Int. J. Environ. Sci. Technol. (2015) 12:2015–2024
DOI 10.1007/s13762-014-0582-3

ORIGINAL PAPER

Evolution of chemical and biological characterization during thermophilic composting of vegetable waste using rotary drum composter

V. Sudharsan Varma · A. S. Kalamdhad

Received: 19 August 2013 / Revised: 6 December 2013 / Accepted: 12 March 2014 / Published online: 9 April 2014

Abstract Vegetable waste usually contains high levels of organic matter, moisture and nutrients that make the waste unsuitable for disposal in municipal landfills. Composting of vegetable waste is in practice by many urban local bodies, and therefore, it was composted along with cow dung and sawdust in a 550-L batch scale rotary drum composter. Four different trials of varying waste combinations of vegetable waste, cow dung and sawdust, i.e., trial 1 (5:4:1), trial 2 (6:2:1), trial 3 (7:2:1) and trial 4 (8:1:1) were composted by adding 10 kg of dry leaves as bulking agent with a total mass of 100 kg. With proper combinations of organic waste mix, a maximum temperature of 66.5 °C was observed in trial 1 and 61.4 °C in trial 2, when compared to other two trials with prolonged thermophilic period. Due to such elevated temperature, higher degradation was observed in trials 1 and 2 with inactivation of pathogens to considerable amounts. Furthermore, final compost had total nitrogen of 2.31 and 3.01 %, total phosphorous of 4.30 and 3.27 % and final carbon-to-nitrogen ratio of 15 and 12, in trials 1 and 2, respectively. Carbon dioxide evolution and oxygen uptake rate of compost samples was analyzed for its stability and was observed to reduce completely at the end of 20 days with lower emission rates.

Keywords Vegetable waste · Composting · Rotary drum composter · Temperature · Carbon-to-nitrogen ratio · Stability

V. Sudharsan Varma (✉) · A. S. Kalamdhad
Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati 781039, India
e-mail: svarma2010@iitg.ernet.in

Introduction

In India, more than one-fourth of the municipal solid waste (MSW) produced comprises vegetables, fruits and animal matter (Sarkar et al. 2010) and the organic fractions of the MSW makes up 40–85 % of the total waste generated (NSWAI 2003). Vegetable waste with high biodegradable organic matter can be successfully composted for its reuse of nutrients as fertilizer and soil conditioner (Crowe et al. 2002). Anton et al. (2005) had reported that composting of vegetable waste may reduce the environmental impact on climate change by 40–70 %, compared to landfilling and incineration. During composting, the organic matter is biologically degraded by several groups of microorganisms to form a final product containing stabilized carbon, nitrogen and other nutrients in the organic fraction.

During composting, about 50 % of added organic matter has been completely mineralized due to the degradation of easily degradable compounds such as proteins, cellulose and hemicellulose by microorganisms. The final residual organic matter consisted of humic-like substances which are highly non-biodegradable and also the most stable fraction of mature compost (Chefetz et al. 1996). In composting, the organic matter degradation is carried out by different diversity of microorganisms including mesophilic bacteria, spore-forming bacteria, fungi and actinomycetes to transform them into stable humic components (Garcia et al. 1992; Bhatia et al. 2012). However, the degradation pattern and humification during composting is considered to follow different pattern depending on the raw materials used for composting (Huang et al. 2006).

Decentralized composting of organic waste has several advantages in reducing the waste quantities that are transported and also the transportation cost. Moreover, application of these types of systems has a positive effect on the overall MSW management costs (Kalamdhad et al. 2009). One of such techniques includes the use of rotary drum composter. Composting time can be drastically reduced to 15–20 days with higher degradation of organic matter without any leachate production. And moreover, the final compost had been completely stabilized with lower carbon dioxide (CO_2) evolution and oxygen uptake rate (OUR). Organic fractions of MSW, vegetable waste, water hyacinth and many other wastes had been successfully composted using rotary drum composter (Tolvanen et al. 2005; Bhatia et al. 2012; Singh and Kalamdhad 2013). In addition, Gajalakshmi and Abbasi (2008) have also reported the possible advantages of composting and the use of rotary drum for effective degradation process.

Kalamdhad et al. (2008) have reported that the C/N ratio of 20–25 will be optimum with rotary drum composting. However, Tchobanoglous et al. (2000) had reported the production of leachate from organic waste composting with drum composter (in-vessel), even though low C/N ratio has been used. Hence, combinations of different waste materials and optimization of bulking agent addition (sawdust and dry leaves) during composting process will overcome this issue. Therefore, the present study dealt with the composting of vegetable waste using rotary drum in four different waste combinations including vegetable waste, cow dung and sawdust, i.e., trial 1 (5:4:1), trial 2 (6:3:1), trial 3 (7:2:1) and trial 4 (8:1:1), by adding 10 kg of dry leaves in each of the trial as bulking agent. Compost quality and stability was studied throughout the 20 days of composting period with 2-day interval period. The experiments were carried out in the Department of Civil Engineering, Indian Institute of Technology, Guwahati, India, during the period of April 2012 to August 2012.

Materials and methods

Feedstock material

Vegetable waste was collected from various hostels and dry leaves from Indian Institute of Technology Guwahati campus, Guwahati, India. Cow dung was collected from nearby dairy farm, and sawdust was collected from saw mill, Amingaon village, Guwahati, India. Prior to composting, the maximum particle size of the vegetable waste was restricted to 1 cm for better mixing and degradation. Before addition of waste into the drum composter, mixing of waste materials plays a crucial role in degradation process. Since cow dung also has high amount of moisture content as compared to vegetable waste, mixing of cow dung directly to the vegetable waste will add up more moisture content, and during degradation, it will result in leachate production and odor. Sometimes, the added cow dung will be adhered along with degraded vegetable waste resulting in clumps with improper degradation. Hence, the best practice is to mix manually the cow dung with sawdust to form as a free flowing material. This type of mixing will result in lower moisture content, and it should be followed by the addition of vegetable waste. Dry leaves were crushed manually to smaller pieces less than 1 cm and finally mixed to the vegetable waste mix so that it provides better porosity and aeration.

The compost was prepared by mixing different proportions of vegetable waste, cow dung and sawdust mixture in four different trials: trial 1 (5:4:1), trial 2 (6:3:1), trial 3 (7:2:1) and trial 4 (8:1:1), by adding 10 kg of dry leaves in each of the trial as bulking agent, with final amount of 100 kg. Table 1 shows the waste composition and initial characterization of waste materials.

Rotary drum composter design

In order to study the compost stability, a rotary drum composter of 550 L capacity was used as similar to Kalamdhad and Kazmi (2009). The main unit of the composter, i.e., the drum is of 0.92 m in length and 0.9 m diameter, made up of a 4-m-thick metal sheet. Drum was rotated manually once in every 24 h for proper mixing, and aerobic conditions are maintained by opening up both half-side doors of the drum after rotation.

Experimental analysis

Temperature was monitored using a digital thermometer throughout the composting period. Five hundred grams of each grab sample were collected from six different locations by compost sampler without disturbing the adjacent materials. Finally, all the grab samples were mixed thoroughly to make a homogenized sample. Triplicate samples were collected and stored at 4 °C for subsequent analysis. The stability parameters, i.e., OUR and CO_2 evolution was performed as described by Kalamdhad et al. (2008). The biodegradable organic matter was measured as soluble biochemical oxygen demand (BOD) (by the dilution method) and soluble chemical oxygen demand (COD) (by the dichromate method). Bacterial population (1:10 w/v waste:water extract) including total coliforms (TC) and fecal coliforms (FC) were analyzed by inoculation of culture tube medias with Lauryl tryptose broth and EC medium using the most probable number (MPN) method (APHA 1995).

Subsamples were air-dried immediately, ground to pass to 0.2-mm sieve and stored for further analysis. The stored subsamples were analyzed for the following parameters: pH and electrical conductivity (EC) (1:10 w/v waste:water extract), total nitrogen (TN) using Kjeldahl method and

Table 1 Waste composition and Initial characteristics of waste materials

Trial/parameters	Waste materials		
	Vegetable waste (kg)	Cattle manure (kg)	Sawdust (kg)
Trial 1 (90 kg) + 10 kg dry leaves	45	36	9
Trial 2 (90 kg) + 10 kg dry leaves	54	27	9
Trial 3 (90 kg) + 10 kg dry leaves	63	18	9
Trial 4 (90 kg) + 10 kg dry leaves	72	9	9
pH	5.23 ± 0.02	7.92 ± 0.01	6.86 ± 0.02
Electrical conductivity (dS m^{-1})	1.88 ± 0.01	3.10 ± 0.02	1.06 ± 0.02
Moisture content (%)	91.20 ± 2.22	75.14 ± 0.52	41.02 ± 0.32
Ash content (%)	10.12 ± 0.16	38.22 ± 2.12	1.90 ± 0.12
Total organic carbon (TOC) (%)	49.84 ± 2.22	32.22 ± 1.24	53.44 ± 1.22
Total nitrogen (%)	2.59 ± 0.07	1.35 ± 0.20	0.55 ± 0.02
Nitrate nitrogen (NO_3–N) (%)	ND	ND	ND
Ammonical Nitrogen (NH_4–N) (%)	0.65 ± 0.04	0.36 ± 0.04	0.23 ± 0.03
Total phosphorous (mg L^{-1})	6.6 ± 0.25	7.8 ± 0.41	1.22 ± 0.05
Available phosphorus (mg L^{-1})	1.10 ± 0.14	1.15 ± 0.04	0.61 ± 0.06
C/N ratio	19 ± 0.24	23.46 ± 0.40	95 ± 2.16
Chemical oxygen demand (COD) (mg L^{-1})	4300 ± 20	440 ± 16	480 ± 30
Biochemical oxygen demand (COD) (mg L^{-1})	1950 ± 30	120 ± 20	250 ± 20
CO_2 evolution (mg g^{-1} VS day^{-1})	26 ± 2.83	17.2 ± 0.2	13.2 ± 0.6
Oxygen uptake rate (OUR) (mg g^{-1} VS day^{-1})	29.4 ± 0.8	18.9 ± 0.7	10.9 ± 0.54

ND not detected

ammonical nitrogen (NH_4-N) was analyzed by KCL extraction method. Volatile solids (VS) were determined by loss ignition method (on dry mass basis) at 550 °C for 2 h. The total organic carbon was calculated from VS. Total and available phosphorus (acid digest) was performed using stannous chloride method (APHA 1995). The flame photometer (Systronic 128) was used for analysis of Na, K and Ca concentration, and atomic absorption spectrometer (Varian Spectra 55B) was used for analysis of Mg, Zn, Cu, Mn, Fe, Ni, Pb, Cd and Cr concentration after digestion of the 0.2 g sample with 10 mL H_2SO_4 and $HClO_4$ mixture (5:1) in block digestion system (Pelican Equipments Chennai-India) for 2 h at 300 °C.

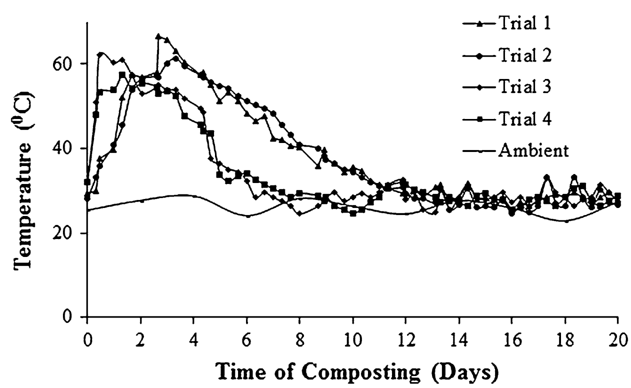

Fig. 1 Temperature pattern during composting period

Results and discussion

Physicochemical parameters

Temperature

Figure 1 shows the temperature profile of different trials during rotary drum composting. In all the trials, a fast increase in temperature was recorded indicating a higher microbial activity. Due to the higher indigenous microbial populations, the initial lag period was not recorded and early thermophilic period was observed in all the trials. Even though rise in temperature was recorded in the early stages of all the trials, the temperature pattern was completely different in all trials during the study, which might be due to the varying amount of vegetable waste added in all the trials. A maximum of 66.5 °C was observed in trial 1, 61.4 °C in trial 2, 60.9 °C in trial 3 and 57.4 °C in trial 4. Eventhough maximum temperature was observed in trial 1, maximum soluble BOD reduction was observed in trial 2, while TOC and VS reduction was observed high in trial 1. Gray et al. (1971) have reported that temperature greater than 65 °C might inactivate the fungi, actinomycetes and most of the bacteria which play a major role in degradation during thermophilic stages and only spore-forming bacteria can be developed. As soon the thermophilic stage was achieved in trials 1 and 2, the top layer of the compost was completely observed with the spores of microbial communities due to such elevated temperature. However, such findings were not observed in trials 3 and 4. Trial 2 was observed to maintain a longer thermophilic period when compared to all other trials. Temperature greater than 55 °C for 2 days would be sufficient to maximize sanitation and destroy pathogens (Petrica et al. 2009). The present investigation was observed to maintain such elevated temperature more than 6 days and started to decrease, which might be due to the depletion of readily biodegradable components. Hence, trials 1 and 2 were observed to provide higher thermophilic conditions to the compost when compared to other two trials due to proper combinations of waste materials.

pH and electrical conductivity (EC)

The changes in pH were observed to carry out the same pattern in all the trials, ranging from slight acidic to slight alkaline conditions (Fig. 2). Initially, the pH was in the range of 6.7, 6.7, 5.8 and 6.4, and finally, it increased toward alkaline conditions and was in the range of 7.7, 8.0, 7.9 and 7.8 in trials 1, 2, 3 and 4, respectively. The pH value was observed to maintain constant during the final stages of composting, which can be attributed to the stabilization of compost and with lower activities of microbial population. Most compost has a pH value between 6 and 8 (Tiquia and Tam 2000).

Due to higher temperatures during composting process, loss of organic matter was observed high which gradually increased the value of EC in all the trials. Figure 2 shows increase in EC in all trials. The increase in EC can be considered due to the increase in mineral cation concentration that is not attenuated by salt leaching or by binding to stable organic complex and majorly due to loss of organic matter (Francou et al. 2005). The increase in EC due to degradation of organic matter during composting process was in accordance with the reports by Singh and Kalamdhad (2013).

Moisture, volatile solids (VS) and total organic carbon (TOC)

Organic matter degradation in composting can be viewed as a result of rise in temperature. As the temperature rises, loss in moisture content can be observed. Figure 3 depicts the loss of moisture content during the composting period. Hence, loss of moisture during the composting process can be viewed as an index of decomposition rate (Liao et al. 1996). However, the composting material should have

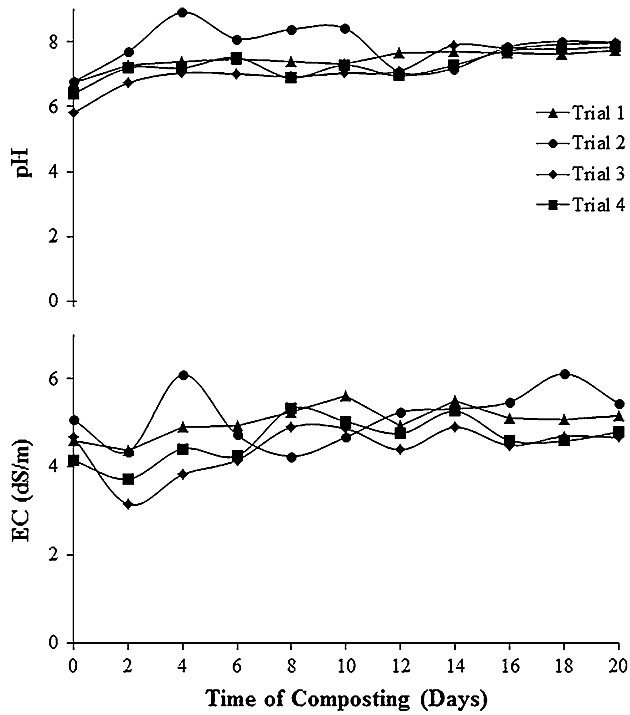

Fig. 2 pH and EC variation during composting period

minimum moisture content for the survival of microorganisms (Kalamdhad et al. 2008). With higher temperatures in trial 1, it was observed with higher moisture loss of 15.6 % as compared to 9.6 and 7.8 % in trial 2 and 3. In addition, out of 15.6 % reduction during the total 20 days, 10.5 % was reduced within 10 days of the composting period in trial 1. This major reduction is mainly due to the higher temperatures maintained in the compost. Therefore, it can be considered that higher temperatures in the compost environment will lead to major reduction in moisture content. Due to large amount of vegetable waste addition in trial 4, release of moisture content was observed high during the process and the addition of 10 kg dry leaves was not sufficient. Hence, moisture content reduction was not observed proper in trial 4. During microbial metabolism, heat and moisture are released as by-products; in case of inadequate bulking material, the moisture can be trapped in the system, and it reduces the temperature in the composting system.

Along with moisture loss, VS reduction was also observed to reduce drastically due to higher temperature (Fig. 3). As the composting proceeded, due to active microbial action on organic content, higher VS reduction was observed in trials 1 and 3. A maximum of 11.4 and 13.3 % reduction in VS was observed in trials 1 and 3, as compared to 7.2 and 1.7 % in trials 2 and 4, respectively. Even though complete degradation of vegetable waste was achieved at the end of 20 days, the added dry leaves contributed more TOC and VS; hence, reuse of those leaves

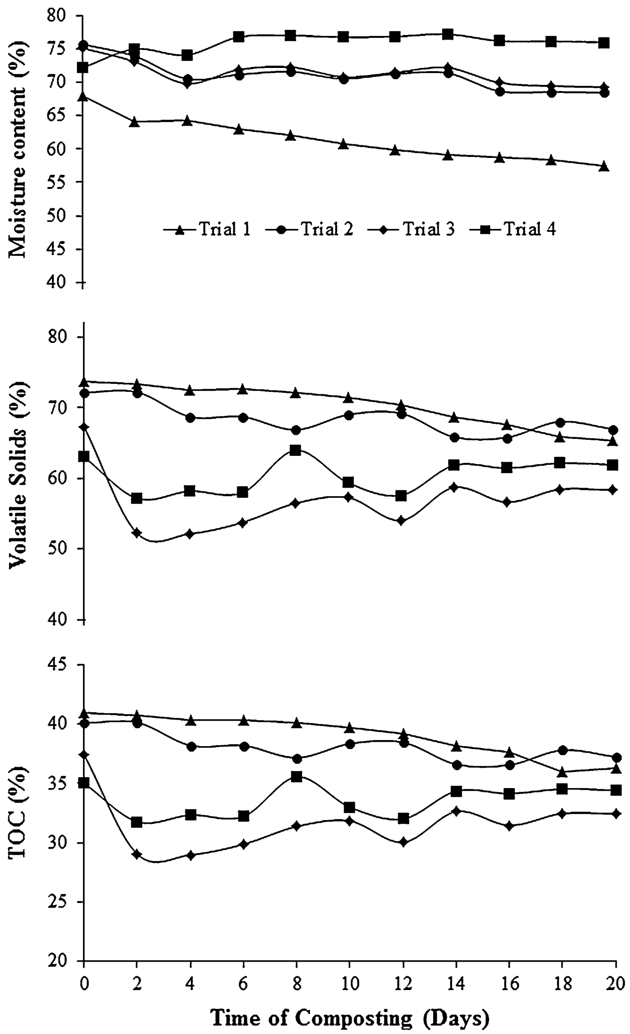

Fig. 3 Moisture content, VS and TOC changes during composting period

after sieving can be suggested. Therefore, the final compost was full of partially degraded dried leaves at the end of 20 days, with complete removal of vegetable waste. However, trials 1 and 3 were observed with higher reduction when compared to all other trials. Similar studies were reported by Kalamdhad et al. (2009) on composting of vegetable waste by adding dry leaves in 3.5-m^3 full-scale rotary drum for 7 days, in which the final compost was sieved by 0.6-mm sieve and the leaves were reused. Hence, it can be considered due to elevated temperatures higher moisture loss was observed in trial 1 and VS reduction was observed in trials 1 and 3.

The changes in TOC during the composting period are detailed in Fig. 3. As the composting proceeds, carbon dioxide is emitted from the composting mass as a metabolic end product. Thus, the total organic carbon content of the composting decreased with mass reduction (Singh et al. 2009). TOC during composting period was initially in the range of 40.9, 40.0, 37.3 and 35.0 % and finally reduced to 36.3, 37.2, 32.41 and 34.4 % in trials 1, 2, 3 and 4, respectively, at the end of 20 days. Eventhough dry leaves were partially degraded at the end of composting, the aim of adding dry leaves was only to serve as bulking agent, so it can be reused along with initial material after sieving. However, vegetable waste was completely degraded at the end of 20 days. Finally, trial 1 was found to have higher reduction in TOC when compared to all other trials. Hence, it can be clearly stated that dry leaves and sawdust contributed to TOC and VS more at the end of composting period.

C/N ratio, nitrogen (NH_4-N and TN) and phosphorous (TP and AP) dynamics

C/N ratio between 10 and 15 in the compost indicates a good degree of maturity (Heerden et al. 2002; Singh et al. 2009). Similar results were observed in the present study with final C/N ratio of 15 and 12 in trials 1 and 2, respectively. The proper degradation in these two trials may be due to the appropriate combination of waste materials. Microorganisms are considered to utilize carbon as a source of energy and the nitrogen for building cell structures, thereby reducing the C/N ratio. However, in trials 3 and 4, not much change was observed. Similar results were observed during the present study in trials 1 and 2, stating the maturity of compost (Fig. 4).

Figure 4 shows the variation in the ammonical nitrogen (NH_4-N) and TN content. Due to enhanced emissions of ammonia (NH_3) and its transformation to gaseous state, NH_4-N was observed to decrease. The decrease might be due to NH_3 volatilization at high temperature and pH rise which was clearly observed in the study. In addition, decrease in NH_4-N can be considered to be due to immobilization as nitrogenous compounds such as amino acids, nucleic acids and proteins by microbes as reported by Sanchez-Mondero et al. (1999). The reduction in NH_4-N was observed from 1.31, 1.41, 1.24 and 1.41 % to 0.85, 0.45, 0.80 and 0.78 % at the end of 20 days in trials 1, 2, 3 and 4, respectively. During the thermophilic phase, the reduction in NH_4-N was observed to follow 42, 77, 19 and 49 % in trials 1, 2, 3 and 4. From the results, it can be clearly stated that the major reduction in NH_4-N has been occurring during the active thermophilic phase (initial 10 days) of the composting period. Hence, for all trials, the emissions of NH_3 and so as reduction in NH_4-N coincided with the maximum of temperature during the composting period.

The maximum NH_4-N content in mature compost should be <0.4 % (Zucconi et al. 1981), and the present study values were not supported. The major focus of the present work was to process the vegetable waste and

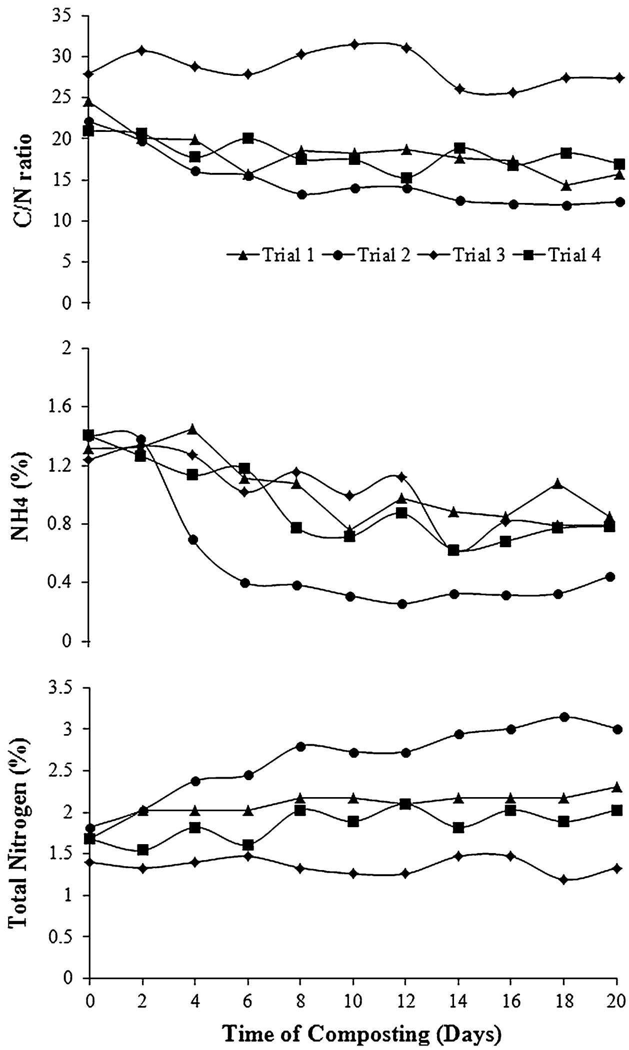

Fig. 4 C/N, NH_4 and TN changes during composting period

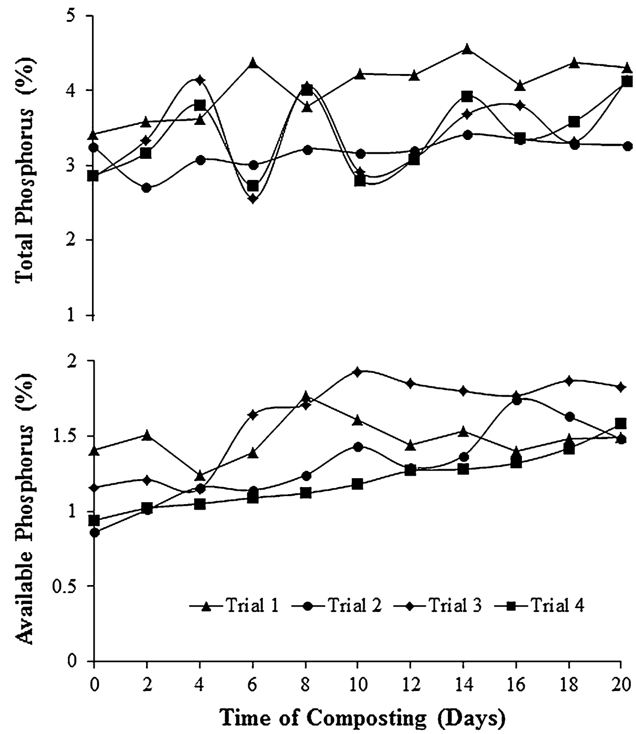

Fig. 5 TP and AP changes during composting period

stabilize it. Hence, the stabilization of compost was achieved within 20 days using rotary drum composter, which was the least time reported elsewhere by the authors (Kalamdhad et al. 2008, 2009; Bhatia et al. 2012; Singh et al. 2009). Hence, for the stabilization of waste, CO_2 evolution and OUR of compost were the major parameters reported by many researchers (Lasaridi and Stentiford 1998; Knoepp and Vose 2002). In addition, C/N ratio of final compost within 10–15 represents the stabilized compost (Singh et al. 2009) and C/N less than 20 represents matured compost (Heerden et al. 2002), which was achieved in the present study. Furthermore, BOD/COD ratio of 0.02 also represents the stabilization of compost as reported by Kalamdhad et al. (2009). Moreover, alkaline pH of the final compost all supports the data. Therefore, the stabilization of compost was completely achieved and supported by reports of many researchers as mentioned above. With respect to NH4-N, a value below 0.04 % represents the maturity of compost as reported by Zucconi et al. (1981), but those reports were supported by experiments conducted for around 150 days. However, many other stabilized composts were not satisfied with the ammonia results as reported by Zucconi et al. (1981), such as experiments conducted by Tiquia and Tam (2000); Kalamdhad et al. (2009). Hence, with all the reports, the present has satisfied most of the standards proposed for stability and maturity.

Transformation of TN depends on the biodegradability of the materials and the ratio of C/N within the biodegradable fraction. TN in all trials was found to increase during the active thermophilic phase due to high NH_3 volatilization. The increase in TN may be considered due to net loss of dry mass as CO_2 evolution and moisture loss by generation of heat by microbial action on organic matter (Bishop and Godfrey 1983). Therefore, TN increased from 1.68, 1.82, 1.40 and 1.68 % to 2.31, 3.01, 1.33 and 2.03 % in trials 1, 2, 3 and 4, respectively, at the end of 20 days (Fig. 4).

Higher amounts of TP and AP were observed in the initial period of composting, which might be contributed by the mix of waste materials in different combinations (Fig. 5). However, TP was observed to increase from 3.41, 3.26, 2.84 and 2.86 % to 4.30, 3.27, 4.14 and 4.13 % in trials 1, 2, 3 and 4, respectively, at the end of 20 days. The increase in TP content is considered due to mineralization of organic material. The higher mineralization of organic can be presented well during the thermophilic phase of the

Table 2 Concentration of micronutrients and heavy metals (dry weight) during composting period

Day	Sodium ($g\ kg^{-1}$)				Potassium ($g\ kg^{-1}$)			
	541	631	721	811	541	631	721	811
0	1.25 ± 0.14	2.72 ± 0.07	2.64 ± 0.08	1.49 ± 0.03	14.08 ± 0.40	9.25 ± 0.05	16.73 ± 0.77	9.88 ± 0.12
20	1.36 ± 0.04	1.75 ± 0.01	2.43 ± 0.00	2.06 ± 0.01	25.67 ± 0.67	14.72 ± 0.03	13.16 ± 1.08	14.77 ± 0.35

Day	Calcium ($g\ kg^{-1}$)				Magnesium ($g\ kg^{-1}$)			
	541	631	721	811	541	631	721	811
0	8.27 ± 0.80	4.88 ± 0.06	11.13 ± 0.30	1.65 ± 0.07	5.40 ± 0.33	5.77 ± 0.03	5.43 ± 0.35	4.78 ± 0.09
20	10.36 ± 0.94	5.64 ± 0.00	28.83 ± 0.16	11.79 ± 0.13	7.41 ± 0.32	7.54 ± 0.06	7.04 ± 0.20	6.28 ± 0.10

Day	Chromium ($mg\ kg^{-1}$)				Cadmium ($mg\ kg^{-1}$)			
	541	631	721	811	541	631	721	811
0	54.75 ± 3.89	26.50 ± 1.41	66.50 ± 4.24	61.25 ± 2.47	71.00 ± 0.71	70.25 ± 2.12	68.00 ± 4.95	62.25 ± 0.35
20	38.50 ± 2.83	35.50 ± 1.41	44.00 ± 5.66	30.50 ± 2.83	68.50 ± 0.71	75.00 ± 2.83	55.25 ± 0.35	55.25 ± 1.77

Day	Nickel ($g\ kg^{-1}$)				Lead ($g\ kg^{-1}$)			
	541	631	721	811	541	631	721	811
0	0.184 ± 0.010	0.154 ± 0.002	0.154 ± 0.002	0.159 ± 0.004	0.99 ± 0.06	0.86 ± 0.02	0.83 ± 0.07	0.75 ± 0.04
20	0.191 ± 0.002	0.181 ± 0.007	0.181 ± 0.007	0.139 ± 0.010	0.96 ± 0.05	0.89 ± 0.04	0.83 ± 0.03	0.67 ± 0.13

Day	Iron ($g\ kg^{-1}$)				Manganese ($mg\ kg^{-1}$)			
	541	631	721	811	541	631	721	811
0	11.80 ± 0.62	6.91 ± 0.04	10.22 ± 0.15	9.77 ± 0.17	0.562 ± 0.005	0.674 ± 0.005	0.433 ± 0.006	0.438 ± 0.006
20	12.40 ± 0.05	10.78 ± 0.01	11.53 ± 0.26	8.19 ± 0.49	0.588 ± 0.004	0.865 ± 0.006	0.478 ± 0.005	0.481 ± 0.007

Day	Zinc ($g\ kg^{-1}$)				Copper ($g\ kg^{-1}$)			
	541	631	721	811	541	631	721	811
0	0.2353 ± 0.0006	0.2629 ± 0.0001	0.2202 ± 0.0008	0.2209 ± 0.0070	0.15 ± 0.03	0.05 ± 0.00	0.04 ± 0.00	0.04 ± 0.00
20	0.2952 ± 0.0006	0.3531 ± 0.0045	0.2708 ± 0.0023	0.2474 ± 0.0004	0.05 ± 0.00	0.09 ± 0.01	0.03 ± 0.00	0.03 ± 0.00

composting period. Such elevated temperatures were observed during the initial 10 days of the composting period due to higher microbial activity. Hence, during the thermophilic period, maximum increase in TP was observed in all the trials. Similarly, AP was observed to increase from 1.41 to 1.49 %, 0.86 to 1.48 %, 1.16 to 1.83 % and 0.86 to 1.48 % in trials 1, 2, 3 and 4, respectively, at the end of 20 days.

Nutrients and heavy metals

Even though nutrient content is low compared to synthetic fertilizers, usually compost is applied at greater rates with significant amounts of nutrient content. These nutrients majorly include nitrogen, phosphorous and potassium (Darlington 2001). Moreover, these micronutrients and heavy metals are observed in significant amounts in vegetable waste, and during composting, it is observed to increase due to mass loss caused by the mineralization of organic fractions (Fang and Wong 1999). Table 2 illustrates the total concentration of micronutrients (Na. K, Ca, Mg) and heavy metals (Cr, Cd, Ni, Pb, Fe, Mn, Zn and Cu) in trials 1, 2, 3 and 4, respectively, during the 20 days of composting period. The increase in total metal concentration can be considered due to loss of net weight during composting. Moreover, few heavy metals like Fe, Zn, Ca and Mg have been reported to be of bioimportance to humans in their daily medicinal and dietary allowances (Singh and Kalamdhad 2011).

Biological analysis

Biodegradable organic matter The organic fractions in the compost mix can be directly measured as soluble BOD and COD. The percentage of the readily bioavailable organics has been considered important for the compost quality (Bernal et al. 1997). The organic fraction

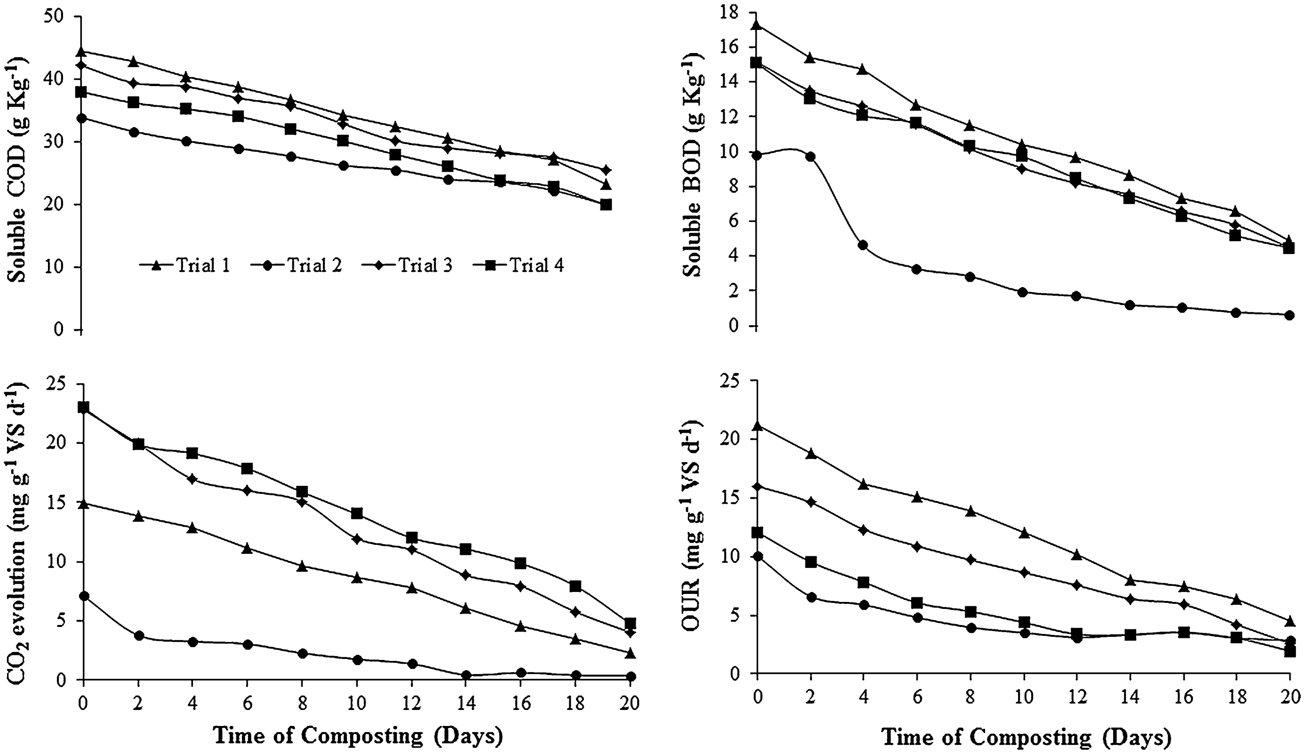

Fig. 6 Soluble COD, soluble BOD, CO_2 evolution and OUR during composting period

degradation can be measured by the decrease in soluble BOD and COD. With proper mixing and agitation, higher degradation was carried out during the process by which the soluble BOD and COD are decreased drastically, resulting in decreased emission of carbon dioxide, ultimately indicating the stabilization of compost.

Soluble BOD values decreased from 17.35 to 4.92 g Kg^{-1} in trial 1, 9.85 to 0.65 g Kg^{-1} in trial 2, 15.18 to 4.52 g Kg^{-1} in trial 3 and 15.10 to 4.49 g Kg^{-1} in trial 4, respectively, within 20 days of composting period. A maximum of 93 % reduction in soluble BOD was observed in trial 2 as compared to 72 % in trial 1, 70 % in both trials 3 and 4. In addition, out of 93 % destruction of bioavailable organics in trial 2, around 80 % of the total soluble BOD reduced was observed during the initial 10 days, i.e., during the active thermophilic phase. Correspondingly, soluble COD values decreased 44.41–23.21 g Kg^{-1} in trial 1, 33.91–19.95 g Kg^{-1} in trial 2, 42.22–25.55 g Kg^{-1} in trial 3 and 38.01–19.94 g Kg^{-1} in trial 4, respectively (Fig. 6). As compared to all the trials, higher soluble COD reduction of 47.5 % was observed in trial 1. In other trials, it was in the range of 41.2, 39.5 and 47.5 % in trials 2, 3 and 4, respectively. In comparison with all trials, an average of 20–22 % of soluble COD reduction was observed during the active thermophilic phase (initial 10 days).

In addition, low soluble BOD/COD ratio may indicate the presence of either organic matter has stabilized such that microbial activities have been ceased due to hard materials at the end of composting period (Mangkoedihardjo 2006). Similar findings were observed during the process with reduction in soluble BOD/COD from 0.39 to 0.21, 0.29 to 0.03, 0.35 to 0.17 and 0.39 to 0.22 in trials 1, 2, 3 and 4, respectively. Kalamdhad and Kazmi (2009) reported that final BOD/COD ratio was 0.02, stating the stability of the compost. Eventhough the trials in present study were not similar with such reports, trial 2 was observed with final soluble BOD/COD of 0.03.

CO_2 evolution and oxygen uptake rate (OUR)

The aerobic respiration during composting process can be directly related by the emissions of CO_2 by the microbial activity, and it is measured as the direct method of compost stability, since it measures carbon derived from the compost material being carried out (Kalamdhad et al. 2008). The compost stability can be directly related to the decomposition rate of organic content present and expressed by the rate of biological activity. Figure 6 shows the emissions of CO_2 during the process. Due to higher microbial action on organic content of vegetable waste mix, higher amounts of CO_2 were observed in the initial days. As the composting preceded, these emissions were drastically reduced from 14.9, 7.1, 22.8 and 23.0 mg g^{-1} VS day^{-1} to 2.2, 0.4, 4.1 and 4.8 mg/g VS/day in trials 1, 2, 3 and 4, respectively, at the end of 20 days. The decrease in CO_2 emissions was observed towards the end of composting period stating clearly the deprival of organic content resulting higher degradation.

With higher biodegradable matter in vegetable waste and propagation of microorganisms, OUR will be observed high during the composting process (Iannotti et al. 1993). The rates of oxygen demand will be reduced with lower food available to the microorganisms as the compost proceeds. Similar findings were observed in the present study with initial values ranging in the order of 21.3, 10.1, 16.0 and 12.1 mg g^{-1} VS day^{-1} denoting higher microbial activity and finally reduced to 4.5, 2.9, 2.6 and 1.9 mg g^{-1} VS day^{-1} in trials 1, 2, 3 and 4, respectively, at the end of 20 days. The lower values of OUR at the end of 20 days clearly state that the vegetable waste has been degraded by the microorganisms and converted to a stabilized compost. Hence, at the end of 20 days, the compost has been completely stabilized with lower CO_2 and OUR values.

Coliform

In composting, elevated temperatures and extended thermophilic stages are involved in the inactivation of pathogens and also by the competition with the favored thermophilic microbes (Yadav et al. 2010). Such elevated temperatures are observed in trials 1 and 2, with highest of 66.5 °C in trial 1 resulting in higher removal of TC and FC. The average number of TC bacteria was initially observed in the range of 0.93×10^{11}, 11×10^{11}, 2.1×10^{11} and 1.6×10^{12} MPN g^{-1} of wet weight in trials 1, 2, 3 and 4 and finally reduced to 0.21×10^{3}, 2.4×10^{3}, 1.5×10^{3} and 0.93×10^{4} MPN g^{-1} at the end of 20 days. However, the fecal coliform was in the order of 0.14×10^{7}, 11×10^{7}, 0.93×10^{6} and 2.9×10^{7} MPN g^{-1} in trials 1, 2, 3 and 4 and reduced to 0.15×10^{2}, 2.4×10^{2}, 0.75×10^{2} and 0.75×10^{3} MPN g^{-1} at the end of 20 days. The recommended fecal coliform and streptococci densities for compost hygienization are 5.0×10^{2} and 5.0×10^{3} MPN/g, respectively (Vuorinen and Saharinen 1997). Hence, it can be concluded that the higher temperatures in trials 1 and 2 had played a major role in the destruction of pathogens.

Conclusion

Proper combination of waste materials in trial 1 (5:4:1), i.e., vegetable waste, cow dung, sawdust and addition of 10 kg dry leaves as bulking agent, has produced a stabilized compost at the end of 20 days. Addition of bulking agents such as sawdust and dry leaves played a major role during composting process by rising to elevated temperature and maintaining a prolonged thermophilic phase that was observed in trial 1 with a maximum of 66.5 °C. As a result, higher degradation of organic matter and inactivation of indicator organisms was observed. Longer thermophilic phase due to active microorganisms provided proper degradation in carbon and nitrogen ratio. With higher reduction in organic fractions, such as VS and TOC, the final compost was completely stabilized in terms of lower CO_2 evolution and OUR. However, trial 2 was also observed to have similar reductions as in trial 1. Increase in heavy metals was also observed at the end of 20-day composting period due to loss of organic matter.

Acknowledgments The authors gratefully acknowledge the financial support of the Ministry of Drinking Water and Sanitation, Government of India (Grant No. W. 11035/07/2011-CRSP (R&D) 12/12/2012).

References

Anton MA, Munoz P, Montero JI, Soliva M (2005) Improving waste management in protected horticulture. Agron Sustain Dev 25:447–453

APHA (1995) Standard methods for the examination of water and wastewater, 19th edn. American Public Health Association, Washington

Bernal MP, Paredes C, Sanchez-Monedero MA, Cegarra J (1997) Maturity and stability parameters of composts prepared with a wide range of organic wastes. Bioresour Technol 63:91–99

Bhatia A, Ali M, Sahoo J, Madan S, Pathania R, Ahmed N, Kazmi AA (2012) Microbial diversity during rotary drum and Windrow Pile composting. J Basic Microbiol 1:5–15

Bishop PL, Godfrey C (1983) Nitrogen transformation during sludge composting. Biocycle 24:34–39

Chefetz B, Hatcher PG, Hadar Y, Chen Y (1996) Chemical and biological characterization of organic matter during composting of municipal solid waste. J Environ Qual 25:776–785

Crowe M, Nolan K, Collins C, Carty G, Donlon B, Kristoffersen M, Brogger M, Carlsbaek M, Hummelshoj RM, Thomsen CL (2002) Part 3: Technology and market issues. EEA, Copenhagen

Darlington W (2001) Compost—A guide for evaluating and using compost materials as soil amendments, vol 714. Soil and Plant Laboratory, Inc, Orange Office, California, pp 282–8777

Fang F, Wong JWC (1999) Effects of lime amendment on availability of heavy metals and maturation in sewage sludge composting. Environ Poll 106:83–89

Francou C, Poitrenaud M, Houot S (2005) Stabilization of organic matter during composting: influence of process and feedstocks. Compost Sci Util 13:72–83

Gajalakshmi S, Abbasi SA (2008) Solid waste management by composting: state of the art. Crit Rev Environ Sci Technol 38:311–400

Garcia C, Hernandez T, Costa F (1992) Characterization of humic acids from uncomposted and composted sewage sludge by degradative and non-degradative techniques. Bioresour Technol 41:53–57

Gray KR, Sherman K, Biddlestone AJ (1971) Review of composting—part 1. Proc Biochem 6:32–36

Heerden IV, Cronje C, Swart SH, Kotze JM (2002) Microbial, chemical and physical aspects of citrus waste composting. Bioresour Technol 81:71–76

Huang GF, Wu QT, Wong JWC, Nagar BB (2006) Transformation of organic matter during co-composting of pig manure with saw dust. Bioresour Technol 97:1834–1842

Iannotti DA, Pang BL, Toth D, Elwell L, Keener HM, Hoitink HAJ (1993) A quantitative respirometric method for monitoring compost stability. Compost Sci Util 1:52–65

Kalamdhad AS, Kazmi AA (2009) Rotary drum composting of different organic waste mixtures. Waste Manag Res 27:129

Kalamdhad AS, Pasha M, Kazmi AA (2008) Stability evaluation of compost by respiration techniques in a rotary drum composter. Resour Conserv Recycl 52:829–834

Kalamdhad AS, Singh YK, Ali M, Khwairakpam M, Kazmi AA (2009) Rotary drum composting of vegetable waste and tree leaves. Bioresour Technol 100:6442–6450

Knoepp JD, Vose JM (2002) Quantitative comparison of in situ soil CO2 flux measurement method. USDA Forest Service, Southern Research Station. Research Paper SRS-28

Lasaridi KE, Stentiford EI (1998) A simple respirometric technique for assessing compost stability. Water Res 32:3717–3723

Liao PH, Jones L, Lau AK, Walkemeyer S, Egan B, Holbek N (1996) Composting of fish wastes in a full-scale in-vessel system. Bioresour Technol 59:163–168

Mangkoedihardjo S (2006) Revaluation of maturity and stability indices for compost. J Appl Sci Environ Manag 10:83–85

National Solid Waste Association of India (NSWAI) (2003) Urban municipal solid waste management. Special Bulletin of the National Solid Waste Association of India, Mumbai

Petrica I, Sestanb A, Sestanc I (2009) Influence of wheat straw addition on composting of poultry manure. Process Saf Environ Prot 87:206–212

Sanchez-Mondero MA, Roig A, Cegarra J, Bernal MP (1999) Relationships between water-soluble carbohydrate and phenol fractions and the humification indices of different organic wastes during composting. Bioresour Technol 70:193–201

Sarkar S, Banerjee R, Chanda S, Das P, Ganguly S, Pal S (2010) Effectiveness of inoculation with isolated Geobacillus strains in the thermophilic stage of vegetable waste composting. Bioresour Technol 101:2892–2895

Singh J, Kalamdhad AS (2011) Effects of heavy metals on soil, plants, human health and aquatic life. Int J Res Chem Environ 1:15–21

Singh J, Kalamdhad AS (2013) Assessment of bioavailability and leachability of heavy metals during rotary drum composting of green waste (Water hyacinth). Ecol Eng 52:59–69

Singh YK, Kalamdhad AS, Ali M, Kazmi AA (2009) Maturation of primary stabilized compost from rotary drum composter. Resour Conserv Recycl 53:386–392

Tchobanoglous G, Theisen H, Vigil S (2000) Integrated solid waste management engineering and management issues. McGraw-Hill, New York 978

Tiquia SM, Tam NFY (2000) Fate of nitrogen during composting of chicken litter. Environ Pollut 110:535–541

Tolvanen O, Nykanen J, Nivukoski U, Himanen M, Veijanen A, Hanninen K (2005) Occupational hygiene in a finish drum composting plants. Waste Manag 25:427–433

Vuorinen AH, Saharinen MH (1997) Evolution of microbiological and chemical parameters during manure and straw co-composting in a drum composting system. Agric Eco Environ 66:19–29

Yadav KD, Tare V, Ahammed MMA (2010) Vermicomposting of source-separated human faeces for nutrient recycling. Waste Manag 30:50–56

Zucconi F, Forte M, Monac A, De Bertoldi M (1981) Evaluating toxicity of mature compost. Biocycle 22:54–57