. and Nain, L. (2014). Microorganisms in the conversion of agricultural wastes to compost. Proc. Indian Natn. Sci. Acad. 80(2), 473-481.

Stanford, D. and English, L. (1949). Use of flame photometer in rapid soil tests of K and Ca. Agron. J. 4, 446-447.

Tiwari, A., Singh, R., Agrawal, S. B. and Rawat. (2017). Effect of various additives on efficiency of earthworm to convert obnoxious weeds into vermicompost. Chem. Sci. Review Letters. 6(21), 458-463.

Tognetti, C., Mazzarino, M. J. and Laos, F. (2007). Improving the quality of municipal organic waste compost. Bioresour. Tech. 98(5), 1067-1076. https://doi.org/10.1016/j.biortech.2006.04.025

Valaškova, V. and Baldrian, P. (2006). Degradation of cellulose and hemicelluloses by the brown rot fungus Piptoporus betulinus—production of extracellular enzymes and characterization of the major cellulases. Microbiol. 152(12), 3613-3622. doi:10.1099/mic.0.29149-0

Valdrighi, M. M., Pera, A., Agnolucci, M., Frassineti, S., Lunardi, D. and Vallini, G. (1996). Effects of compost-derived humic acids on vegetable biomass production and microbial growth within a plant (Cichorium intybus)-soil system: a comparative study. Agric., Ecosyst.Env. 58(2), 133-144. https://doi.org/10.1016/0167-8809(96)01031-6
Ververis, C., Georghiou, K., Danielidis, D., Hatzinikolaou, D. G., Santas, P., Santas, R. and Corleti, V. (2007). Cellulose, hemicelluloses, lignin and ash content of some organic materials and their suitability for use as paper pulp supplements. *Bioresour. Tech.* 98(2), 296-301. https://doi.org/10.1016/j.biortech.2006.01.007

Viji, J. and Neelanarayanan, P. (2013). Production of vermocompost by utilizing paddy (*Oryza sativa*) straw (pre-digested with *Trichoderma viridae*) and *Eudrilus eugeniae*, *Perionyx excavatus* and *Lamptio mauriti*. *Int. J. Pharma Bio Sci.* 4(4), 986-995.

Walkley, A. and Black, I. A. (1934). An examination of the Degtjareff method for determining the organic matter and proposed modification of the chromic acid titration method. *Soil Sci.* 37(1), 29-38.

Xu, P. and Li, J. (2017). Effects of microbial inoculant on physical and chemical properties in pig manure composting. *Compost Sci. Utilization*. 25(sup1), S37-S42. https://doi.org/10.1080/1065657X.2017.1295886

Zhu, N. (2007). Effect of low initial C/ N ratio on aerobic composting of swine manure with rice straw. *Bioresour. Tech.* 98, 9-13. https://doi.org/10.1016/j.biortech.2005.12.003