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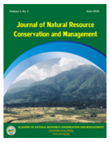

Changes in physicochemical and microbial properties during standardization of on-farm composting of municipal solid waste

Y.P. Singh[1,*], Sanjay Arora[1], V.K. Mishra[2], R.K. Gupta[3] and Shyam Ji Mishra[1]

[1]*ICAR-Central Soil Salinity Research Institute, Regional Research Station, Lucknow-226002, Uttar Pradesh, India*
[2]*ICAR-Research Complex for North Eastern Hill Region, Umiam-793103, Meghalaya, India*
[3]*Bohra Institute of Allied Health Sciences, Lucknow-212208, Uttar Pradesh,India*
**Corresponding author Email: ypsingh.agro@gmail.com*

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ABSTRACT

To overcome the hazardous problems due to the generation of municipal solid wastes, its management for agriculture purposes is a promising approach. It can be used to improve soil fertility and also as a source of organic amendment to reclaim the salt-affected soils. The present study was conducted to develop on-farm municipal solid wastes compost through the combined use of municipal solid waste and agricultural waste. To standardize the on-farm composting protocol, seven treatment combinations with two decomposing agents like earthworms and microbes were used and monitored for the physical, biochemical, and microbial changes during the composting process till maturity. The composting process was completed in all treatments at 120 days. During the composting period, temperature under different treatments varied between 24 to 27 °C and moisture content ranged between 43.88 to 69.32%. After 120 days of composting, the pH of the composting material increased slightly from 6.97 to 7.48 while electrical conductivity increased over the 30 days of composting. Total nitrogen, total phosphorus, total potassium, and calcium contents were also higher at the maturity of the compost whereas, the total carbon, C: N, C: P, and C: K ratios lowered with an increase in the composting period. The lowest C: N ratio (17.13) and highest microbial population were recorded in treatment $T_{7,}$ where 50% municipal solid waste + 50% agricultural wastes were mixed and enriched with earthworm (*Eisenia fetida*) and degrading microbes. With the standardization of this on-farm composting protocol, the physico-chemical and microbial properties of municipal solid waste can be changed and converted into quality compost within 120 days to improve soil fertility and productivity.

Keywords: Agriculture wastes, Municipal solid waste, On-farm composting Physico-chemical and microbial changes, Standardization

INTRODUCTION

About 1.3 billion tons of municipal solid waste (MSW) is generated per year in the world as byproducts of industrial, mining, municipal, agricultural, and other processes and is expected to rise by about 2.2 billion tons per year by 2025. The data represent a substantial increase in per capita waste generation rates, from 1.2 to 1.4 kg day^{-1} per person in the coming fifteen years (Hoornweg and Bhada-Tata, 2012). According to the report of the Central Pollution Control Board (CPCB), India produces 12.74 million tons of MSW per day (CPCB, 2012). It is increasing with a growing population, changing lifestyles, migration of people from rural areas to cities, and rapidly growing tourism generating an enormous quantity of MSW every day. The amount of MSW generated per capita is estimated to increase at a rate of 1–1.33% annually (Pappu *et al.,* 2007; Shekdar, 1999; Bhide and Shekdar, 1998). In India, it is generally produced from household kitchens, commercial complexes, industries, and agriculture. Rapid industrialization and urbanization are increasing the amount of MSW day by day. Municipal Bodies/ Urban Local Bodies (ULB) in various cities collect the MSW, transport it to the dump yards, and dispose of in open-ground dumping or non-sanitary landfills. These landfill sites are an environmental hazard – emanating methane causing the greenhouse effect, smell and dirt causing health problems, and leachate contaminating the groundwater, etc. Various studies have reported that the MSW generation rates in small towns are lower than those of metro cities and the per capita generation rate of MSW in India ranges from 0.2 to 0.5 kg day^{-1} (Siddiqui *et al.,* 2006; Sharholy *et al.,* 2005; CPCB, 2004; Kansal, 2002; Singh and Singh, 1998; Kansal *et al.* 1998; Bhide and Shekdar, 1998; Dayal, 1994; Khan, 1994). The per capita generation rate in some states like Gujarat, Delhi, and Tamil Nadu and cities like Chennai, Kanpur, Lucknow, and Ahmadabad is very high. This may be due to the high living standards, rapid economic growth, and the high level of urbanization.

Uttar Pradesh, one of the largest states in India produces about 5515 tons of MSW per day (CPCB, 2012), and facing one of the major challenge to manage municipal solid waste management is one of the major challenges faced by the state government, particularly in urban areas. The government of Uttar Pradesh has initiated an integrated municipal solid waste management project for composting of MSW and its utilization for agricultural practices. MSW compost, with high organic matter content and low concentration of inorganic and organic pollutants, allows an improvement of physical, chemical, biochemical, and microbial characteristics and constitutes low-cost soil recovery (Walter *et al.,* 2006). Furthermore, municipal solid waste compost (MSWC) represents a source of nutrients that can improve soil fertility and may contribute to restoring the productivity of salt-affected soils (Lakhdar *et al.,* 2008). Most of the studies on the use of municipal solid waste compost (MSWC) are confined to enhancing soil productivity in agricultural lands and rebuilding fertility (Hanay *et al.,* 2004). The industrially processed municipal solid waste compost available in the market is very costly (about US$ 150/ton) and beyond the reach of resource-poor small and marginal farmers. On-farm composting of MSW is an attractive proposition for turning organic waste materials into a farm resource. However, farmers are unable to make the best use of the composting opportunities available to them. This is because they face various constraints; among them are the availability of low-cost on-farm composting technology and lack of awareness. Therefore, it is of utmost importance to standardize the method for on-farm composting for the production of cost-effective organic manure.

Therefore, the present study was conducted to standardize the protocol for on-farm composting and monitoring the physico-chemical and microbial changes during the composting process to get aesthetically acceptable, safer from health points and useful compost for improving soil health and crop productivity and many other important practical applications like soil amendments and beneficial to the growth of the plants (Wilson *et al.,* 1980).

MATERIALS AND METHODS

Sample collection and processing

The MSW samples were collected in polythene bags from ten dumping sites of Lucknow city viz. Dubagga, Pulton Chawni, Aliganj, Telibagh - 1 and 2, Rashmi Khand, Nahar Chauraha, Buddheswar Chauraha, Aishbagh, and Buddha Park and labeled properly. To analyze physical properties, degradable and non-degradable materials were separated from each sample and weighed. The degradable materials received from each sample were mixed to make a composite representative sample, dried at room temperature, and ground to pass through a 0.2 mm sieve for its chemical analysis.

The on-farm composting study was conducted under aerobic conditions at the Research Farm of ICAR-Central Soil Salinity Research Institute, Regional Research Station, Lucknow, India, from October 2014 to January 2015 and monitored for physico-chemical and microbial changes occurred during the composting. MSW collected from Municipal Corporation, Lucknow was segregated into degradable and non-degradable components. The degradable material alone or in combination with agricultural wastes was enriched with earthworm and microbial treatments. The chopped agricultural wastes of mustard straw, paddy straw, and leaf litter of *Casuarina* and *Pongamia* were used as composting material. Before mixing with degradable MSW and agriculture wastes these were analyzed for their chemical composition. For rapid decomposition, three efficient degrading microbial cultures such as strains of *Aspergillus niger*, *Trichoderma spp.* and *Bacillus spp.* and earthworm (*Eisenia fetida*) were used with seven treatments consisted of T_1: 100% MSW, T_2: 100% MSW + microbes, T_3: 50% MSW + 50% agricultural wastes + microbes, T_4: 100% MSW + earthworms, T_5: 50% MSW + 50% agricultural wastes + earthworms, T_6: 100% MSW + earth worms + microbes, T_7: 50% MSW + 50% agricultural wastes + earth worms + microbes. Composting material was filled in 12 feet long, 4 feet wide, and 4 feet high vermi beds. A uniform quantity of water was applied at alternate days in each bed and the moisture content was monitored at regular intervals. The composting material was turned at every 15-day interval.

Sampling procedure

During composting, samples were collected from three places in each treatment bed at 30 days interval, and mixed as a composite sample. Part of the sample was kept in refrigerator at 4°C temperature for microbial study and the remaining sample was dried, grounded, and sieved through 0.2 mm sieve for chemical analysis.

Analytical methods

Physical analysis

Temperature from each treatment was recorded daily at 11:00 AM with a 60 cm long metal probe thermometer (Poinceter and Day, 1973) fixed in each bed. To monitor the changes in moisture content, samples were collected from 3 places in each bed at 30 cm depth, mixed and made a composite sample, and analyzed moisture content gravimetrically on a fresh weight basis.

Chemical analysis

To maintain changes in pH and electrical conductivity (EC), sample analysis was done in a 1:5 (waste: water) ratio using a digital pH meter (Systronics µ pH System 361) and EC meter (Systronics, Conductivity TDS meter 308). Total nitrogen was estimated by the Micro Kjeldahl distillation apparatus. Total carbon was analyzed by LOI method using a muffle furnace. Potassium and phosphorous content was estimated by digestion with diacid and the total potassium by flame photometrically and total phosphorus by ammonium molybdate-Meta vandate yellow color complex (Jackson, 1973).

Microbial analysis

To analyze the microbial changes during composting, isolation on differential media such as nutrient agar for the bacterial population and potato dextrose agar for the fungal population was used. The serial dilution of 10^{-3} and 10^{-4} of the compost samples was prepared to isolate the microbes from the compost samples using the spread plate technique. Spread 1µl sample of both dilutions on different mediums and incubated at 30°C for 48 hours. After incubation, the viable colonies were counted using colony counters (Buchanan and Gibbons, 1974; Dubey and Maheshwari, 2006).

RESULTS AND DISCUSSION

Physico-chemical properties of MSW

Data given in Fig. 1 revealed that the MSW constitutes 37.5% of degradable and 62.5% of non-degradable materials. The degradable material contains 5% paper/cardboard, 31% organic matter including kitchen waste, and 2% wood twigs whereas, non-degradable material consists mainly of 36%, stone/pebbles/brick pieces, 15% plastic and polythene, 6% metal and 5% glass on a weight basis.

Before filling in the beds, the initial properties of both MSW and agriculture wastes were analyzed separately using standard procedures. From the analyzed data, it was observed that the MSW was near neutral in reaction having a pH of 6.97. Total carbon content was 28.35%, total nitrogen 0.52%, and the C: N ratio was 54.86. The agriculture wastes including Pongamia and Casuarina leaves, mustard, and paddy straw have a total carbon content of

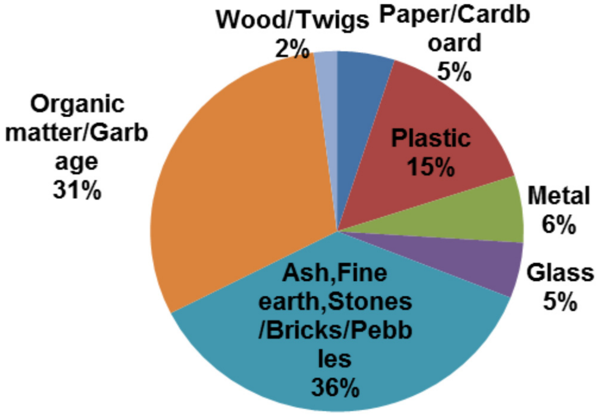

Fig. 1. Physical properties of municipal solid waste of Lucknow city

Table 1. Initial properties of municipal solid waste and agricultural wastes used for composting

Property	Municipal solid waste	Agricultural waste			
		Pongamia leaves	Casuarinas leaves	Mustard straw	Paddy straw
pH (1:2)	6.97	-	-	-	-
Nitrogen (%)	0.52	2.2	1.7	0.56	0.45
Phosphorus (%)	0.05	0.15	0.18	0.36	0.17
Potassium (%)	0.28	0.63	0.42	0.64	0.39
Calcium (%)	0.36	0.46	0.51	0.12	0.09
Magnesium (%)	0.10	0.32	0.30	0.05	0.10
Sulfate (%)	0.11	0.27	0.42	0.17	0.23
Total Carbon (%)	28.35	42.06	53.88	52.49	39.65
C: N	54.86	19.11	31.69	93.73	88.11

42.06, 53.88, 52.49, and 39.65%, respectively. The highest total nitrogen content (2.2%) was recorded in Pongamia leaves followed by Casuarin*a* leaves (1.7%), mustard straw (0.56%), and paddy straw (0.45%). The lowest C: N ratio was recorded in Pongamia leaves (Table 1). Total P and K content in MSW was found to be 0.05% and 0.28% respectively, whereas, it was estimated as 0.36% and 0.64% in mustard straw in that order which is the highest value among all the agricultural wastes (Table 1). The calcium, magnesium, and sulfate contents were also analyzed in MSW and chopped agriculture wastes. The highest calcium, magnesium, and sulfate contents were found in Casuarina leaves (0.51%), Pongamia leaves (0.32%), and Casuarina leaves (0.42%) respectively whereas, it was lowest in paddy straw (0.09%), mustard straw (0.05%) and raw MSW (0.11%) in that order.

Biophysical and microbial changes during composting

Composting is a regular decomposition of organic matter to produce a fine product called compost. The composting process entails managing and accelerating the biological and oxygen-demanding process as a mixture of organic materials passes through a series of stages that are characterized by an increase in temperature and microbial population (Haight and Tayler, 2000). During the composting process, several changes in temperature, moisture content, physico-chemical, and microbial properties have been observed.

Changes in temperature

Temperature is one of the imperative parameters that play an important role in the composting process (Khalil *et al.,* 2011). In our study, temperature varies between 21.6 to 27°C in different treatments throughout the composting period. The initial temperature of T_1 to T_7 was recorded at the start of composting and the highest temperature (25.2°C) was observed in treatment T_4, whereas the lowest temperature (22.8°C) was observed in treatment T_1. The lower range of temperature may be due to high moisture content during the winter season (Fig. 2). In some of the treatments it increased and in others

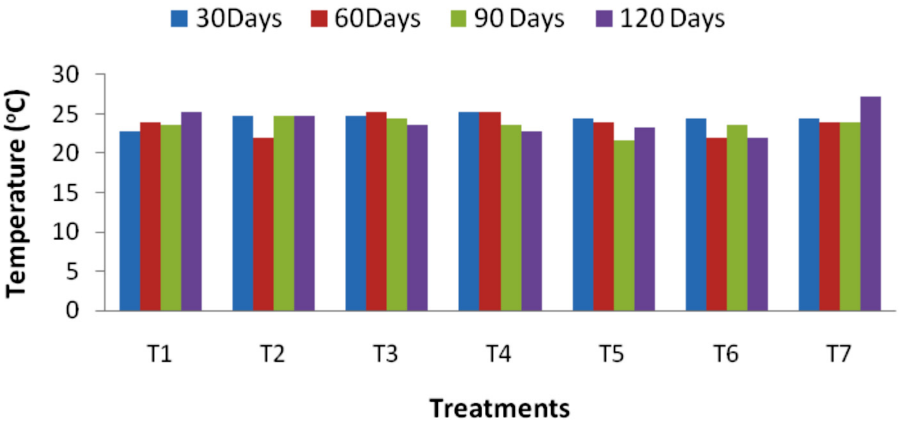

Fig. 2. Changes in temperature of different treatments at certain time intervals

it decreased with different time intervals. In matured compost, the maximum temperature was recorded in treatment T_7 having both MSW and agricultural wastes in equal ratio and enriched with earthworm and microbes. Maximum temperature (27.2°C) was recorded in treatment T_7 followed by T_1 (25.3°C), while minimum in T_6 (22°C at maturity (Fig. 2). There was no significant difference in temperature between the treatments. Narkhede and coworkers, (2010) also recognized the same outcome during composting of municipal solid waste. Another study also demonstrated that high moisture content and low amount of composting material mass were the reasons for low temperature (Hasanimehr *et al.*, 2011).

Change in moisture content

The moisture content is a very promising parameter of the composting process and is expressed as a percentage of fresh weight (Shyamala and Belagali, 2012). The moisture content of the composting blend is a chief environmental variable as it provides a medium for the transportation of dissolved nutrients necessary for the metabolic and physiological activities of micro-organisms (Elango *et al.,* 2009). From the data, it is evident that the moisture content under different treatments was unstable throughout the composting process, which may be due to a change in microbial population (Narkhede *et al.,* 2010). The moisture content varies between 33.31 to 44.76% in different treatments at 30 DOC and it followed an increasing trend in all the treatments at 60 DOC, however, it reduced at 90 DOC in all the treatments. At maturity of compost (120 DOC) the moisture content was increased in all the treatments except T_6 and T_7 where it was decreased as compared to 90 DOC. The moisture content ranged between 43.88% to 69.32% under different treatments at maturity (Fig. 3). Decline in moisture content percentage during the composting may be due to increasing temperature and high evaporation rate (Larney and Blackshow, 2003).

Changes in pH and EC

The pH of waste used for composting was initially slightly acidic (6.80–6.97) and later it became slightly alkaline because of ammonia formation and at the end of composting it dropped close to neutral. It may be due to humus formation with its pH buffering ability. Khalil *et al.* (2011) have also reported a similar trend. At 30 days of sampling the pH of different treatments observed in between 7.48 to 8.15. It decreased up to 90 DOC and declined later at 120 days of sampling ranging between 7.32 to 7.72, which seems neutral in reaction (Fig. 4). It may be due to the stabilization of organic acids (Khalil *et al.,* 2011, McKinley and Vestal, 1985). The most constructive pH range for composting is 6.0–8.0 because at this pH range microorganisms exhibited maximum growth and activity. Organic acids are completely oxidized, stabilizing the pH value at the end of the composting process (Khalil *et al.,* 2011). In comparison with the recommended standard (Bord na Mona, 2003) pH values were found to be higher than the normal range which implies that, during the degradation process decrease in pH can be attributed to the production of CO_2 from atoms of organic acids and loss of nitrogen (Higfenberg, 2009).

Electrical conductivity (EC) is a major factor in determining the quality of compost as high salt

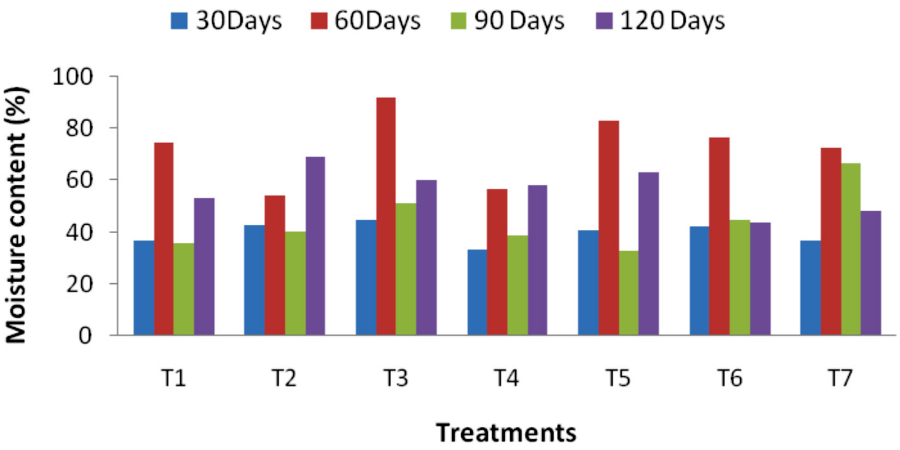

Fig. 3. Moisture content of different treatments at certain day interval

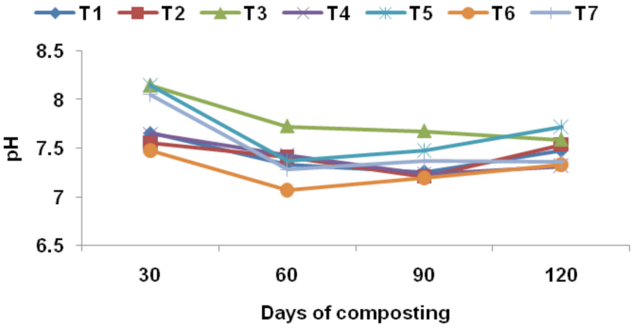

Fig. 4. Changes in pH of different treatments of MSWC

concentration can inhibit seed germination (Rawat *et al.,* 2013). The results indicate that the EC recorded at the initial days of composting were decreased in some treatment, whereas in some treatment it was increased at maturity of compost (Fig. 5). At the end of composting highest EC was recorded in treatment T_6 where MSW was enriched with both microbes and earthworms and minimum EC was observed in the treatment T_3. The decline in EC may be because of the more stable bond between ions and organic matter throughout composting (Moretti *et al.,* 2015).

Changes in chemical properties

Changes in nutrient contents like total nitrogen, total phosphorus, total potassium, calcium, and total carbon during composting were monitored at 30-day intervals up to 120 DOC. At 30 DOC, the highest total nitrogen (0.50%) was found in treatments T_3 and T_5 followed by the treatments T_2, T_4, T_6, T_7, and T_1 with 0.47, 0.46, 0.43, 0.42, and 0.40% respectively (Fig. 6a). At the end of composting (120 DOC) the highest total nitrogen was estimated in the treatment T_7 (0.79%) which is followed by the treatment T_6, T_3, T_5, T_2, T_4, and T_1 with 0.65, 0.58, 0.56, 0.51, 0.51 and 0.43% respectively. It is imperative to report here that total nitrogen percent at 60 and 90 DOC exhibited increasing trends in all the treatments, this may be due to the concentration effect caused by the strong degradation of labile organic compounds (Bernal *et al.,* 1998). The evolution of N showed that mineralization of the organic compounds occurred during the active phase of composting with the ammonium nitrogen (NH_4-N) formation. Usually, total N concentration is enhanced during composting when organic matter loss is greater than the loss of NH_3 (Bernal *et al.,* 1998). However, at 120 DOC there was a gradual decrease in total nitrogen percent, which might be because nitrogen losses occurred due to NH_3 volatilization, denitrification, and leaching (Rich *et al.,* 2014).

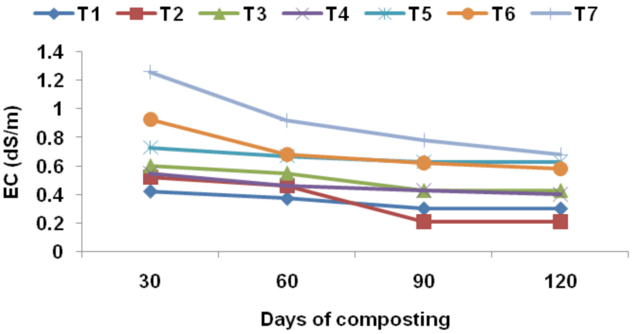

Fig. 5. Changes in EC of different treatments of MSWC

The total phosphorus and total potassium (Fig. 6b & c) were estimated initially at 30 DOC and subsequently at 30-day intervals up to maturity (120 DOC). At 30 DOC highest total P (0.33%) was recorded in treatment T_2 followed by the treatments T_5, T_7, T_3, T_4, T_6, and T_1 with 0.31, 0.31, 0.26, 0.26, 0.25, and 0.21%, respectively. It enhanced frequently at 60, 90, and 120 DOC and stabilized at maturity (Fig. 6b). Study showed that all the treatments have the approximately corresponding value for the total phosphorus which varies between 0.39 to 0.41% at maturity.

Potassium is an important nutrient of plants which immobilized in organic matter. During the decomposition of organic matter, the potassium is liberated and finally, compost contains potassium in the available form. Because of highly soluble, its concentration increases with the progress of decomposition (Gallando and Nogales 1987; Kumar *et al.* 2014). The present study revealed that treatment T_7 estimated the highest potassium content (0.61%) which is followed by the treatments T_5, T_6, T_4, T_2, T_3, and T_1 with 0.56, 0.54, 0.53, 0.50, 0.50, and 0.49% in that order at 30 DOC (Fig. 6c). Total potassium content was pursuing the increasing trend at 60, 90 and 120 DOC as compared to 30 DOC. At 120 DOC the highest total potassium was found in treatment T_5 (0.76%) which is followed by the treatments T_7, T_6, T_4, T_3, T_1, and T_2 with 0.74, 0.67, 0.65, 0.58, 0.57 and 0.56% in that order and acquired constant value. The total phosphorus and potassium levels in all the treatments followed the increasing trends when compared with primary values and therefore C: P and C: K ratios decreased with increased time intervals. Inbar *et al.* (1993); Khalil *et al.* (2011); and Moretti *et al.* (2015) also reported similar results during composting.

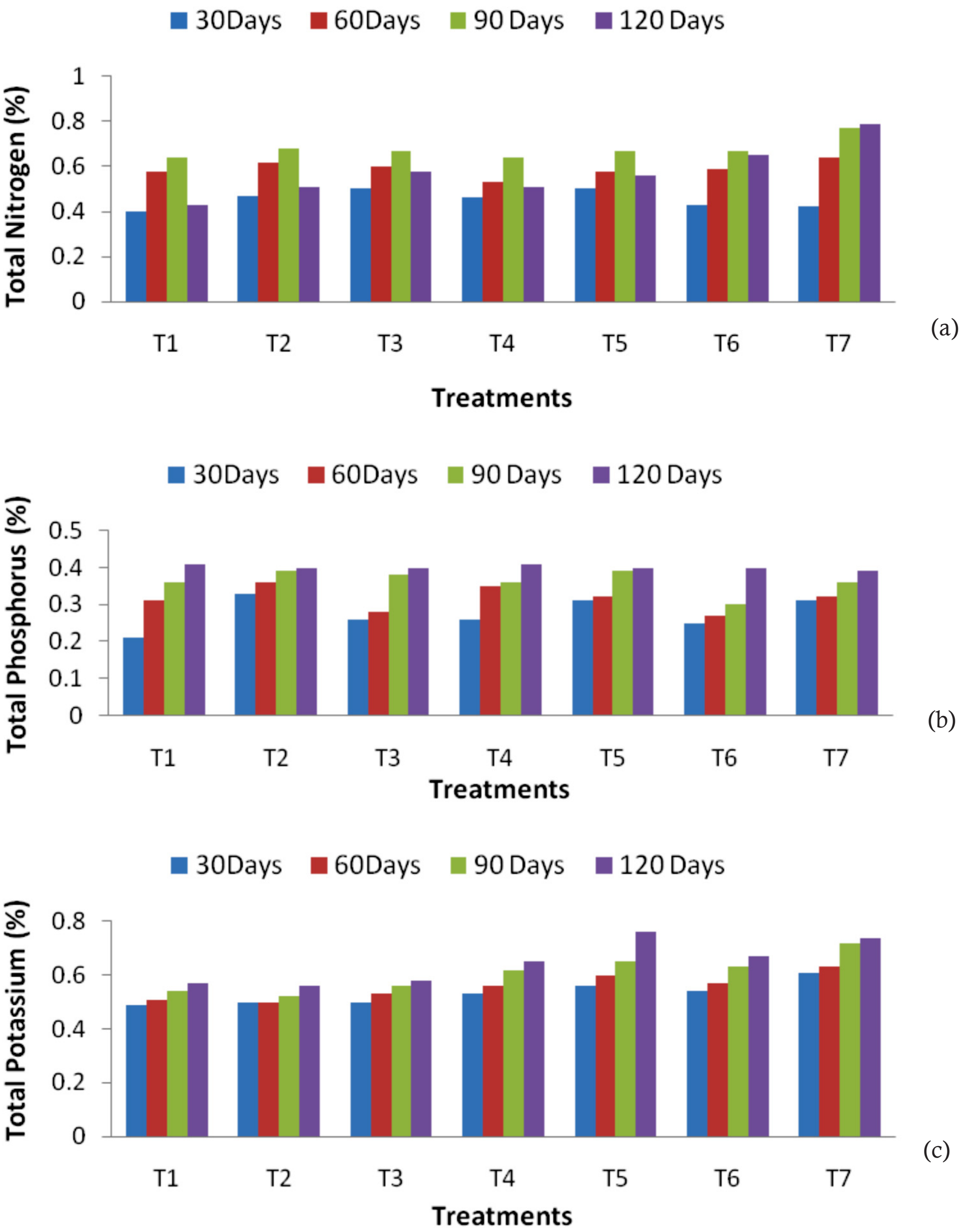

Fig. 6. Changes in (a) total N (b) total P and (c) total K during composting

Calcium is a vital nutrient and is required by organisms and plant cells to maintain their structure. The major sources of calcium in municipal solid waste are vegetables, food, animal wastes, organic wastes, etc. Investigation showed that calcium content varied between 10 to 17 ppm in treatments T_1 to T_7 at 30 DOC. However, at maturity, it increased 12-27 times and reached the level of 210 to 270 ppm in different treatments. Moretti *et al.* (2015) also reported that calcium levels were enhanced at the maturity of composting as compared to initial values. Heavy metal contents like As, Cd, Ni, and Pb were found below the detectable limits.

The highest total carbon content was found as 14.61% in treatment T_7 whereas the lowest was in treatment T_4 at 30 DOC. At maturity, the highest and lowest total carbon content was found in the treatments T_5 (13.69%) and T_1 (11.14%) respectively. It was observed that the total carbon content decreased at the maturity as compared to 30 DOC in the treatments T_1, T_2, T_4, $T_{5,}$ and T_7 with 19, 14, 2, 2, and 7% respectively. The total carbon content declined continuously during decomposition and stabilized at maturity in all the treatments. This was due to the breakdown and transformation of complex

Table 2. Changes in the C: N ratio under different treatments at a certain interval

Treatment	30Days	60Days	90 Days	120 Days
T_1	34.50	18.74	16.31	25.89
T_2	27.82	19.55	16.58	22.17
T_3	26.44	25.71	17.41	23.50
T_4	24.69	25.07	16.31	21.94
T_5	27.84	20.96	20.71	24.44
T_6	27.97	19.49	18.12	18.51
T_7	34.78	20.71	15.64	17.13

Table 3. Changes in microbial properties during composting

Treatment	Initial (30 Days)		Maturity (120 days)	
	Bacterial population (Cfu/gm)	Fungal population (Cfu/gm)	Bacterial population (Cfu/gm)	Fungal population (Cfu/gm)
T_1	48×10^4	45×10^4	26×10^4	33×10^4
T_2	54×10^4	60×10^4	44×10^4	26×10^4
T_3	79×10^4	60×10^4	56×10^4	36×10^4
T_4	73×10^4	42×10^4	60×10^4	28×10^4
T_5	69×10^4	52×10^4	54×10^4	23×10^4
T_6	79×10^4	41×10^4	68×10^4	18×10^4
T_7	98×10^4	79×10^4	75×10^4	48×10^4

organic compounds into simpler compounds and evolution of CO_2 and the assimilation of carbon by microorganisms (Carbera *et al.,* 2005; Contreras-Ramos *et al.*, 2004).

Change in Carbon Nitrogen Ratio (C: N)

The C: N ratio determines the nutritive balance and it is an imperative index to estimate whether compost has been stabilized thoroughly (Kumar *et al.,* 2010; Rich *et al.,* 2014). It is observed that the C: N ratio decreased at 60 and 90 DOC in all the treatments. However, at 120 DOC C: N ratio followed an increasing trend in all the treatments but it was less than the levels recorded at 30 DOC. It is because the N remains in the system while some of the C is released as CO_2. Further nitrogen-fixing bacteria indirectly help in decreasing the C: N ratio by making more nitrogen available from added organic matter (Rasal *et al.,* 1988., Shinde *et al.,* 1992). Data given in Table 2, showed that the lowest C: N ratio at 30 DOC was found in the treatment T_4 (24.69%) which is followed by the treatment T_3, T_2, T_5, T_6, T_1 and T_7 with 26.44, 27.82, 27.84, 27.97, 34.5 and 34.78% respectively. The lowest C: N ratio at maturity was observed in treatment T_7 (17.13%) which is followed by the treatments T_6, T_4, T_2, T_3, T_5, and T_1 with 18.51, 21.94, 22.17, 23.50, 24.44, and 25.89% in the same order. Other studies also reported the decreasing trends of the C: N ratio where the initial value falls at maturity (Bernal *et al.,* 1998; Verma *et al.,* 2013; Moretti *et al.,* 2015).

Changes in microbial properties

Microorganisms are the major biological agents for the decomposition of municipal solid waste (Gaur *et al.,* 1980). They produce CO_2, water, energy, and other organic products using organic wastes as food material (Pathak *et al.,* 2012). Microbial changes in the initial and final decomposed MSW were analyzed to monitor the quality of the developed compost (Table 3). During the composting process, several changes occurred in different microbial populations. The experimental analysis showed that the bacterial and fungal count (Cfu/ml) was higher at the initial stage and it was reduced in all the treatments at maturity. The highest population of bacteria and fungus at 30 and 120 DOC was recorded in treatment T_7, whereas, the lowest was in treatment T_1 and T_6 respectively. This is because of the depletion of nutrients which is an indicator of the completion of composting process. Pathak *et al.* (2012) also recorded a decreasing trend in microbial population with the composting age.

CONCLUSION

The study concluded that the combined use of municipal solid waste and agricultural wastes used for composting is an alternate option for waste management. The municipal solid waste compost prepared through on-farm composting using 50% municipal solid waste + 50% agricultural wastes enriched with earthworms (*Eisenia fetida*) and degrading microbial strains produced nutrient-rich, cost-effective quality compost. It is also concluded that the compost produced with this protocol is nutrient-rich and cost-effective which may improve the physical, biochemical, and microbial properties of the soil resulting in improved soil fertility and productivity. The use of municipal solid waste compost as a source of organic manure may reduce dependency on inorganic fertilizers and promote organic farming.

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