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ORIGINAL RESEARCH

Vermicomposting of different organic materials using the epigeic earthworm *Eisenia foetida*

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Abstract

Purpose The present research was conducted with the objective of exploring the vermicomposting process, which involves different stages such as building of a vermicompost station; import of a compost earthworm (*Eisenia foetida*); and production of vermicompost using dry grass clippings, rice straw and cow manure. The vermicompost produced can be of significant value to the end users like farmers for replacement of chemical fertilizers and procuring better prices for the organic produce using such composting material locally available at much lower cost.

Methods Vermicomposting was done using *Eisenia foetida* with three treatments [T1 (Rice straw), T2 (Rice straw + grass) and T3 (Grass)]. Temperature, humidity and pH were measured during the process. The population of earthworms, the production of vermicompost, and the chemical and microbial characteristics of the vermicompost were recorded after sixty (60) days and hundred twenty (120) days. The data were analyzed statistically using Sigma Plot 12.0.

Results Results indicated that for all the three treatments the temperature was in the range of 0–35 °C, the humidity was between 80 and 100% and the pH fluctuated in the range of 5.5–7.0 and stabilized to near neutral on the 60th day. The combination of rice straw and grass had the highest rate of vermicompost production of 105 kg/m^2 followed by grass and rice straw with 102.5 kg/m^2 and 87 kg/m^2, respectively, at the end of 120 days.

Conclusion The harvested vermicompost had an excellent nutrient status, confirmed by the chemical analyses, and contained all the essential macro- and micronutrients.

Keywords *Eisenia foetida* · Dry grass clippings · Rice straw · Cow manure · Vermicompost

Introduction

Vermicomposting is the process of producing compost by utilizing earthworms to turn the organic waste into high-quality compost that consists mainly of worm cast in addition to decayed organic matter (Ismail 2005; Devi and Prakash 2015). Vermicomposting helps to convert the organic wastes (agro-wastes, animal manure and domestic refuse) into highly nutrient fertilizers for plant and soil (Gajalakshmi and Abassi 2004). Vermicompost is a finely divided peat-like material with excellent structure, porosity, aeration, drainage and moisture-holding capacity (Ismail 2005; Edwards et al. 2011). Vermicompost, an organic fertilizer rich in NPK, micronutrients and beneficial soil microbes (nitrogen fixing and phosphate solubilizing bacteria and actinomycetes), is a sustainable alternative to chemical fertilizers, which is an excellent growth promoter and protector for crop plants (Sinha et al. 2011; Chauhan and Singh 2015). Today vermicompost is an important component of organic farming systems, because it is easy to prepare, has excellent properties and is harmless to plants. Vermicompost improves the physical, chemical and biological properties of the soil as well contributes to organic enrichment (Ansari and Jaikishun 2011; Chauhan and Singh 2013). In 1996 the Ministry of Agriculture, Animal Husbandry and Fisheries (LVV) in Suriname made an attempt to investigate vermicomposting, but did not achieve significant results (Nanden and Dipotaroeno 1996). Since then, no research has been

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conducted in this area in Suriname. Investigations on vermicomposting and its impact on vegetable production are necessary, especially as it can be used as a bio-fertilizer. Research on vermicomposting will provide farmers with an environment-friendly fertilizer and assist in promoting the agriculture sector towards a greener future. The use of such technology will help in cost management in agriculture which is increased in the recent years and has added to the burden of farmers in terms of chemical fertilizers and chemical pesticides. Consequently, the cost of production has increased many folds. Use of organic source of fertilizers like vermicompost could be an effective solution to the problem where it could substitute the chemical inputs in crop productivity and reduce the economic cost and on the other hand may also lead to organic produce which fetches higher price in the market. The increase in living standards around the world has created a growing demand for such organic produce, or cultivation using only natural pesticides and fertilizers, which are perceived to be healthier for consumers and environment friendly (Kaplan 2016).

In Suriname, the agriculture sector depends mainly on imported agro-chemical inputs, i.e., chemical fertilizers and pesticides, with high costs (Kaplan 2016). Substituting these chemical fertilizers with the organic inputs, such as vermicompost, can provide an impulse for organic farming systems. Therefore, this research aimed at technology development and modifications for the production of quality vermicompost from locally available organic waste materials using composting earthworm.

Materials and method

General

This study, carried out at the Anton de Kom University of Suriname, Paramaribo (2015–2016), consisted of different stages, viz. building of a vermicompost station at the University compound; import of a composting epigeic earthworm, *Eisenia foetida*, from Guyana; and production of vermicompost using dry grass clippings, rice straw and cow manure.

Phase 1: field experiment

Construction of the vermicompost station

A vermicompost station of $10 \times 8 \times 3\ m^3$ (l × w × h) was built in a shaded area, following Ismail (2005). The vermicomposting units were set up at the vermicompost station using the Vermitech Pattern reported by Ismail (2005). Concrete units of $150 \times 100 \times 60\ cm^3$ were built as containers for culturing the earthworms. The concrete units had the drainage holes ($2 \times 2\ cm^2$) to facilitate the effective water drainage. The roof of the station was made of zinc sheets with underneath isolation paper to ensure a cool environment. The walls of the vermicompost station were built of wired mesh to facilitate air flow.

Preparation of culture bed

The culture bed (Fig. 1) was prepared as described by Ismail (2005):

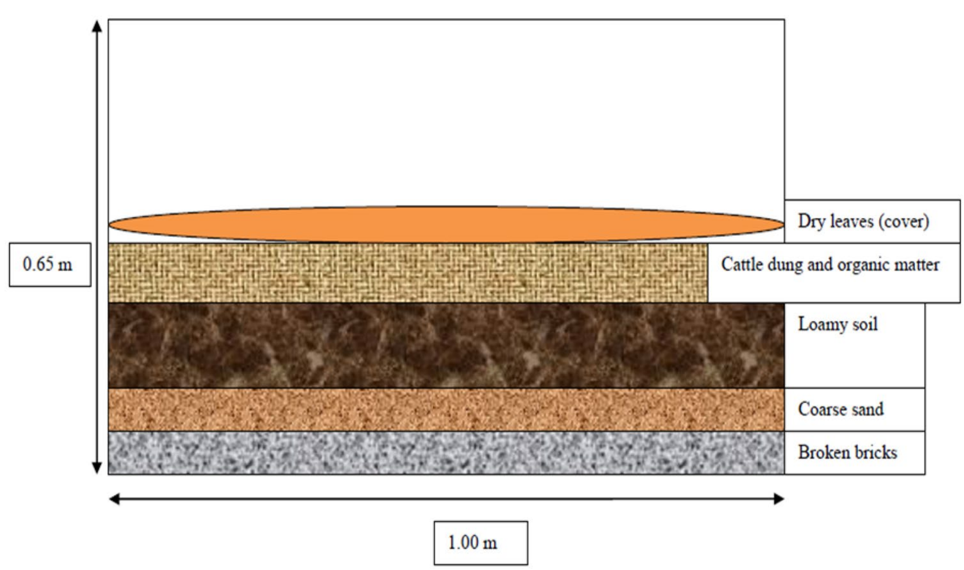

Fig. 1 Set up of culture bed in a unit

1st layer: A basal layer of vermibed comprising broken bricks, then a layer of sand to the thickness of 6–7.5 cm was set up to ensure proper drainage.

2nd layer: Loamy soil up to the height of 15 cm, which was moistened. The earthworms, *Eisenia foetida,* were inoculated into this layer.

3rd layer: Lumps of fresh/dry cattle dung were scattered over the soil.

4th layer: The soil was then covered with dry grass clippings/rice straw up to 10 cm thickness.

The entire unit was covered with banana leaves to protect the earthworms from sunlight and birds. It was kept moist by sprinkling of water twice a week and turned once a week, up to the harvest of the vermicompost.

Phase 2: import of *Eisenia foetida*

In the second phase, two hundred (200) composting earthworms, *Eisenia foetida* (epigeic species), were imported from the University of Guyana (Guyana). The earthworms were cultured for 120 days in one unit and were used for the production of vermicompost from dry grass clippings and cow manure. The dry grass clippings were collected from the University garden after the lawn was mowed and stored in bags. The cow manure was procured from dairy farm units. The organic waste consisted of 5 kg cow manure and 2 kg dry grass clippings on a weekly basis. After a hundred and twenty (120) days, the following parameters of the vermicompost were analyzed:

1. The total population of earthworms by passive method (Edwards and Bohlen 1996): physically separating the earthworms from the vermicompost;
2. The total amount of the vermicompost produced (weight in kg);
3. Chemical analyses using the methods applied in the soil laboratory of the Anton de Kom University of Suriname: pH-H_2O using a pH meter; electrical conductivity (EC in mS/cm) using a conductivity meter; total organic carbon (TOC in %) by Titrimetry using the Walkley–Black method; total nitrogen (N in %) using the Kjeldahl method; C:N ratio; total phosphorus (P in %) determined by the colorimetric method using a spectrophotometer; total potassium (K in %), total manganese (Mn in ppm), total copper (Cu in ppm), total zinc (Zn in ppm) and total iron (Fe in %) by the absorption method using the Atomic Absorption Spectrophotometer (AAS).
4. Microbial analyses: To guarantee food safety, the cow manure and vermicompost were analyzed for the presence of *Salmonella* and *E. coli* bacteria in the Veterinary Diagnostic Laboratory of the Ministry of Agriculture. The presence of *Salmonella* in various matrices was detected using the modified semi-solid Rappaport-Vassiliadis medium (MRSV) method (draft Annex D of the ISO 6579:2002 (E); the presence of *E. coli* bacteria was determined by the plate count method (NEN-EN-ISO 4833-1:2013).

Phase 3: experimental design for Vermicomposting

Field design

The vermicomposting experiment was conducted on a cemented earth surface. For the vermibed of each combination of the cow manure, dry grass clipping/rice straw wastes in 5:1 ratio, the size was $1.50 \times 1.00 \times 0.10\ m^3$. In each unit, 25 *Eisenia foetida* earthworms were inoculated. The entire unit was moistened and covered with dry banana leaves. It was moistened twice a week and turned once a week, up to the seventh week. The first application of feed consisted of 10 kg of cow manure and 2 kg of rice straw (Treatment 1), 10 kg of cow manure and 2 kg of dry grass clippings (Treatment 2), 10 kg of cow manure and combination of 1 kg of rice straw and dry grass clippings (Treatment 3). Every 2 weeks, the earthworms were fed with 5 kg of cow manure and 1 kg of dry rice straw (Treatment 1), 5 kg of cow manure and 1 kg of rice straw (Treatment 2) and 5 kg of cow manure and combination of 5 kg of cow manure and combination of 1 kg rice straw and 1 kg dry grass clippings (Treatment 3). Three treatments were maintained with four replications each (Fig. 2):

- Treatment 1: cow manure + rice straw
- Treatment 2: cow manure + dry grass clipping
- Treatment 3: cow manure + combination of rice straw and dry grass clipping (1:1 ratio)

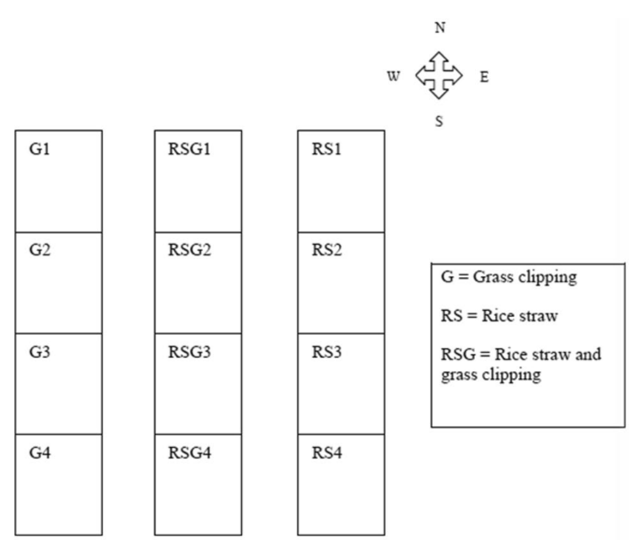

Fig. 2 Schematic overview of the experimental design for vermicomposting

On a weekly basis, during the process of vermicomposting the temperature, humidity and pH were determined in each vermicompost unit. The temperature was measured with a field compost thermometer (REOTEMP FG20P Backyard Compost Thermometer Fahrenheit with Basic Composting). The humidity was measured with a compost moisture meter (NRG MS810 Soil Moisture Sensor Indoor/Outdoor). The humidity ranges were as follows: 10–40% (dry); 40–80% (moist); 80–100% (wet). The pH was measured with a soil pH meter (Kelway Soil Acidity/Moisture Meter). After 60 and 120 days, the total earthworm population and the total production of vermicompost were determined and chemical analyses of the vermicompost were conducted. The total population of earthworms was estimated using a hand-sorting method according to Zicsi (1962). This was done using sample sizes of 20 × 20 cm for estimating the total population per square meter (Fig. 3) in 4 samples taken from each treatment. The earthworm population consisted of three age groups viz. juvenile, non-clitellate and clitellate earthworms (Fig. 4). The total amount of the vermicompost produced was collected in plastic waste bags and weighed in kilograms. Productivity of vermicompost was calculated in percentage using the formula:

$$\text{Productivity of vermicompost (\%)} = \frac{\text{Harvested vermicompost (kg)}}{\text{Total mass of feed(kg)}} \times 100\%.$$

The chemical analysis of vermicompost and the feeding materials (dry grass clippings, rice straw and cow manure) was done to determine the levels of pH-H_2O, EC, C, N, C/N ratio, P, K, Mn, Cu, Zn and Fe, using the methods already described.

For the statistical analyses of the data, the Sigma Plot 12.0 software was used. The data were processed using an Analysis of Variance of Simple Classification and differences between means (one-way ANOVA). Treatments which were significant different were analyzed with the Tukey's hoc test. Significance was set at the 0.05 level.

Fig. 3 Hand sorting method

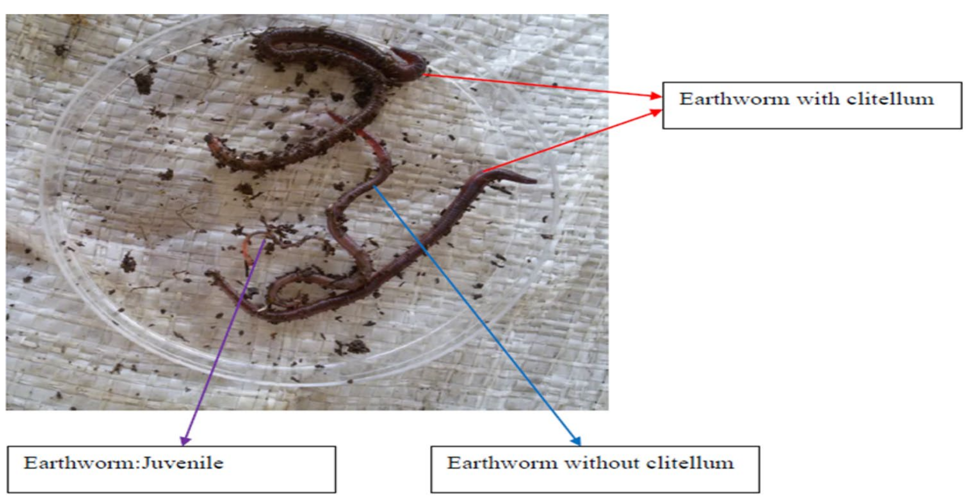

Fig. 4 Earthworms of different age groups

Results and discussion

Analyses of vermicompost (after 60 and 120 days of composting period)

The temperature in the vermicompost unit was measured weekly and recorded was 27 °C (average), i.e., within the range of 0–35 °C as per the classification given by Domínguez and Edwards (2011). The results for humidity indicated that the unit was moist to wet (85%), which was in the range of 80–90% for rapid growth. The pH recorded between 6.50 and 7.50 was in the range of 5–9 for vermicomposting (Domínguez and Edwards 2011).

The total amount of vermicompost produced was 65 kg and the estimated total population of earthworms by the passive method was 300 (adult and juvenile). According to Fadaee (2012), the number of initial worms used in vermicompost was 5000 and after 90 days this number increased to 13,000. Sinha et al. (2010) and Edwards et al. (2011) described that 0.50 kg (1 lb) of earthworms can process about 0.50 kg (1 lb) of organic material (at 75–85% moisture) and produce approximately 0.25 kg of vermicompost per day (40–50% conversion rate). A satisfactory population of earthworms, as defined by Edwards and Arancon (2004), is at least 9–18 kg of earthworms per m^2 (2–4 lb ft^{-2}).

The chemical analysis was conducted in one mixed sample of dry grass clippings, one mixed cow manure sample, and one mixed vermicompost sample. The results obtained are shown in Table 1.

The pH was slightly acidic in the vermicompost, followed by the raw material and the cow manure, i.e., 6.50, 6.50 and 6.20, respectively. The soluble salt concentrations (measured as electric conductivity) in the resulting vermicompost, raw material and cow manure were 3.71 mS/cm, 3.00 mS/cm and 5.72 mS/cm, respectively, indicating a slight decrease in salinity in the vermicompost compared to the cow manure. The total organic carbon was 18.53%, 42.96% and 21.02% in the vermicompost, raw material and cow manure, respectively. The total nitrogen was 1.36% in the vermicompost and 1.88% in the raw material. The C/N ratio in the vermicompost, and cow manure was the same (13:1) but quite high (23:1) in the raw material. Total phosphorus was 0.58%, 0.26% and 0.78% in the vermicompost, raw material and cow manure, respectively. The total potassium was 0.56% in the vermicompost, 1.23% in raw material and 0.86% in cow manure, indicating a decrease in the vermicompost, compared to the cow manure and raw material. The total zinc, manganese, copper and iron concentrations are higher in the vermicompost than in the raw material, indicating an accumulation of these micro-elements in the vermicompost, but lower than in cow manure. Vermicompost contains essential micronutrients and the nutrient status is in line with that reported by earlier researchers (Ismail 1997; Ansari and Sukhraj 2010; Ansari et al. 2016).

Table 2 indicates that *Salmonella* was absent in 25 g of cow manure and vermicompost and the number of *E. coli* was less than 10 CFU per gram of cow manure and vermicompost, showing that the vermicompost was hygienic according to Domínguez and Edwards (2011).

The temperature observed during the process of vermicomposting in the twelve vermicomposting units during the first 8 weeks was recorded to be 27.45 °C in T1 (rice straw) followed by 27.08 °C in T3 (rice straw + grass) and 27.31 °C in T2 (Grass) as shown in Fig. 5. The fluctuation of the temperature in °C was restricted to ± 0.25 (T1), ± 0.31 (T2) and ± 0.23 (T3). During the second 8 weeks, the temperature was recorded to be 27.65 °C in T1 (rice straw) followed by 27.62 °C in T3 (rice straw + grass) and 27.59 °C in T2 (grass) as shown in Fig. 6. The fluctuation of the temperature in the second period was restricted to ± 0.51 (T1), ± 0.38 (T2) and ± 0.25 (T3) in °C. In both periods, the temperature was in the range of 0–35 °C, according to Domínguez and Edwards (2011).

The humidity recorded in the twelve vermicomposting units during the first 8 weeks was 91.30% in T1 (Rice straw), followed by 95.40% in T3 (rice straw + grass) and 98.60% in T2 (Grass) as displayed in Fig. 6. During the second 8 weeks, the humidity was 92.50% in T1 (rice straw), followed by 92.80% in T3 (rice straw + grass) and 95.80% in T2 (grass). In both these periods, the humidity was 80–100%, which indicated a wet environment, slightly above the range (80–90%) given by Domínguez and Edwards (2011) for a rapid growth of *Eisenia foetida* during the process of vermicomposting.

The pH for all three treatments fluctuated from 5.5 to 7.0 (Fig. 7) until it was almost neutral on the 60th/120th day, when the compost was ready to harvest. This was in line with the findings of Domínguez and Edwards (2011), who reported a pH range of 5–9 during the process, the values reaching near neutrality, when the vermicompost was ready for the harvest. This may occur due to the production of CO_2 and the organic acids produced during the microbial metabolism. Several researchers have reported that most species of earthworms prefer a pH of about 7.0 (Singh 1997; Narayan 2000; Pagaria and Totwat 2007; Suthar 2008; Panday and Yadav 2009).

The number of earthworms of the three age groups, juvenile, non-clitellate and clitellate, were counted using the hand count method (Zicsi 1962) in 4 samples of 20 cm × 20 cm for estimating the total population per square meter, as displayed in Table 3. At the 60th day, the total number of earthworms per square meter was estimated to be 875, 1150 and 1025 in T1, T2 and T3, respectively, thus

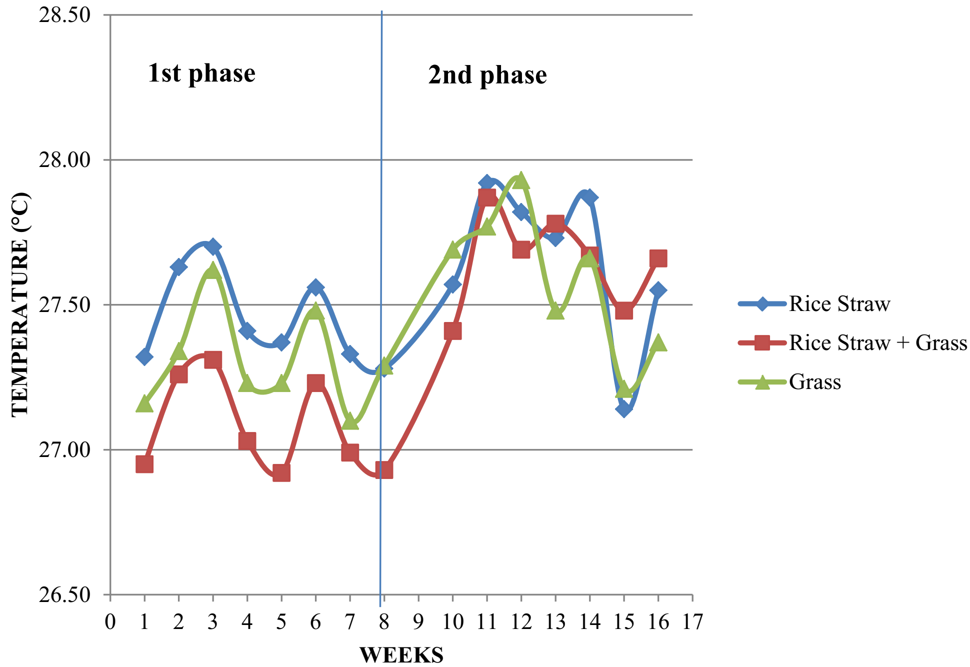

Fig. 5 Temperature (°C) changes during the first and second 8 weeks of vermicomposting

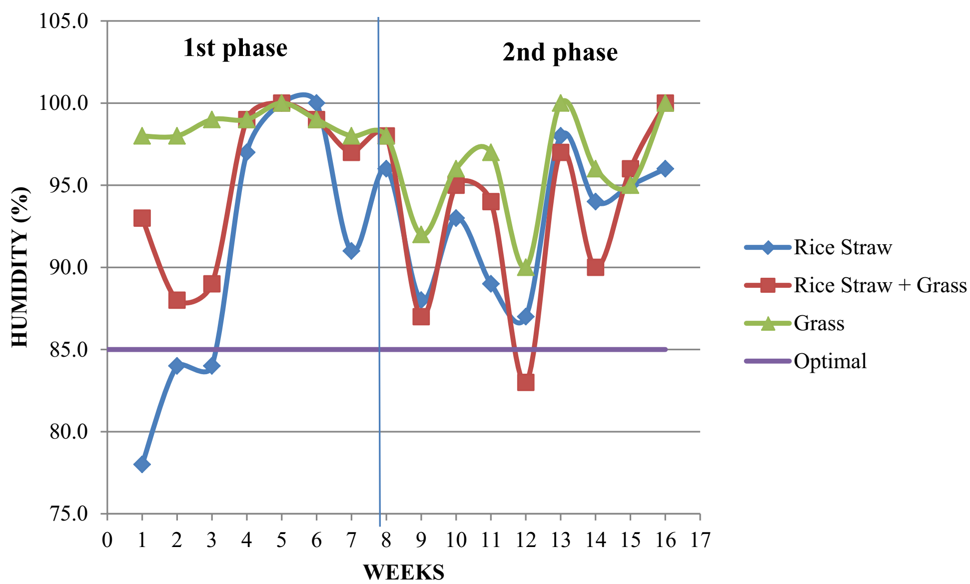

Fig. 6 Humidity changes during the first and second 8 weeks of vermicomposting

showing no significant difference between the treatments when analyzed by the Tukey's multiple range test ($P \leq 0.05$). At 120 days, the total number of earthworms per square meter was 900, 800 and 1050 in T1, T2 and T3, respectively, showing no significant difference between the treatments. A satisfactory population of earthworms has been defined by Edwards and Arancon (2004) as having at least 9–18 kg of earthworms per m^2. On an average, 2000 adult worms weigh 1 kg and one million approximately 1 ton, according to Sinha et al. (2010).

The total amount of feed given to the earthworms in the first 60 days was 168 kg. The produced vermicompost was collected per unit and determined in kilograms. At the first harvest, the average weight per unit for the treatments T1, T2 and T3 was 10.90 kg, 9.80 kg and 13.80 kg, respectively. The total amount of feed given to the earthworms in the second 60 days was 96 kg. At the second harvest, the average weight per unit for the treatments T1, T2 and T3 was 10.90 kg, 15.90 kg and 12.50 kg, respectively. There was no significant difference among the treatments, as determined by the Tukey's test ($P \leq 0.05$).

The combination of rice straw and grass (T3) had the highest productivity of 32.70%, followed by rice straw (T1) with 25.90% and grass (T2) with 23.20% productivity for

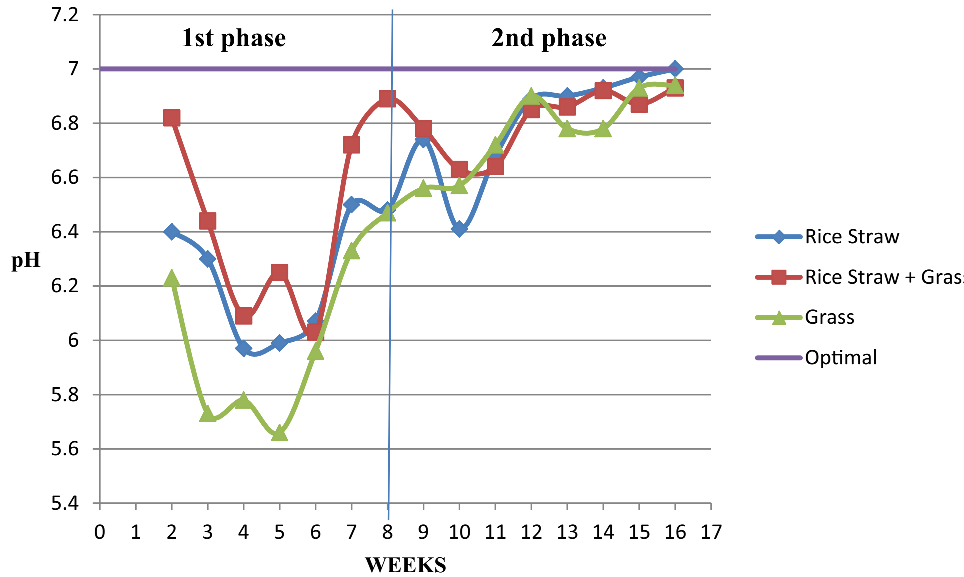

Fig. 7 pH changes during the first and second 8 weeks of vermicomposting

Fig. 8 The three types of vermicompost

the first harvest. T2 had the highest productivity of 66.20%, followed by T3, 52.1% and T1, 45.30%, for the second harvest (Table 4), which was approximately 10 days earlier. According to Ansari and Jaikishun (2011), the increase in production of vermicompost and a shorter period of harvest could be possible due to the increase of worms in the units.

The vermicompost produced had a dark color, a mull-like soil odor and was homogeneous (Fig. 8), which was in line with the earlier results of Domínguez and Edwards (2011).

Table 5 presents the values of pH and soluble salt concentrations (electric conductivity) of rice straw, dry grass clippings, rice straw + dry grass clippings, cow manure and the different vermicompost obtained.

The pH recorded for the raw feedstock was the highest (7.80) for the combination of rice straw and dry grass (RS + DG), followed by rice straw (7.30) and dry grass clipping (6.50). The pH of the three feedstocks differed significantly, as shown by the Tukey's test ($P \leq 0.05$). Further, the pH of the cow manure (CM) was 6.00. For the first set of the harvested vermicompost, the pH was 6.60 for RSV60, 6.40 for RSGV60 and 6.20 for GV60. The pH of the three different treatments differed significantly. For the second set of the harvested vermicompost, the pH was 6.80 for RSV120, 6.60 for RSGV120 and 6.30 for GV120, showing a significant inter-treatment difference ($P \leq 0.05$). In both sets of the vermicompost, the pH was 6–7. According to Edwards and Bohlen (1996), this range (6–7) of vermicompost promotes the availability of plant nutrients like NPK. The neutral pH of vermicompost was in line with some earlier findings (Guerrero et al. 1999; Chiluvuru et al. 2009; Nath et al. 2009; Mane and Raskar 2012; Okwor et al. 2012. Microbial decomposition of organic matter during vermicomposting leads to production of organic acids which shifts the pH to near neutral (Garg and Kaushik 2004; Nath et al. 2009; Das et al. 2012). The electric conductivity (EC) for the raw feedstock was 3.98 mS/cm for RS + DG, 3.90 mS/cm for RS, and 3.00 mS/cm for DG. The EC of RS + DG and RS did not show significant difference mutually but differed significantly from that of DG ($P \leq 0.05$). The EC of the cow manure (CM) was 8.37 mS/cm. For the first set of the harvested vermicompost, the EC was 5.45 mS/cm for GV60, 4.65 mS/cm for RSV60 and 4.55 mS/cm for RSGV60. The EC of GV60 differed from RSV60 and RSGV60 significantly but the EC of RSV60 and RSGV60 mutually did not differ significantly. For the second set of the harvested vermicompost, the EC was recorded to be 7.80 mS/cm for GV120, 7.20 mS/cm for RSGV120 and 6.90 mS/cm for RSV120. The EC of GV120 differed from RSV120 significantly but the EC of RSGV120 did not differ significantly from GV120 and RSV120, as depicted by the Tukey's test ($P \leq 0.05$). The EC of both sets of the vermicompost was above 2–3 mS/cm, which was considered by Edwards and

Arancon (2004) as a range for established plants. Electrical conductivity is dependent on freely available minerals and ions generated during ingestion and excretion by the earthworms (Garg et al. 2006a) and the raw materials used for vermicomposting (Atiyeh et al. 2002). The increase in EC in the vermicompost as shown in Table 5 could be due to the loss of weight of organic matter and the release of different mineral salts in available forms (Wong et al. 1997; Kaviraj and Sharma 2003; Nath et al. 2009). In Table 6, the values of C/N ratio, total organic carbon and total nitrogen in rice straw, dry grass clippings, rice straw + dry grass clippings, cow manure and different obtained vermicompost are shown.

The total organic carbon (TOC) in the raw materials DG, RS and RS + DG was 42.96%, 41.23% and 37.70%, respectively. There was a significant difference between DG and RS + DG; RS and RS + DG, but no significant difference between DG and RS according to the Tukey's test ($P \leq 0.05$). The total organic carbon in CM was 17.69%. The TOC in the first harvest in GV60, RSGV60 and RSV60 was 20.70%, 18.37% and 16.67%, respectively. In the second harvest, it was 23.70%, 23.30% and 23.20% in RSV120, GV120 and RSGV120, respectively. For the first and second harvest, there were no significant differences among the different treatments, as revealed by the Tukey's test ($P \leq 0.05$). The variation in total organic carbon in the vermicompost ranged from 16.67 to 23.70%, which is similar to the results (18.5–23%) obtained by Mane and Raskar (2012). During the process of vermicomposting, the earthworms feed on the organic matter and microbial degradation takes place. As observed in Table 5, the percentage of organic carbon is lower in the vermicompost than in the raw material, indicating that the earthworms accelerated the decomposition of the organic matter. Carbon is a major component of organic molecules, which are the building blocks of all organisms and, thus, are needed as the source of energy for the composting process (Ismail 2005; Ansari and Jaikishun 2011; Ansari and Rajpersaud 2012).

The total nitrogen (TN) in the raw material was the highest (1.88%) in DG, followed by RS + DG (1.34%), and RS (1.07%), showing a significant difference among the treatments. The TN in CM was 1.48%. The TN in the first harvested vermicompost in GV60, RSV60 and RSGV60 was 1.41%, 1.31% and 1.25%, respectively. For the first harvest, there was a significant difference between GV60 and RSGV60 but no significant difference among the other treatments ($P \leq 0.05$). The TN in the second harvested vermicompost in GV120, RSGV120 and RSV120 was 1.80%, 1.60% and 1.50%. There was a significant difference between GV120 and RSGV120; GV120 and RSV120, but no significant difference between RSGV120 and RSV120 ($P \leq 0.05$). The TN was relatively higher in the second than in the first harvest of vermicompost. Earlier studies have reported the value of N between 0.9 and 1.5% (Kale 1998; Chaudhuri et al. 2000; Kitturmath et al. 2007; Giraddi 2007, 2011; Meenatchi 2008; Waseem et al. 2013). Suthar (2009) noted that the total N (range 2.49–3.17%) was higher in the end product. Suthar (2007) suggested that the earthworms enhance the N levels in the vermicomposting substrate by adding their excretory products, mucus, body fluid, enzymes and even through decaying tissues of dead worms in the vermicomposting subsystem. According to Suthar (2009), the final N content could be related to the quality of the substrate used for worm feeding and probably because of mineralization of the organic matter, as pointed out by Garg and Kaushik (2005).

The initial feedstock (RS, RS + DG and DG) had a high C:N ratio, 39:1, 28:1 and 23:1, respectively. The CM had a C:N ratio of 12:1. The final vermicompost of RS at 60 and 120 days had a C:N ratio of 13:1 and 16:1, respectively. The vermicompost combination of RS and DG had the same C:N ratio (15:1) at 60 and 120 days. The C:N ratio of the vermicompost of DG at 60 and 120 days was 15:1 and 13:1, respectively. It was observed that the C:N ratio, which is one of the most widely used indicators of the organic waste maturity, is decreased in the process of vermicomposting, which was acceptable according to Domínguez and Edwards (2011) and endorsed some earlier studies (Kale 1998; Gupta and Garg 2008; Suthar 2008, 2009; Solis-Mejia et al. 2012). According to Kaushik and Garg (2003), the decrease of carbon/nitrogen ratio is due to a rapid decomposition of the organic waste, and the mineralization and stabilization during the process of vermicomposting. Senesi (1989) reported that a decline of C:N to less than 20 indicates an advanced degree of maturity in the organic waste. Solis-Mejia et al. (2012) noted that microbial respiration and nitrogenous excretion reduces the C/N ratio of the substrate (the source of carbon is dried plant material and cow manure provides nitrogen input during the process of vermicomposting) during the decomposition process.

As observed in Table 6, the total phosphorus (TP) in the raw feedstock was 0.28%, 0.26% and 0.19% in RS + DG, DG and RS, respectively, showing a significant difference between RS + DG and RS, but no significant difference between the other treatments. The total phosphorus in CM was 0.98%. In the first set of the harvested vermicompost, the TP was 0.95% in GV60, 0.80% in RSV60, and 0.78% in RSGV60. In the second set of the harvested vermicompost, the TP was 0.87% in RSGV120, 0.82% in GV120 and 0.77% in RSV120. For both the sets, the difference among the treatments was not significant ($P \leq 0.05$). Similar results (0.7–0.9%) were obtained by Mane and Raskar (2012). Marlin and Rajeshkumar (2012) recorded a high percentage of P (2.68–3.61%) in vermicompost obtained from the saw dust, city waste, sugarcane trash weed plant, pressed mud and slaughter house waste. During vermicomposting, the release of available P content from the organic waste occurs partly by the earthworm gut phosphatases, and further release of P might be attributed to the P-solubilizing microorganisms present in the worm casts, causing conversion of phosphorus (P) to forms that are more bio-available to plants (Suthar 2009; Goswami et al.2013).

As seen in Table 6, the total potassium (TK) in the raw feedstock was 1.36%, 1.23% and 0.57% in RS, DG and RS + DG, respectively, showing a significant difference between RS and RS + DG. However, there were no significant differences among the other treatments ($P \leq 0.05$). The TK in CM was 0.83%. In the first set of the harvested vermicompost, the TK was 0.58% in RSGV60, 0.54%, in RSV60 and 0.53% in GV60. For the first harvest, there were no significant differences among the other treatments. In the second harvest, TK was 0.70% in RSGV120, 0.68% in RSV120, and 0.60 ± 0.01% in GV120. There was a significant difference between RSGV120 and GV120; RSV120 and GV120 ($P \leq 0.05$). Differences among other treatments were not significant. Similar results (0.64–0.76%) were obtained by Nath et al. (2009) for the rice straw and other waste material vermicompost. In earlier studies, K values between 0.54% and 1.72% were reported (Kale 1998; Chaudhuri et al. 2000; Kitturmath et al. 2007; Giraddi 2007, 2011; Meenatchi 2008; Waseem et al. 2013). Vermicompost contains most nutrients in plant available forms such as phosphates, exchangeable calcium and soluble potassium (Orozco et al. 1996). It contains a high concentration of exchangeable K due to enhanced microbial activity during the vermicomposting process, which consequently enhances the rate of mineralization rate (Suthar 2007). Table 7 displays that the total calcium (T-Ca) in the raw feedstock was 0.95%, 0.93% and 0.62% in DG, RS + DG and RS, respectively, showing a significant difference between DG and RS; RS + DG and RS. The T-Ca in CM was 4.05%. In the first set of vermicompost, the T-Ca was 2.50%, 2.07% and 1.75%, in RSV60, GV60 and RSGV60, showing a significant difference among all the treatments. In the second harvest, the T-Ca was 1.56%, 1.43% and 1.31% in RSGV120, GV120 and RSV120, respectively, showing no significant difference among the treatments ($P \leq 0.05$).

The total magnesium (T-Mg) in the raw feedstock was 0.38%, 0.31% and 0.23% in RS + DG, RS and DG, respectively, showing a significant difference between RS + DG and DG (Table 6). There was no significant difference among the treatments ($P \leq 0.05$). The T-Mg in CM was 1.43%. In the first set of vermicompost, the T-Mg was 0.75%, 0.69% and 0.65%, in GV60, RSV60 and RSGV60, respectively, showing a significant difference between GV60 and RSGV60. There were no significant differences among the treatments ($P \leq 0.05$). In the second harvest, the T-Mg was 0.70%, 10.69% and 0.67% in RSV120, RSGV120 and GV120, respectively, showing no significant differences among the treatments (Table 6).

Table 1 Chemical properties of raw feedstock and vermicompost

Parameter	Cow manure	Dry grass clippings	Vermicompost
$pH\text{-}H_2O$	6.20	6.50	6.50
EC (mS/cm)	5.72	3.00	3.71
Total organic carbon (%)	21.02	42.96	18.53
Total-N (%)	1.57	1.88	1.36
C/N ratio	13:1	23:1	13:1
Total-P (%)	0.78	0.26	0.58
Total-K (%)	0.86	1.23	0.56
Total-Mn (ppm)	633	235	544
Total-Cu (ppm)	34.8	6.80	26.90
Total-Zn (ppm)	921	118	611
Total-Fe (%)	1.62	0.18	1.56

Table 2 Presence of *Salmonella* and *E. coli* in cow manure and vermicompost

Microbes	Cow manure (S)	Vermicompost (V)
Salmonella	Absent per 25 g	Absent per 25 g
E. coli	< 10 CFU per gram	< 10 CFU per gram

The T-Ca content in the different vermicompost treatments varied between 1.31% and 2.50%, which was higher than in the raw feedstock. Similar results (2.0–2.57%) for vermicompost were obtained by Suthar (2009). Elvira et al. (1996) reported no significant increase in T-Ca for vermicomposting of paper-mill sludge, although the gut processes associated with calcium metabolism are primarily responsible for the enhanced content of inorganic calcium in the vermicompost (Hartenstein and Hartenstein 1981; Garg et al. 2006b; Suthar 2008). The T-Mg was higher in the harvested vermicompost than in the raw feedstock, which is in line with the investigation of Vennila et al. (2012) who also reported that the vermicompost prepared through a conventional method has a standard value of 0.46% Mg. The obtained T-Mg values in this study were higher than vale reported by Vennila et al. 2012. According to Edwards et al. (2011), the content of T-Ca and T-Mg in the finished vermicompost is indicative of its nutrient value.

The total concentrations of the micronutrients, viz. manganese (T-Mn), copper (T-Cu), zinc (T-Zn) and iron (T-Fe) in rice straw, dry grass clippings, rice straw + dry grass clippings, cow manure and different obtained vermicompost are shown in Table 6. The T-Cu in the raw feedstock exhibited a significant difference among the different treatments with the highest (12 ppm) being in RS + DG, followed by DG (6.80 ppm), and RS (1.80 ppm). The T-Mn, T-Zn and T-Fe in the feedstock did not differ significantly among the treatments ($P \leq 0.05$). In the

Table 3 Estimation of total population of *E. foetida* earthworms per m^2

	Juvenile	Non-clitellate	Clitellate	Total
At 60 days				
Rice straw (T1)	775	75	25	875^a
Dry grass clippings (T2)	1025	100	25	1150^a
Rice straw + dry grass clippings (T3)	975	25	25	1025^a
At 120 days				
Rice straw (T1)	625	175	100	900^a
Dry grass clippings (T2)	600	175	25	800^a
Rice straw + dry grass clippings (T3)	750	275	25	1050^a

Table 4 Harvest data of vermicompost (mean ± SEM)

Units (composition)	Rice straw (T1)	Grass (T2)	Rice straw + grass (T3)
Total mass of feed (kg) initially	168	168	168
Average harvest per unit (kg)	10.90 ± 0.72^a	9.80 ± 2.50^a	13.80 ± 4.04^a
1st harvested vermicompost (kg)	43.50	39	55
Productivity of vermicompost (%)	25.90	23.20	32.70
Total mass of feed (kg) secondly	96	96	96
Average harvest per unit (kg)	10.90 ± 0.43^a	15.90 ± 2.87^a	12.50 ± 2.50^a
2nd harvested vermicompost (kg)	43.50	63.50	50
Productivity of vermicompost (%)	45.30	66.20	52.10
Total harvested vermicompost (kg)	87	102.50	105

Table 5 pH and EC of raw feedstock and the vermicompost

Treatments	pH-H_2O	EC (mS/cm)	TOC (%)	TN (%)	C/N ratio
Raw feedstock					
Rice straw (RS)	7.30 ± 0.03^b	3.90 ± 0.06^a	41.23 ± 0.06^a	1.07 ± 0.04^c	39:1
Dry grass clipping (DG)	6.50 ± 0.06^c	3.00 ± 0.09^b	42.96 ± 0.96^a	1.88 ± 0.05^a	23:1
Rice straw + dry grass clipping (RS + DG)	7.80 ± 0.00^a	3.98 ± 0.10^a	37.70 ± 0.95^b	1.34 ± 0.05^b	28:1
CM: cow manure (CM)	6.00 ± 0.03	8.37 ± 0.30	17.69 ± 0.72	1.48 ± 0.05	12:1
1st harvest					
Rice straw vermicompost (RSV60)	6.6 0 ± 0.00a	4.65 ± 0.02^b	16.67 ± 3.58^a	1.31 ± 0.01^{ab}	13:1
Rice straw + grass vermicompost (RSGV60)	6.40 ± 0.03b	4.55 ± 0.16^b	18.37 ± 0.25^a	1.25 ± 0.01^b	15:1
Grass vermicompost (GV60)	6.20 ± 0.00c	5.45 ± 0.15^a	20.70 ± 0.36^a	1.41 ± 0.04^a	15:1
2nd harvest					
Rice straw vermicompost (RSV120)	6.80 ± 0.03^a	6.9 ± 0.18^b	23.70 ± 0.75^a	1.50 ± 0.04^b	16:1
Rice straw + grass vermicompost (RSGV120)	6.60 ± 0.0^b	7.2 ± 0.18^{ab}	23.20 ± 0.59^a	1.60 ± 0.04^b	15:1
Grass vermicompost (GV120)	6.30 ± 0.0^c	7.8 ± 0.08^a	23.30 ± 0.41^a	1.80 ± 0.02^a	13:1

Values represent mean ± SEM

first harvested vermicompost, the T-Mn in RSV60 was the highest (807 ppm), followed by RSGV60 (648 ppm) and GV60 (609 ppm). The difference between RSV60 and RSVG60 and between RSV60 and GV60 was found to be significant. For the total concentrations of Cu, Zn and Fe, there was no significant difference among the treatments. Concentrations ranged between 38.30 ppm and 47.60 ppm for Cu, between 771 ppm and 808 ppm for Zn and between 1.77% and 1.86% for Fe. In the second harvested vermicompost, the T-Mn was 570 ppm, 539 ppm and 462 ppm, in RSV120, RSGV120 and GV120, respectively, showing a significant difference between RSV120 and GV120 and between RSGV120 and GV120. For T-Zn, the values were 424 ppm in RSGV120, 423 ppm in GV120

Table 6 Macro-elements in raw feedstock and vermicompost

Treatments	TP (%)	TK (%)	T-Ca (%)	T-Mg (%)	T-Mn (ppm)	T-Cu (ppm)	T-Zn (ppm)	T-Fe (%)
Raw feedstock								
Rice straw (RS)	0.19 ± 0.03^{b}	1.36 ± 0.05^{a}	0.62 ± 0.01^{b}	0.31 ± 0.02^{ab}	757 ± 6.93^{a}	1.80 ± 1.08^{c}	66 ± 13.59^{a}	0.09 ± 0.03^{a}
Dry grass clipping (DG)	0.26 ± 0.01^{ab}	1.23 ± 0.26^{ab}	0.95 ± 0.02^{a}	0.23 ± 0.03^{b}	235 ± 23.20^{a}	6.80 ± 0.30^{b}	118 ± 15.91^{a}	0.18 ± 0.02^{a}
Rice straw + dry grass clipping (RS + DG)	0.28 ± 0.02^{a}	0.57 ± 0.03^{b}	0.93 ± 0.08^{a}	0.38 ± 0.04^{a}	234 ± 29.56^{a}	12.00 ± 0.82^{a}	143 ± 27.92^{a}	0.17 ± 0.01^{a}
Cow manure (CM)	0.98 ± 0.02	0.83 ± 0.05	4.05 ± 0.41	1.43 ± 0.04	698 ± 54.82	67.70 ± 14.83	1056 ± 128.43	2.79 ± 0.27
1st harvest								
Rice straw vermicompost (RSV60)	0.81 ± 0.10^{a}	0.54 ± 0.01^{a}	2.50 ± 0.09^{a}	0.69 ± 0.01^{ab}	807 ± 5.21^{a}	38.30 ± 2.53^{a}	808 ± 33.56^{a}	1.82 ± 0.06^{a}
Rice straw + grass vermicompost (RSGV60)	0.78 ± 0.01^{a}	0.58 ± 0.08^{a}	1.75 ± 0.03^{c}	0.65 ± 0.02^{b}	648 ± 36.16^{b}	39.20 ± 2.33^{a}	771 ± 32.41^{a}	1.86 ± 0.03^{a}
Grass vermicompost (GV60)	0.95 ± 0.07^{a}	0.53 ± 0.02^{a}	2.07 ± 0.06^{b}	0.75 ± 0.0^{a}	609 ± 4.03^{b}	47.60 ± 7.09^{a}	792 ± 61.35^{a}	1.77 ± 0.01^{a}
2nd harvest								
Rice straw vermicompost (RSV120)	0.77 ± 0.02^{a}	0.68 ± 0.02^{a}	1.31 ± 0.12^{a}	0.70 ± 0.03^{a}	570 ± 10.76^{a}	27.60 ± 0.62^{a}	335 ± 3.99^{b}	0.69 ± 0.04^{a}
Rice straw + grass vermicompost (RSGV120)	0.87 ± 0.06^{a}	0.70 ± 0.02^{a}	1.56 ± 0.13^{a}	0.69 ± 0.01^{a}	539 ± 16.68^{a}	37.10 ± 5.70^{a}	424 ± 27.24^{a}	0.98 ± 0.16^{a}
Grass vermicompost (GV120)	0.82 ± 0.03^{a}	0.60 ± 0.01^{b}	1.43 ± 0.18^{a}	0.67 ± 0.02^{a}	462 ± 12.45^{b}	27.60 ± 2.78^{a}	423 ± 1.38^{a}	0.81 ± 0.04^{a}

Values represent mean ± SEM

and 335 ppm in RSV120. For T-Zn, there was a significant difference between RSGV120 and RSV120 and between GV120 and RSV120 ($P \leq 0.05$). For T-Cu and T-Fe, there was no significant difference among the treatments. The Cu concentrations varied from 27.60 to 37.10 ppm, whereas Fe concentrations varied from 0.69 to 0.98%.

Earlier studies reported values 2.00–37.70 ppm for Cu, 5.70–120.00 ppm for Zn and 10.00–105.00 ppm for Mn (Kale 1998; Chaudhuri et al. 2000; Kitturmath et al. 2007; Giraddi 2007, 2011; Meenatchi 2008; Waseem et al. 2013). According to Edwards et al. (2011), vermicompost typically contains adequate amounts of micronutrients, which have been substantiated by our results for T-Mn, T-Cu, T-Zn and T-Fe in the first and second harvest of vermicompost. The vermicompost has been shown to have high levels of total and available nitrogen, phosphorous, potassium (NPK) and micronutrients, the microbial and enzyme activities and the growth regulators (Karmegam and Daniel 2009; Prakash and Karmegam 2010). In India also, earthworms have been successfully utilized for vermicomposting of leaf litters (Karmegam and Daniel 2000), rice straw (Reddy and Ohkura 2004), municipal solid waste (MSW) (Kaviraj and Sharma 2003), paper waste (Prakash et al. 2008), silkworm litter (Sekar and Karmegam 2009) and beverage industry sludge (Singh et al. 2010).

Economic analyses

Table 7 presents the cost–benefit analysis of vermicomposting. The total cost of setting a vermicompost station of 12 units is USD 8059.70, whereas the total fixed and variable costs are USD 2758.21. With an annual production of 4800 kg and sale revenue of SRD 5.00 per kg, the estimated profit will be SRD 14,760.00 or USD 4405.97. The payback period will be approximately 2 years and the cost of production of 1 kg vermicompost is SRD 2.00 or USD 0.60.

Conclusion

The vermicomposting of dry grass clippings, rice straw and cow manure using *Eisenia foetida* was successful. The produced vermicompost had a dark color, a mull-like soil odor and was homogeneous. It had all the essential macro- and micro-plant nutrients like N, P, K, Ca, Mg, Mn, Cu, Zn and Fe, indicating the achievement of getting an environment friendly nutrient-rich fertilizer for the agriculture sector. Possibilities of the production of vermicompost using other

Table 7 Cost-benefit analysis

Economics of vermitech				
Construction and maintenance of a vermicompost station (12 UNITS)				
PRODUCTION CAPACITY				
Total surface area of production				
(1.5 m × 1 m × 0.6 m per unit)	12 units = 10.8 sq m			
Annual targeted production capacity 400 kg × 12 = 4800 kg				
Duration of each run (average per unit) = 45–60 days				
Number of harvests of compost/year 8/unit = 8 × 12 = 96 approx.				
Feasibility report				
Estimated capital investment Vermitech units		SRD	USD	
Brick and mortar with shade made of sheets		25,486.00	7607.76	
Vermibed (sand and bricks)		680.00	202.99	
Implements		534.00	159.40	
Contingencies		300.00	89.55	
Total		27,000.00	8059.70	
(a) Fixed costs				
(i) Depreciation @ 10%		2700.00	805.97	
(ii) Interest @ 15%		3240.00	967.16	270 × 12
Total fixed costs		5940.00	1773.13	
(b) Variable costs				
Costs of inputs @ SRD200/produce		1600.00	477.61	8 cycles for 12 units
Labour 2 h/day @ SRD10/h		900.00	268.66	45 days
Harvesting and packing @ SRD100/harvest		800.00	238.81	
Total variable costs		3300.00	985.07	
Cost return analysis				
1	Total cultivable space	10.8		sq m
2	Estimated production (minimum)	4800		kg
3	Sale revenue (@ SRD5/kg)	24,000.00	7164.18	USD
4	Total fixed cost	5940.00	1773.13	USD
5	Total variable cost	3300.00	985.07	USD
6	Total cost (4 + 5)	9240.00	2758.21	USD
7	Profit (3–6)	14,760.00	4405.97	USD
8	Total capital investment	27,000.00	8059.70	USD
	Pay back period (8/7)	1.83	yr (say, 2 years)	
	Cost of production per kg (6/2)	1.93	SRD (say, SRD2.00 or USD0.60)	

(A minimum of eight harvests can be made in the first year. A minimum of eleven to twelve harvests (every 30 days) can be made in subsequent years

With proper management, the cost of production will be appreciably reduced and the duration and quantity can be improved.)

Prices are converted to USD using an exchange rate of USD1.00 = SRD3.35 (CBvS, 2015)

types of waste material and manure should also be explored in the future studies.

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