

Organic Matter Transformation during Rotary Drum Composting

Ajay S. Kalamdhad^{1*} • Muntjeer Ali² • Meena Khwairakpam² • A. A. Kazmi²

¹ Department of Civil Engineering, Indian Institute of Technology, Guwahati – 781039, India

² Department of Civil Engineering, Indian Institute of Technology (IITR), Roorkee – 247667, India

Corresponding author: * kalamdhad@gmail.com

ABSTRACT

Organic matter transformation using chemical and spectroscopic methods was studied for composting of four carbon/nitrogen (C/N) ratio waste combinations (C/N 16, C/N 22, C/N 30 and C/N 38) of grass cuttings, mix vegetable waste, cattle manure, food waste and sawdust. Temperature, moisture content, ash content, total organic matter, C/N ratio and water-soluble organic carbon (WSOC) concentrations were observed in a rotary drum composter for 20 days. In addition, a spectroscopic method (Fourier-transform infrared) was used to study the chemical composition of the organic matter. Temperature reached above 50°C in all waste combinations indicating the immense oxidation within the rotary drum composter, resulting in a final higher ash content (62.28%) in C/N 16 compared to about 30-32% for C/N 22, 30 and 38. The C/N ratio decreased rapidly from initial values of 16, 22, 30 and 38 to 5.4, 10.9, 16.6 and 27.2 after 20 days of composting. Total organic carbon (TOC) of the compost displayed a similar trend to WSOC, which decreased to around 34, 31 and 18% in C/N 22, 30 and 38 compared to 58% in C/N 16. The infrared spectra of the all treatments exhibited the same band pattern, indicating unnoticeable qualitative changes during the composting process. The decrease of the 2930/1030, 2850/1030 (aliphatic C/aromatic C) and 2930/1630 (aliphatic C/polysaccharide) ratios monitored in all treatments (higher decrease in C/N 16) and an increase of the 1380/2930 ratio indicated progress of the composting process and consequently a higher degree of decomposition.

Keywords: C/N ratio, Fourier transform infrared spectroscopy, organic matter, rotary drum, water-soluble organic carbon

INTRODUCTION

The use of compost in agriculture as soil amendment is one of the practices for the sustainable management of soils that also contributes to the recycling of organic residues. Composting of biological material generally means a full or a partial mineralization of organic compounds by producing CO₂, H₂O, NH₃, or NO₃, sulphates and carbonates of Ca, Mg and K, oxides of Fe and Mn, and phosphates. Some of these mineralization products get lost from the composting biomass as gaseous compounds (CO₂, H₂O, NH₃), some as solutes with the drainage water (NO₃⁻, SO₄⁻, K and Mg hydrogen-carbonates) and some remain as precipitated or adsorbed compounds (NH₄⁺, K⁺, Ca⁺⁺, Mg⁺⁺, phosphates, sesquioxides) in the final compost product (Saad 2001). A small metabolic sidepath of all composting processes, even under strongly oxidative conditions, leads to the decay of biological masses to form fulvic and humic substances (Saad 2001). These are able either to mummify decaying organic tissues or to become strongly precipitated as humates on the surface of clay particles (mull-formation). In both cases these relatively stable or even inert by-products create the dark, blackish grey color of all composts.

Approximately 50% of added organic matter becomes fully mineralized, mostly due to the degradation of easily degradable compounds such as proteins, cellulose and hemicellulose, which are utilized by microorganisms as C and N sources. The residual organic matter contains newly formed macromolecules along with non-degradable organic matter jointly forming humic-like substances, the most stable fraction of mature compost (Chefatez *et al.* 1996). Organic matter is decomposed for the most part of the soil micro-flora, although slight decomposition occurs even under biotic or photochemical conditions (Saad 2001). In aerobic conditions, there is a great diversity of decomposers, consisting of fungi, actinomycetes and a wide range of bac-

teria, which degrade the readily available organic components or transform them into stable humic components (García *et al.* 1992; Diaz-Burgoa *et al.* 1994; Amir *et al.* 2004). It is reasonable to expect that the humification and transformation process might differ depending upon raw materials used for composting (Huang *et al.* 2006). Humic substances constitute the most important fraction of organic matter because of their effect on soil ecology, structure, fertility and plant growth. Many tests have been proposed to assess the biodegradation and humification of organic matter resulting in compost maturity and stability. Changes in compost stability or the degree to which the composts have been decomposed, can be predicted with C/N in the solid phase (Jiménez and García 1992), soluble organic carbon content in water extract (García *et al.* 1991; Inbar *et al.* 1993), humification indices (Jiménez and García 1992; Chefetz *et al.* 1996), oxygen and CO₂ respirometry (Iannotti *et al.* 1994), plant growth bioassay, or NMR and IR spectroscopy (Chen and Inbar 1993). Several studies have investigated organic matter transformation during composting of municipal solid waste, municipal sewage sludge and separated cattle manure using chemical, spectroscopic and microbiological methods (Chefetz *et al.* 1981; Chen and Inbar 1993; Iannotti *et al.* 1994; Hsu and Lo 1999; Adani *et al.* 2001; Gea *et al.* 2004; Jouraiphy *et al.* 2005; Huang *et al.* 2006).

The above-mentioned investigations generally dealt with windrows and static piles types of composting for various kinds of wastes. However, information on transformation of organic matter in high rate composting such as a rotary drum for mixed organic wastes is rather limited. A rotary drum provides agitation, aeration and mixing of the compost, to produce a consistent and uniform end product. In warm, moist environments with ample amount of oxygen and organic material available, aerobic microbes flourish and decompose the waste at a quicker pace. The compos-

ting time is drastically reduced to 2-3 weeks. A rotary drum is small enough that it can be placed at the site of organic waste generation. It can be fitted to handle a continuous flow of waste and has been used to compost such diverse organic wastes as cattle manure, swine manure, municipal organic waste, biosolids, brewery sludge, chicken litter, animal mortalities and food residuals (Vuorinen and Saharinen 1997; Stelmachowski *et al.* 2003; Mohee and Mudhoo 2005; Tolvanen *et al.* 2005; Smith *et al.* 2006; Aboulam *et al.* 2006; Kalamdhad and Kazmi 2008). In addition, stability evaluation during composting in a pilot-scale rotary drum composter was presented by Kalamdhad *et al.* (2008), who proved that the rotary drum is an appropriate and viable technique for composting various kinds of waste while the goal of rotary drum composting is to stabilize the compost as rapidly as possible. Hence, it is essential to check the organic matter transformation and stability to assess the composting process within rotary drum.

The understanding of organic matter transformation throughout the composting process and proper evaluation of compost stability and maturity are essential for successive utilization of composts. Therefore, the objective of this work was to study organic matter transformation during rotary drum composting of different waste combinations of C/N 16, C/N 22, C/N 30 and C/N 38 for 20 days.

MATERIALS AND METHODS

Rotary drum composting

In order to study compost stability, a rotary drum composter of 250 L capacity was used. The main unit of the composter, i.e. the drum, is 0.92 m in length and 0.9 m in diameter, made up of a 4 mm thick metal sheet. The inner side of the drum is covered by anti-corrosive coating. The drum is mounted on four rubber rollers attached to a metal stand and the drum is rotated manually. In order to provide the appropriate mixing of wastes, 40 mm angles are welded longitudinally inside the drum. In addition to that, two adjacent holes are made on the bottom of the drum to drain off excess water. The shredded mixed organic waste is loaded into the drum by means of a plastic container and filled up to 70% of the total volume. Aerobic conditions are maintained by opening up both half side doors of the drum after four rotations are provided manually on a daily basis, which ensure proper mixing and aeration.

Cattle (buffalo) manure (C/N=20), mixed green vegetable (uncooked cabbage, spinach, cauliflower, potato, bottle gourd, raddish, etc.) waste (C/N=18), food waste (cooked) (C/N=16), grass (Japanese carpet) cuttings (C/N=15) and sawdust (teak, aini, banyan, bijasal, etc.) (C/N=540) were derived from various places of Roorkee City, India. Prior to composting, the maximum particle size in the mixed waste was restricted to 1 cm in order to provide better aeration and moisture control. The material is rendered more susceptible to bacterial invasion by exposing a greater surface to attack and destroy the natural resistance of vegetation to microbial invasion (Gotaas 1956). The compost was prepared with four different proportions of MSW composition, as detailed in **Table 1**. About 100 g of each grab samples were collected from six dif-

ferent locations, mostly at the mid span and ends of the composter by a compost sampler without disturbing the adjacent materials. Finally all the grab samples were mixed together and considered as a homogenized sample. Triplicate samples were collected and stored at 4°C immediately for analysis. Temperature was monitored using a digital thermometer throughout the composting period. Sub-samples were air dried, ground to pass to 0.2-mm sieve and stored for further analysis.

Physico-chemical analysis

The moisture content of composts was determined after drying to a constant weight at 105°C in a forced-air oven (TempStar, India). Total nitrogen was analyzed by the Kjeldahl method and total organic carbon (TOC) using a Shimadzu (TOC-V_{CSN}) Solid Sample Module (SSM-5000A), respectively on sub-samples of composts. Ash measurements were determined at 650°C for 2 h in a muffle furnace. Decomposition was calculated from the initial (A_1), final (A_2) ash content and initial TOC (in fractions) according to the equation (Jouraiphy *et al.* 2005):

$$100 \times ((A_2 - A_1) / A_2 \times (100 - C_1)) \times 100$$

Water-soluble organic carbon (WSOC)

Ten grams of each compost sub-sample was weighed into a 250 ml polycarbonate centrifuge tube and extracted with 100 ml of deionized water by shaking for 24 h. The extracts were centrifuged at 8000 rpm for 20 min and filtered through 0.45 µm filter membranes (Pall Corporation, India). Water extracts were stored at 4°C until analysis for water-soluble organic carbon using a Shimadzu TOC-5000A (Huang *et al.* 2006).

Fourier-transform infrared (FTIR) spectroscopy

FTIR spectra were obtained for a wave number range of 400-4000 cm^{-1} on a Perkin Elmer GX FT-IR system equipped with OMNIC software. The samples were prepared for analysis by mixing 1 g of dried KBr with approximately 7-10 mg of sub-sample and compressing the mixture to pellets using a hydraulic press.

Statistical analysis

Repeated measures treated with ANOVA were used to analyze the significant difference between different waste combinations of C/N 16, C/N 22, C/N 30 and C/N 38 for observed parameters using Statistica software. Tukey's *t*-test was also performed to identify the homogeneous type of waste combinations for their different chemical properties i.e. moisture content, ash content, C/N ratio, decomposition, etc. The probability levels used for statistical significance were $P < 0.05$ for the tests.

RESULTS AND DISCUSSION

The composting process

The mesophilic, thermophilic, cooling and curing stages are clearly depicted in all treatments (**Fig. 1**). C/N 16 con-

Table 1 Waste proportion (wet weight basis).

Feedstock material (MSW composition)	C/N 16	C/N 22	C/N 30	C/N 38
Cattle manure (kg)	5	10	16	22
Grass cuttings (kg)	8	6	4	2
Food waste (cooked) (kg)	16	10	10	7
Vegetable waste (uncooked) (kg)	30	20	20	18
Saw dust (kg)	0	2.7	7.5	10
Compost (kg)	5	5	5	5
Total weight of mixture (kg)	63	55.7	61.5	62
Initial C/N ratio	16	22	30	38
Initial Moisture content (%)	72.3 ± 1.2	69 ± 1.5	68.7 ± 0.8	67.7 ± 1.3
Initial ash content (%)	48.5 ± 1.3	53 ± 1.1	49.1 ± 1.3	41.8 ± 0.9
Initial total organic carbon (%)	29.8 ± 0.8	35.2 ± 0.9	41.2 ± 1.3	46.5 ± 1.2
Initial total nitrogen (%)	1.9 ± 0.2	1.5 ± 0.3	1.3 ± 0.2	1.2 ± 0.1

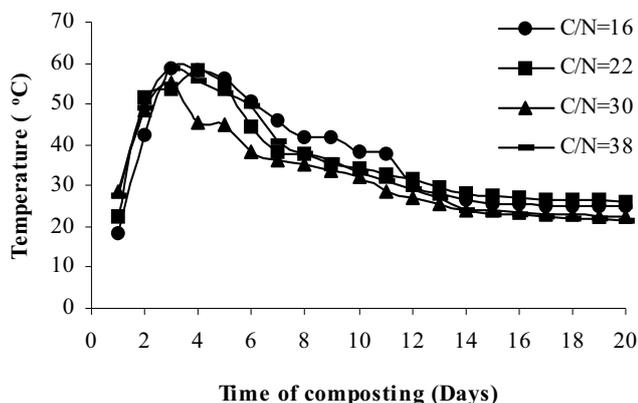


Fig. 1 Temperature profile of the composting materials over time.

taining a high amount of grass cutting reached 59°C (maximum in all 4 cases) and entered the thermophilic phase after two days from the beginning of the treatment. This temperature rise resulted from intense microbial activity favored by the high concentration of easily decomposable organic molecules (Jouraiphy *et al.* 2005). The longer thermophilic phase (5 days) as well as the higher rise in temperature at the beginning of composting was attributed to a sufficient supply of carbon source. Further, a cooling period was observed until the 12th day, and consequently a maturation period. C/N 22 required 4 days, comparative a bit longer than other C/N ratios, to reach a maximum temperature of 58°C. Further, the maturation period was observed from the 12th day after the completion of cooling period of 7 days. In C/N30, the initial temperature was 28.6°C and increased up to 55.2°C and entered the thermophilic phase on day 3 of composting. The thermophilic phase of 3 days and further a cooling period was observed until the 6th day, and consequently a maturation period prolonged up to the 15th day. The temperature reached a maximum of 58.7°C after the third day with an initial C/N ratio of 38 and the cooling period was consequently observed until the 14th day. On analyzing the results by ANOVA, temperature varied significantly among all four treatments ($P < 0.05$).

Moisture loss during the composting process can be viewed as an index of decomposition rate, since the heat generation which accompanies decomposition drives vapo-

rization (Liao 1996). However, the composting material should have a certain moisture content in it for the organism to survive. C/N 16 observed a higher initial moisture content (72.3%) due to the higher content of grass cutting and food waste, which further dropped to 61.7%. Only 14.7% moisture loss was observed since it containing more food/vegetable waste, while in C/N 22, moisture content at the beginning was 69.1% which reduced to 48.5% within 20 days (Table 2). At the beginning moisture content was 68.7 and 67.7%, which reduced further up to 53.5 and 50.1% in C/N 30 and 38, respectively. The difference in moisture content in the top and bottom portions of the composter in all cases was around 2-4%, implying uniformity achieved by rotation. Leachate formation was not observed during the composting period. Lower moisture loss (14.7%) was observed in C/N 16 compared to 29.6, 22.1 and 26.1% in C/N 22, 30 and 38, respectively. On analyzing the results by ANOVA, moisture content varied significantly among all four treatments ($P < 0.05$). Results point out that lower final moisture content observed in C/N 22 (48.5%) indicates lower microbial activities (Gomez *et al.* 2006).

The ash content increased with composting time with 62.2, 30.2, 31.7 and 24.4% for C/N 16, 22, 30 and 38, respectively, owing to the loss of organic matter through microbial degradation (Table 2). The variation in ash content among all four treatments varied significantly ($P = 0.001$). The decrease in organic matter synchronized with an increase in the mass ash of treatments. Decomposition was about 45% in C/N 16, which contained a higher amount of grass cuttings than 31, 35 and 32% in C/N 22, 30 and 38, respectively (Table 3), which indicated that intensive decomposition had taken place during C/N 16. On analyzing the results by ANOVA, decomposition varied significantly among all four treatments ($P < 0.05$).

The change in the C/N ratios reflects the organic matter decomposition and stabilization achieved during composting. The decomposition of organic matter is brought about by living organisms, which utilize carbon as a source of energy and nitrogen for building cell structures. The C/N ratio decreased rapidly from initial values of 16, 22, 30 and 38 to 5.4, 10.9, 16.6 and 27.2 after 20 days of composting (Table 3). Changes in the C/N ratio among all four treatments varied significantly ($P < 0.05$). If the C/N ratio of compost was more, then excess carbon tends to utilize nitrogen in the soil to build cell protoplasm. This results in a loss of soil nitrogen and is known as 'robbing of nitrogen in

Table 2 Changes in moisture content and ash content during composting.

Days	Moisture content (%)				Ash content (%)			
	16	22	30	38	16	22	30	38
1	72.3 ± 1.2 a	69.1 ± 1.3 a	68.7 ± 1.8 a	67.7 ± 1.4 a	48.5 ± 0.8 a	53.2 ± 0.4 a	49.1 ± 0.3 a	41.8 ± 0.4 a
3	72.1 ± 1.7 a	65.7 ± 2.1 ab	68.5 ± 1.4 a	64.3 ± 1.1 b	50.9 ± 0.6 b	55.5 ± 0.3 b	52.7 ± 0.8 b	45.8 ± 0.5 b
5	68.4 ± 1.1 b	64.4 ± 1.5 b	66.6 ± 1.2 ab	63.1 ± 1.7 bc	54.5 ± 1.1 c	59.9 ± 1.1 c	55.8 ± 0.9 c	47.1 ± 0.6 bc
8	65.5 ± 1.5 bc	61.9 ± 1.8 bc	65.5 ± 1.1 bc	60.1 ± 1.3 cd	63.9 ± 0.4 d	61.2 ± 0.6 cd	56.2 ± 0.6 cd	47.9 ± 0.2 c
10	64.3 ± 0.8 cd	59.4 ± 0.8 cd	63.2 ± 0.8 c	57.3 ± 1.5 de	65.2 ± 0.6 d	62.5 ± 1.2 d	57.5 ± 0.7 d	48.4 ± 0.4 c
12	63.1 ± 0.9 cd	57.7 ± 0.7 d	61.3 ± 0.4 d	56.4 ± 0.7 ef	65.9 ± 0.7 d	64.8 ± 0.5 e	58.1 ± 0.4 e	50.1 ± 0.6 d
15	62.9 ± 1.2 cd	51.8 ± 1.1 e	56.6 ± 1.1 d	53.8 ± 0.4 fg	68.4 ± 0.7 e	67.1 ± 0.6 f	58.4 ± 0.2 f	51.7 ± 0.4 e
17	62.5 ± 1.7 cd	50.3 ± 1.7 e	54.8 ± 1.6 d	52.1 ± 1.1 gh	72.6 ± 0.9 f	68.2 ± 0.7 f	62.1 ± 0.8 f	51.8 ± 0.6 e
20	61.7 ± 1.1 d	48.5 ± 1.5 e	53.5 ± 1.4 d	50.1 ± 0.7 h	78.7 ± 0.5 g	69.1 ± 0.6 f	64.7 ± 0.7 f	52.1 ± 0.3 e

Mean value followed by different letters in columns is statistically different (ANOVA; Tukey's test, $P < 0.05$)

Table 3 Changes in C/N ratio and decomposition during composting.

Days	C/N ratio				Decomposition (%)			
	16	22	30	38	16	22	30	38
1	15.9 ± 0.2 a	22.1 ± 0.3 a	30.2 ± 0.2 a	38.3 ± 0.2 a	-	-	-	-
3	11.3 ± 0.4 b	22.7 ± 0.2 b	20.1 ± 0.9 bcdf	38.5 ± 0.3 a	6.6 ± 0.2 b	7.1 ± 1.2 b	11.4 ± 0.8 b	16.3 ± 0.7 b
5	11.2 ± 0.3 b	18.4 ± 0.4 c	21.1 ± 0.4 b	31.3 ± 0.4 b	15.5 ± 1.3 c	17.2 ± 1.8 cd	19.5 ± 0.3 cd	19.6 ± 0.5 c
8	9.3 ± 0.5 c	20.7 ± 0.3 d	19.2 ± 0.5 cdef	28.6 ± 0.6 cdffg	32.7 ± 1.4 def	19.2 ± 0.5 de	19.6 ± 0.4 d	22.1 ± 0.6 de
10	12.2 ± 0.4 b	19.7 ± 0.2 e	19.3 ± 0.2 def	28.4 ± 0.2 dffgh	32.4 ± 0.3 ef	21.5 ± 0.6 e	22.6 ± 0.7 efg	23.4 ± 0.3 e
12	9.1 ± 0.3 c	16.1 ± 0.3 f	18.1 ± 0.4 efg	24.8 ± 0.7 e	33.1 ± 0.4 f	25.3 ± 0.8 fg	23.4 ± 0.6 fg	28.2 ± 1.1 f
15	7.7 ± 0.2 c	13.8 ± 0.4 g	19.2 ± 0.3 f	27.4 ± 0.6 f	36.2 ± 0.7 g	28.6 ± 1.3 gh	24.1 ± 0.3 g	31.7 ± 0.4 ghi
17	6.6 ± 0.3 c	12.6 ± 0.2 h	17.8 ± 0.3 gh	29.4 ± 0.5 g	40.6 ± 1.1 h	29.5 ± 0.6 hi	31.4 ± 1.4 h	31.3 ± 0.3 hi
20	5.3 ± 0.2 c	10.9 ± 0.4 i	16.5 ± 0.5 h	27.1 ± 0.3 h	45.6 ± 1.3 i	30.5 ± 0.9 i	34.7 ± 1.5 i	31.9 ± 0.5 i

Mean value followed by different letters in columns is statistically different (ANOVA; Tukey's test, $P < 0.05$)

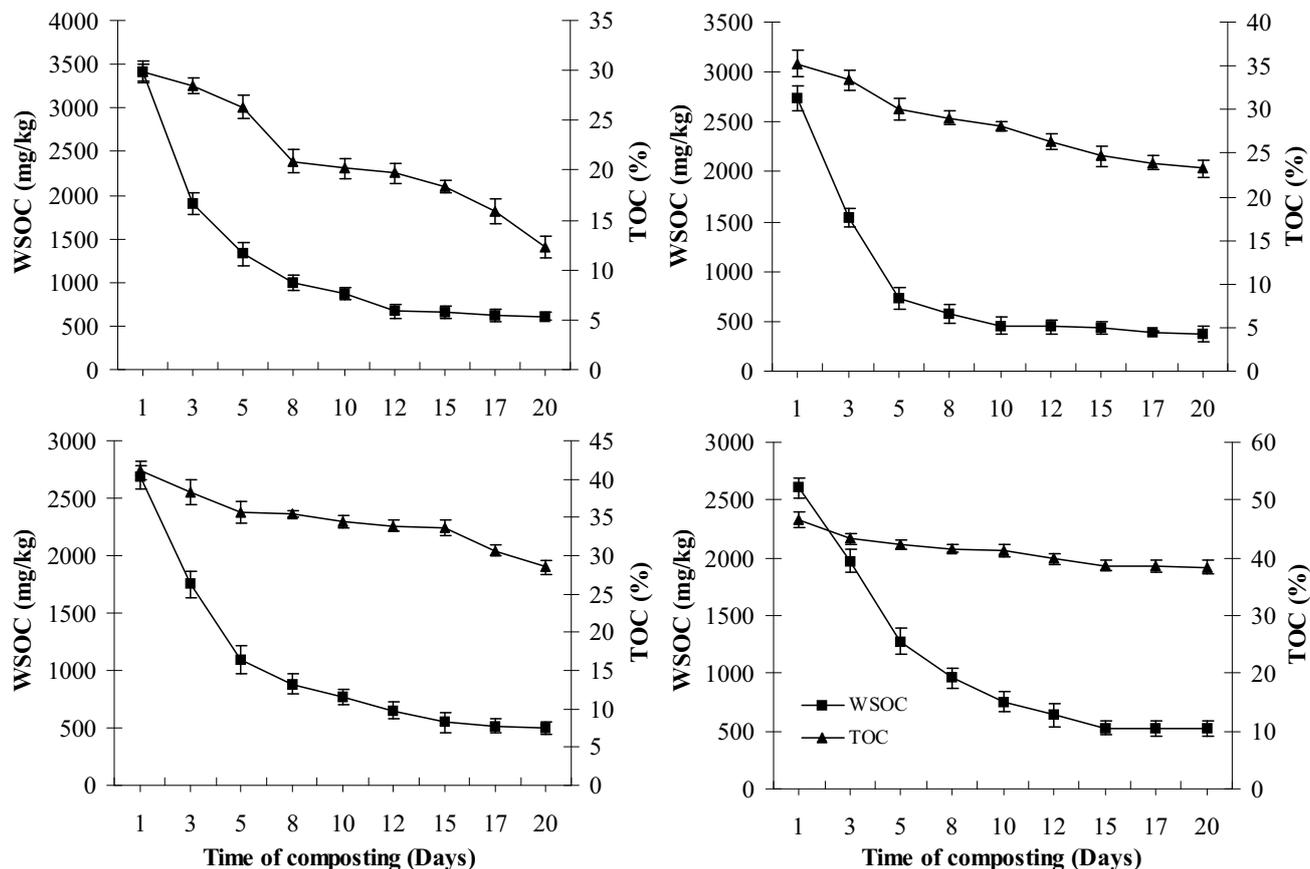


Fig. 2 Reduction in total organic carbon (TOC) and water-soluble organic carbon (WSOC) of the composting materials over time.

the soil' (Gotaas 1956). If, on the other hand, the C/N ratio is too low the resultant product does not help improve the structure of the soil. It is hence desirable to control the process so that the final C/N ratio is ≤ 20 (Hirai *et al.* 1983; CPHEEO 2000). Therefore, it can be concluded that compost with an initial C/N ratio of 30 reached maturation after 20 days of composting, similarly as Huang *et al.* (2004, 2006).

Water-soluble organic carbon (WSOC)

The alkaline pH of the water extracts throughout the composting process was probably due to the release of NH_3 from the composts. WSOC is the most readily active biological parameter in compost, since organic carbon in the water extracts of immature compost consists of sugars, hemicellulose, phenolic substances, amino acids, peptides and other easily biodegradable substances (Hsu and Lo 1999). The WSOC contents of C/N ratios 16, 22, 30 and 38 gradually decreased from initial values of 3144, 2740, 2684 and 2608 mg/kg to 611, 378, 501 and 520 mg/kg, respectively (Fig. 2). On analyzing the results by ANOVA, WSOC varied significantly among all four treatments during 20 days of the composting period ($P < 0.05$). The largest decrease in WSOC content (79%) was observed for C/N 22 after one week of composting. C/N 16 and C/N 30 also observed a significant decreased (67%) after one week of composting. The least decrease (62%) was observed for C/N 30 during the first initial week, but a continuous decrease was observed until the 20 days of the composting period. The decrease in WSOC contents was very low after 12 days of composting in all cases, indicating the stability of finished compost. Final results indicated a 80, 86, 81 and 80% decrease in WSOC contents achieved in C/N 16, 22, 30 and 38, respectively in the rotary drum composter. A continuous decline in WSOC was reported earlier by Inbar *et al.* (1993) and Leita and De Nobili (1991) for cattle manure and municipal solid waste (MSW), respectively.

However, others have reported that there is an initial increase followed by a gradual decrease in WSOC during composting (Dudley *et al.* 1986; Iannotti *et al.* 1994; Hsu and Lo 1999). TOC of the compost displayed a similar trend to WSOC. An exponential model shows a strong correlation with an R^2 value of 0.85, 0.88, 0.87 and 0.94 between TOC and WSOC, respectively in C/N 16, 22, 30 and 38. TOC decreased rapidly from 30, 35.3, 41.2 and 46.5% to 12.3, 23.2, 28.5 and 38.3% after a 20-day composting period respectively in C/N 16, 22, 30 and 38. Around 34, 31 and 18% of the TOC in C/N 22, 30 and 38 were utilized by microorganisms as a source of energy compare to 58% in C/N 16. On analyzing the results by ANOVA, TOC varied significantly among all four treatments ($P < 0.05$). The main components of the WSOC in immature composts are sugars, hemicellulose, phenolic substances, organic and amino acids, peptides, and other easily biodegradable substances (Chen and Inbar 1993; Garcia *et al.* 1991). Humic substances that are resistant to further decomposition are the major components of SOC in mature compost. A decline in WSOC is one of the indicators of compost maturity (García *et al.* 1991; Inbar *et al.* 1991; Saviozzi *et al.* 1992). Results indicated that more degradation of organic matter took place in C/N 16 and 22 compared to C/N 30 and 38 within the 20-day composting period, indicating that the type of raw material greatly affect the WSOC content during composting (Hsu and Lo 1999).

Infrared spectroscopy (FTIR)

The FTIR spectra of the compost at the different stages (1, 7, 15 and 20 days) of treatments (C/N ratios) show similar areas of absorbance and different intensity of certain bands (Fig. 3). The main absorbance bands in all treatment spectra were: a very large broad band centered on 3400 cm^{-1} due to the hydrogen vibrations of alcoholic OH, phenol or carboxyl groups (COOH), but also to N-H vibrations of amides, two distinct peaks at 2930 and 2850 cm^{-1} (C-H asymmetric,

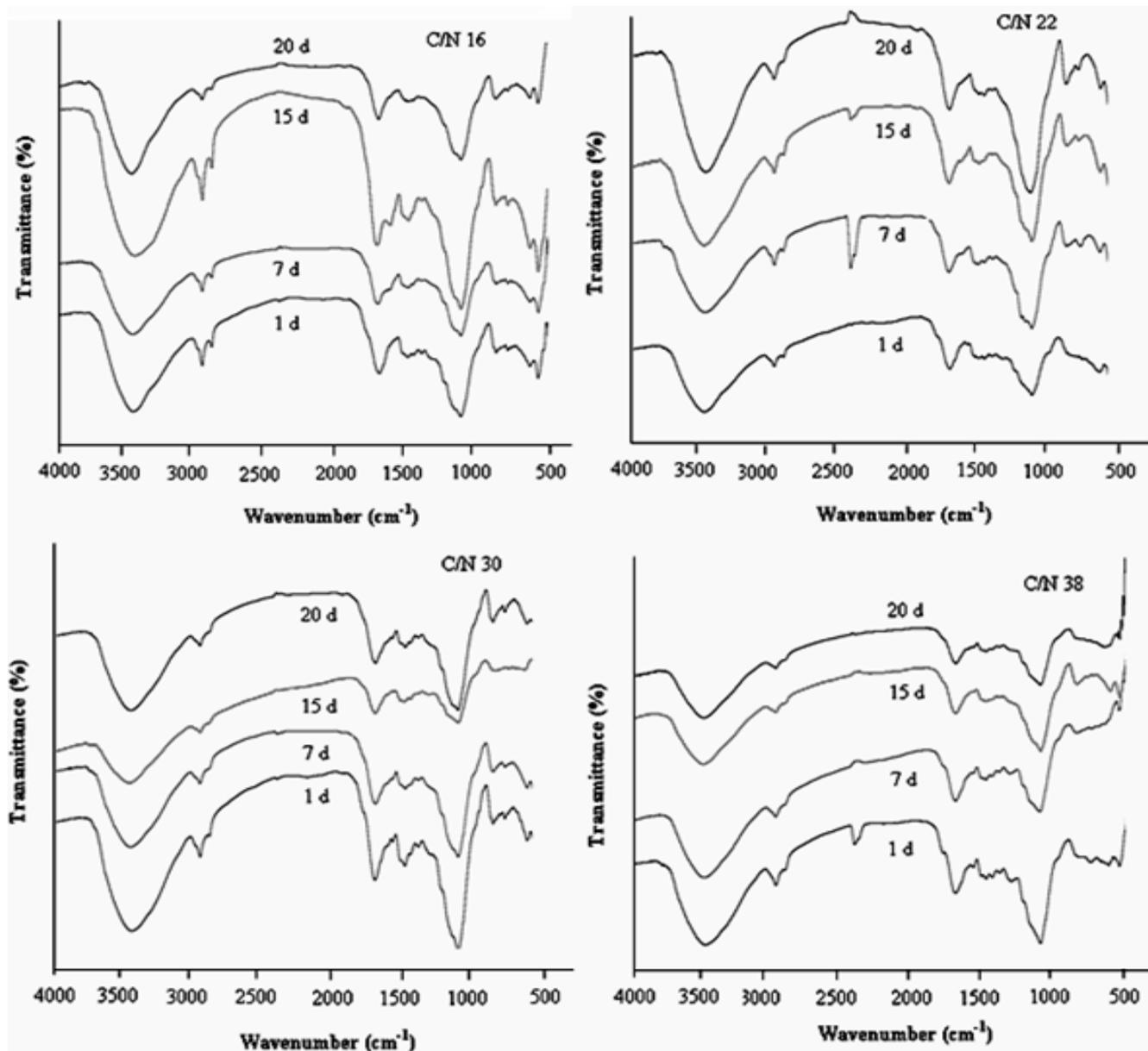


Fig. 3 Infrared spectra of the composting materials over time.

C-H stretch of $-\text{CH}$ aliphatic), a peak at 2365 cm^{-1} due to stretching of CO_2 , a well-pronounced peak at $1630\text{--}1660\text{ cm}^{-1}$ ($\text{C}=\text{C}$ in aromatic structure, COO^- and $\text{C}=\text{O}$ of amides, ketones and/or quinines), a small peak at 1560 cm^{-1} (amide II bonds), the band at $1420\text{--}1430\text{ cm}^{-1}$ is caused by the absorbance of several aliphatic structures, phenolic OH groups, COO^- groups, stretch vibrations of aromatic rings and carbonates, peaks at 1510 , 1462 , 1454 and 1420 cm^{-1} are typically assigned to aromatic rings of lignin, a small peak at 1380 cm^{-1} assigned to ammonium carbonate formed by reaction of ammonia and CO_2 , a broad peak at 1030 cm^{-1} assigned to C-O stretch of polysaccharide, Si-O asymmetric stretch of silicate impurities. The observed results are supported by other researchers (Chen and Inbar 1993; Hsu and Lo 1999; Baddi *et al.* 2004; Castaldi *et al.* 2005; Jouraiphy *et al.* 2005; Huang *et al.* 2006; Grube *et al.* 2006). The above absorbance bands were observed in all C/N ratios but few peaks were observed in only one or two C/N ratios such as a weak band at $1265\text{--}1223\text{ cm}^{-1}$ in C/N 16 and 38 due to amide III or aromatic ethers.

The IR spectra of all treatments exhibited the same band pattern, indicating that no noticeable qualitative changes occurred during the composting process. Changes during composting affected only band intensities, indicating that the increase in composting time does not involve signifi-

cance changes in the compost composition. In particular, a drop occurred in the abundance of structures absorbed in the aliphatic region at around 2930 and 2850 cm^{-1} in all C/N ratios especially in C/N 16. A significant increase in the height of the peak at $1630\text{--}1660\text{ cm}^{-1}$ occurred in C/N 16 and 22 but a small drop was observed in C/N 30 and 38. Conversely, a small rise in the abundance of structures which absorb at around 1034 cm^{-1} occurred in only C/N 22 other than a significant drop observed in C/N 16, 30 and 38. This can be explained with the use of aliphatic and peptide structures and carbohydrates such as polysaccharides, cellulose and hemicellulose by the microbes, to meet their energy needs (Jouraiphy *et al.* 2005, 2008).

Quantitative evaluation of the composting process and maturity is based on the comparison of relative intensity ratios of selected absorbance bands. Smidt and Lechner (2002) and Grube *et al.* (2006) showed similar results in which a decrease of the $2930/1030$, $2850/1030$ (aliphatic C/aromatic C) and $2930/1630$ (aliphatic C/polysaccharide) ratios monitored in all treatments (higher decrease in C/N 16) and an increase of the $1380/2930$ ratio indicated progress of the composting process and consequently a higher degree of decomposition. This is in agreement with the studies of the whole compost FTIR spectra carried out by Hsu and Lo (1999), who also showed that easily biodegradable

organic matter components, such as aliphatic chains, polysaccharides, alcohols and proteins are decomposed and therefore, mature compost contained more aromatic structures of higher stability.

CONCLUSIONS

Organic matter transformation was studied by analyzing changes in WSOC, TOC and IR spectra for different waste composition in a rotary drum. The largest decrease in WSOC and TOC was observed for a lower initial C/N ratio waste composition i.e. C/N 16. The decomposition was 45% for C/N 16 compared to 31, 35 and 32% for C/N 22, 30 and 38, respectively. Similarly, for C/N 16, the IR spectra revealed the largest drop in the aliphatic region at around 2930 and 2850 cm^{-1} . In addition, a greater decrease of the 2930/1030, 2850/1030 (aliphatic C/aromatic C) and 2930/1630 (aliphatic C/polysaccharide) ratios and an increase of the 1380/2930 ratio was observed indicating higher stability. The IR spectra of all treatments exhibited the same band pattern, indicated that no noticeable qualitative changes occurred during the composting process. FTIR spectra indicated that easily biodegradable organic matter components, such as aliphatic chains, polysaccharides, alcohols and proteins are decomposed and therefore, the mature compost contained more aromatic structures of higher stability. Therefore, it can be insinuated that rotary drum composting is more efficient for composting of various kinds of waste at lower initial C/N ratios i.e. C/N 16.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of the Department of Science and Technology (DST), Government of India.

REFERENCES

- Aboulam S, Morvan B, Revel J-C** (2006) Use of a rotating-drum pilot plant to model the composting of household waste on an industrial scale. *Compost Science and Utilization* **14**, 184-190
- Adani F, Lozzi P, Genevini P** (2001) Determination of biological stability by oxygen uptake on municipal solid waste and derived products. *Compost Science and Utilization* **9**, 163-178
- Amir S, Hafidi M, Merlina G, Hamdi H, Revel J-C** (2004) Elemental analysis, FTIR, ^{13}C -NMR of HA from sewage sludge composting. *Agronomie* **24**, 13-18
- Baddi GA, Alburquerque JA, Gonzalvez J, Cegarra J, Hafidi M** (2004) Chemical and spectroscopic analysis of organic matter transformations during composting of olive mill wastes. *International Biodeterioration and Biodegradation* **54**, 39-44
- Castaldi P, Alberti G, Merella R, Melis P** (2005) Study of organic matter evolution during municipal solid waste composting at identifying suitable parameters for the evaluation of compost maturity. *Waste Management* **25**, 209-213
- Chefetz B, Hatcher PG, Hadar, Y, Chen Y** (1996) Chemical and biological characterization of organic matter during composting of municipal solid waste. *Journal of Environmental Quality* **25**, 776-785
- Chen Y, Inbar Y** (1993) Chemical and spectroscopic analysis of organic matter transformations during composting in relation to compost maturity. In: Hoitink HAJ, Keener HM (Eds) *Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects*, Renaissance, Washington, pp 551-600
- CPHEEO** (2000) *Manual on Municipal Solid Waste Management*, Central Public Health and Environmental Engineering Organization, New Delhi, pp 243-261
- Diaz-Burgos MA, Polo A, Calcinai M, Masciandaro G, Ceccanti B** (1994) Use of pyrolysis-gas chromatography to evaluate sludge humification. In: Senesi N, Miano TM (Eds) *Humic Substances in the Global Environment and Implications on Human Health*, Elsevier, Amsterdam, pp 1285-1289
- Dudley LM, McNeal BL, Baham JE** (1986) Time-dependent changes in soluble organics, copper, nickel, and zinc from sludge amended soils. *Journal of Environmental Quality* **15**, 188-192
- García C, Hernández T, Costa F** (1991) Changes in carbon fractions during composting and maturation of organic wastes. *Environmental Management* **15**, 433-439
- García C, Hernández T, Costa F** (1992) Characterization of humic acids from uncomposted and composted sewage sludge by degradative and non-degradative techniques. *Bioresource Technology* **41**, 53-57
- Gea T, Barrena R, Artola A, Sánchez A** (2004) Monitoring the biological activity of the composting process: Oxygen Uptake Rate (OUR), Respiriometric Index (RI), and Respiratory Quotient (RQ). *Biotechnology and Bioengineering* **88**, 520-527
- Gomez RB, Lima FV, Ferrer AS** (2006) The use of respiration indices in the composting process: A review. *Waste Management and Research* **24**, 37-47
- Gotaas HB** (1956) *Composting-Sanitary, Disposal and Reclamation of Organic Wastes*, World Health Organization, Geneva, pp 7-37
- Grube M, Lin JG, Lee PH, Kokorevicha S** (2006) Evaluation of sewage sludge-based compost by FT-IR spectroscopy. *Geoderma* **130**, 324-333
- Hirai MF, Chanyasak V, Kubota H** (1983) A standard measurement for compost maturity. *Biocycle* **24**, 54-56
- Hsu JH, Lo SL** (1999) Chemical and spectroscopic analysis of organic matter transformations during composting of pig manure. *Journal of Environmental Pollution* **104**, 189-196
- Huang GF, Wong JWC, We QT, Nagar BB** (2004) Effect of C/N on composting of pig manure with sawdust. *Waste Management* **24**, 805-813
- Huang GF, Wu QT, Wong JWC, Nagar BB** (2006) Transformation of organic matter during co-composting of pig manure with saw dust. *Bioresource Technology* **97**, 1834-1842
- Iannotti DA, Grebus ME, Toth BL, Madden LV, Hoitink HAJ** (1994) Oxygen respirometry to assess stability and maturity of composted municipal solid waste. *Journal of Environmental Quality* **23**, 1177-1183
- Inbar Y, Chen Y, Hadar Y** (1991) Carbon-13 CPMA NMR and FTIR spectroscopic analysis of organic matter transformations during composting of solid wastes from wineries. *Soil Science* **152**, 272-282
- Inbar Y, Hadar Y, Chen Y** (1993) Recycling of cattle manure: the composting process and characterization of maturity. *Journal of Environmental Quality* **22**, 857-863
- Jiménez EI, García VP** (1992) Determination of maturity indices for city refuse composts. *Agriculture, Ecosystem and Environment* **38**, 331-343
- Jouraihy A, Amir S, El-Gharous M, Revel J-C, Hafidi M** (2005) Chemical and spectroscopic analysis of organic matter transformation during composting of sewage sludge and green plant waste. *International Biodeterioration and Biodegradation* **56**, 101-108
- Jouraihy A, Amir S, Winterton P, El-Gharous M, Revel J-C, Hafidi M** (2008) Structural study of the fulvic fraction during composting of activated sludge-plant matter: Elemental analysis, FTIR and C-13 NMR. *Bioresource Technology* **99**, 1066-1072
- Kalamdhad AS, Kazmi AA** (2008) Mixed organic waste composting using rotary drum composter. *International Journal of Environment and Waste Management* **2**, 24-36
- Kalamdhad AS, Pasha M, Kazmi AA** (2008) Stability evaluation of compost by respiration techniques in a rotary drum composter. *Resource, Conservation and Recycling* **52**, 829-834
- Leita L, De Nobili M** (1991) Water-soluble fractions of heavy metals during composting of municipal solid waste. *Journal of Environmental Quality* **20**, 73-78
- Mohee R, Mudhoo A** (2005) Analysis of the physical properties of an in-vessel composting matrix. *Journal of Powder Technology* **155**, 92-99
- Saad SAM** (2001) Processes and balance of organic matter turnover and transformation of mineral compounds during decomposition of biogenic material in the presence of soil material. PhD thesis, Georg-August-University Göttingen, Germany, pp 7-34
- Saviozzi A, Levi-Minzi R, Riffaldi R, Benetti A** (1992) Evaluating garbage compost. *Biocycle* **33**, 72-75
- Smidt E, Lechner P** (2002) Compost quality assessment and process control using Fourier transform infrared spectroscopy. *Proceedings of an International Symposium on Composting and Compost Utilization*, Columbus, Ohio, pp 1-11
- Smith DR, Cawthon DL, Sloan JJ, Freeman TM** (2006) In-vessel, mechanical rotating drum composting of institutional and food residuals. *Compost Science and Utilization* **14**, 155-161
- Stelmachowski M, Jastrzebska M, Zarzycki R** (2003) In-vessel composting for utilizing of municipal sewage-sludge. *Applied Energy* **75**, 249-256
- Tolvanen O, Nykanen J, Nivukoski U, Himanen M, Veijanen A, Hanninen K** (2005) Occupational hygiene in a finish drum composting plants. *Waste Management* **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. *Agriculture, Ecosystem and Environment* **66**, 19-29