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Estimation of Compost Stability During Rotary Drum Composting of Municipal Solid Waste

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ABSTRACT

Studies are conducted to evaluate the stability of compost prepared by three combinations (C/N 16, 22 and 30) of grass cutting, mix vegetable waste, cattle dung, food waste, paper waste and saw waste in a rotary drum composter. Variations in key stability parameters were observed to assess the stability of compost. The decrease in CO_2 evolution rates for the C/N 16, 22 and 30 strongly recommended the viability of rotary drum for all kind of municipal organic waste with different C/N ratios. Results indicated the compost of C/N 22 with lower final Oxygen Uptake Rate (OUR), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) can be considered as the very mature compost with a Solvita® maturity index of 8, and were ready for usage as a soil conditioner. Therefore, it can be suggested that rotary drum composting of mixed organic waste at initial C/N ratio of 22 can produce stable compost within 20 days of composting.

1) INTRODUCTION

Composting technique is defined as a biological conversion process that converts organic matter into useful manure substances. Composting technique is the cheapest and environment friendly method which can be used for sewage sludge treatment and disposal [1]. An efficient and promising technique in decentralized composting is the rotary drum composting that produces a consistent and homogenous end product without any odor or leachate related problems. The rotary drum reactor can be used for organic waste composting of raw municipal solid waste (MSW) prior to other conventional composting techniques [2]. Rotary drum provides agitation, aeration and mixing of the compost, to produce a consistent and uniform end product. Due to its decentralized processing of the waste with complete mixing and aeration, the time required for the process will be reduced gradually. Stability of the compost is based on the organic matter degradation and its stability during the composting process. In warm, moist environments with ample amount of oxygen and organic material available, aerobic microbes flourish and decompose the waste at a quicker pace [3, 4]. It can be fitted to handle a continuous flow of waste and have been used to compost such diverse organic wastes as cattle manure, swine manure, municipal biosolids, brewery sludge, chicken litter, animal mortalities and food residuals [2, 5]. Kalamdhad and Kazmi [2] has reported that a maximum of 70% reduction in the input volume of the waste can be achieved by the in vessel systems. Furthermore the output material can be successfully applied as soil conditioner. Even though rotary drum composting is a proven-technology that can be applied on the spot, there are many aspects that should be improved in the performance of current composting facilities [6]. Composting is a natural aerobic process by which the microorganisms act upon the organic matter to transform them into a complex metastable compound (Humic substances) with the release of by-products such as CO_2, H_2O. The final product is free of viable human and plant pathogens

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and plant seeds that do not attract insects or vectors, that can be handled and stored without nuisance, and that is beneficial to the growth of plants. Characterized by moderate and almost unchanging microbial growth, stability is an essential parameter for compost quality assessment [7, 8]. Compost stability can be defined as the extent to which readily biodegradable material has decomposed. Compost is considered unstable if it contains a high proportion of biodegradable matter that may sustain high microbial activity.

If the material contains mainly recalcitrant or humus-like matter, it is not able to sustain microbial activity and therefore, it is considered stable. Compost stability is important for product quality assessment, as it affects the response of plants to compost application and its potential for odor generation and pathogen re-growth. Stability prevents nutrients from becoming tied up in rapid microbial growth, allowing them to be available for plant needs. Therefore, it is essential to check the stability of compost produced by rotary drum composter to ensure about the technology and operational performance.

Different methods for measuring stability, based on physical (temperature, aeration demand, odor and color, optical density of water extracts), chemical (volatile solids, C/N ratio, COD, polysaccharides, humic like substances, etc.) and biological (respiration measured either as O_2 consumption, CO_2 production or heat generation, enzyme activities, ATP content, seed germination and plant growth, etc.) characteristics of composts have been proposed, but none has found universal acceptance. Current thought is that respirometric techniques are well suited for compost stability measurement. Many researchers have done studies on stability of compost using either physico-chemical and/or biological methods [7, 9, 10, 11, 12]. The above-mentioned investigations generally dealt with the windrows and static piles types of composting for various kinds of wastes. However, information on stability of compost in rotary drum for the mixed organic wastes is rather limited. While the goals of rotary drum composting technique is to stabilize the compost as rapidly as possible. Hence, it is essential to check the stability to asses the composting process within rotary drum.

Evaluation of compost stability in a rotary drum composter using different waste combinations of same kinds of wastes has already studied [13]. Therefore, the objective of this study is to evaluate the stability of compost in a rotary drum composter using different waste mixtures (C/N 16, C/N 22 and C/N 30) of different kinds of wastes. The emission of ammonia gas is usually very high at low C/N ratios of sewage sludge [14, 15]. Hence the loss of ammonia during composting process should be controlled to enhance the agronomic value of the compost and to reduce atmospheric pollution. The stability of compost is assessed by monitoring physico-chemical and microbial parameters viz. temperature, volatile solids, CO_2, OUR, BOD and COD. The results of this study would be very useful in selecting the best possible combination of wastes to achieve stable compost within short duration.

2) MATERIALS AND METHODS

In order to study the compost dynamics, a rotary drum composter of 250 L capacity was used [2]. The main unit of the composter, i.e. the drum is of 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 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. One rotation at a time on daily basis was made to ensure that the material on the top portion moved to the central portion, where it will be subjected to higher temperature. Thereafter aerobic condition was maintained by opening half side doors. Turning of the compost material is the most common method of supplying oxygen to the composting system conducted in enclosed reactors. It also exposes fresh substrate to the micro-organisms and releases ammonia which is accumulated in the void space of compost material [16]. In addition to that, two adjacent holes are made on bottom of the drum to drain off excess water. The shredded mixed organic waste is loaded into the drum by means of plastic container and filled up to 70% of the total volume.

Cattle (Buffalo) dung, grass cuttings, student hostels food waste (pulses and cooked vegetable), mixed green vegetables waste (uncooked) and paper waste collected from boys hostels, girls hostels and faculty residences of Indian Institute of Technology Guwahati campus, India. Saw dust was purchased from nearby saw mill. 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 compost was prepared with three different proportioning of waste mixtures of C/N 16, 22 and 30 are detailed in **Table 1**.

Temperature was monitored using a digital thermometer throughout the composting period. Temperature observations were taken at three different locations in the composter; i.e. at its center and at two ends. About 100 g of each grab samples were collected from six different locations within drum, mostly at the mid span and ends of the composter by compost sampler without disturbing the adjacent materials. Finally all the grab samples are mixed together and considered as homogenized sample. Triplicates homogenized samples were collected and stored at 4^{o}C. The biodegradable organic matter was measured as BOD by the dilution method and COD by the dichromate method [17].

Table 1: Waste compositions

Mixing weight (kg)							Initial weight (kg)	Moisture content (%)	C/N ratio
Cattle dung	Grass cuttings	Food waste (Cooked)	Vegetable waste (Uncooked)	Paper waste	Saw dust	Manure			
0	15	10	15	0	0	5	45	68.04	16
25	0	0	20	0	10	5	60	61.12	22
18	0	25	10	4	10	5	69	64.93	30

Microbial respiration of compost samples, based on CO_2 evolution, was measured using static measurement. Approximately, 10 g of sample was sealed in a 0.5 L vessel along with a beaker containing a known weight of oven dried (105°C) soda lime (1.5-2.0 mesh). The samples were incubated at room temperature (24± 2°C). Soda lime trap were removed after 24 hours, oven dried and reweighed to determine CO_2 absorbed. The OUR was measured on a liquid suspension of compost (8 g of compost in 500 ml of distilled water added with $CaCl_2$, $MgSO_4$, $FeCl_3$ and phosphate buffer at pH 7.2, made up according to the standard methods BOD test procedures [17] incubated at room temperature (24±2°C) [13]. The DO probe was placed in the sample bottle, its sensor being at a depth of 5-7 cm below the water surface. The suspension was continuously stirred by means of a magnetic stirrer. The O_2 concentration was measured continuously and this value quoted as the OUR in mg O_2/ gVS/day. Finally, the CO_2 test values and OUR were used to determine the Solvita® maturity index on a scale of 1-8 which then represent the maturity level of the compost samples).

All the results reported are the means of three replicates. Repeated measures treated with ANOVA were made using Statistica software. The objective of statistical analysis is to determine any significant differences among the parameters analyzed for different C/N ratios during the composting process.

3) RESULTS AND DISCUSSION

3.1 Temperature

A graph showing the variation of temperature of composting material with time is illustrated in **Figure 1**. The mesophilic, thermophilic, cooling and curing stages are clearly depicted. C/N 16 containing high amount of grass cutting reached 70°C maximum in all 3 Runs) and entered the thermophilic phase after the few hours from the beginning, indicating quick establishment of microbial activities in the composter. The longer thermophilic phase (6 days) as well as the higher rise in temperature in the beginning of composting was attributed to sufficient supply of carbon source. Further a cooling period was observed up to the end of composting period. In C/N 22, temperature was increased up to 60°C and entered the thermophilic phase at the very third day of composting process. Furthermore the thermophilic phase was observed for 5 days followed by a cooling period. However, C/N 30 required 5 days, a comparative longer time, to reach a maximum temperature of only 50°C with short thermophilic phase when compared to C/N 16 and 22. This was due to high initial C/N, which did not provide a favorable condition for the growth and biological activity of microorganism. The rotation causes mixing up of the top mesophilic layer and the inner thermophilic layer, thereby yielding a uniform mixing of the compost material. On analyzing the results by ANOVA, variation in temperature profile during composting was significantly reported among all three mixtures of C/N ratios ($P<0.0001$).

3.2 Volatile solids (VS)

The content of volatile solids decreased with composting time with about 33%, 22% and 30% for C/N 16, 22 and 30, respectively, owing to the loss of organic matter through microbial degradation **(Figure 2).** VS decreased significantly among C/N 16, 22 and 30 ($P<0.0001$). The larger amount of sawdust in C/N 30 contained higher amount of recalcitrant decomposable compounds, such as cellulose and lignin which may account for the insignificant lower degree of organic matter loss as compared to C/N 22 contained grass cutting and mixed vegetable waste after the 20 days of composting [18].

3.3 CO_2 evolution

The respiration rate based on CO_2 respirometry was measured after overnight preincubation at room temperature followed by the final weight of soda lime after oven dry. The CO_2 evolution rates of the C/N 16, 22 and 30 decreased from initial values of 6.3, 8.3 and 11.6 to 0.77, 1.15 and 1.47 mg CO_2 /g VS/day, respectively **(Figure 3)**. ANOVA results showed significant variation in CO_2 evolution among the C/N ratios. The greatest decreased in CO_2 evolution (55%) was observed during C/N 30 after the one week of composting process. Consequently, C/N 22 also observed a significant decrease early during composting. The highest decrease in rate of respiration activity in the C/N 16 occurred during the initial 3 days and between 10 to 15 days. The decrease in CO_2 evolution was very low after the 17 days of composting in all C/N ratios, indicated the stability of finished compost.

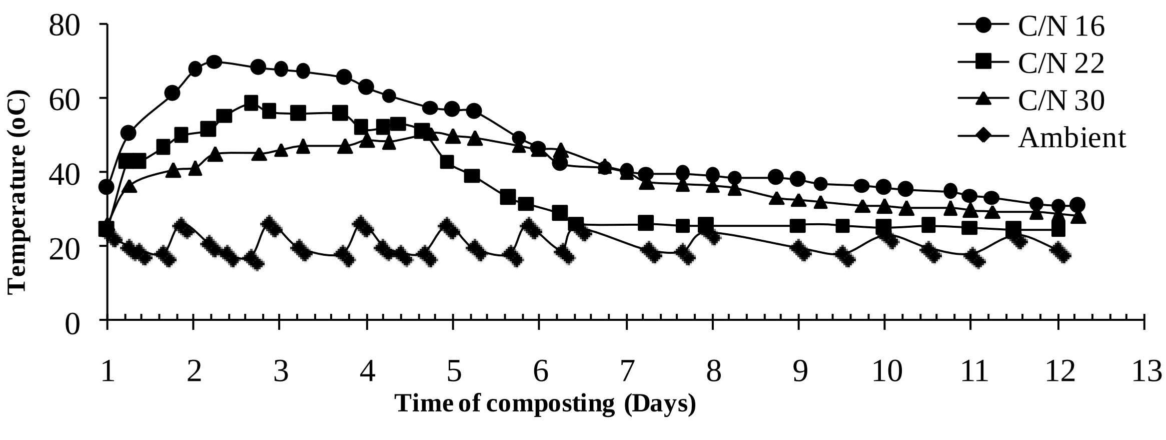

Figure 1. Temperature profile of composting materials over time

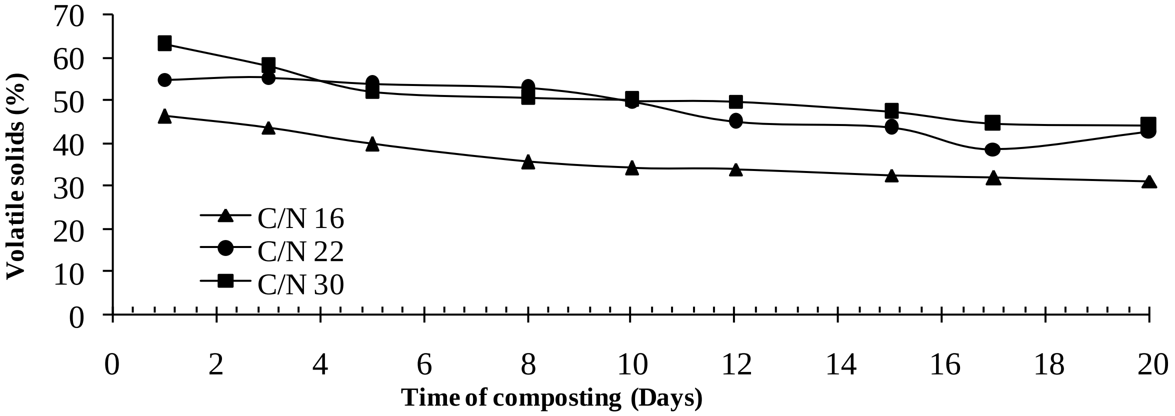

Figure 2. Volatile solid of composting materials over time

The greater differences in CO_2 evolution initially among the three C/N rations imply that compost source material have a great impact on the compost stabilization process (Wu et al. [11]. The similarity of final values of CO_2 evolution strongly recommended the viability of rotary drum for all kind of waste with different C/N ratios. The Solvita® maturation index based on CO_2 evolution increased from 4.97, 3.98 and 2.34 to 7.71, 7.52 and 7.36, respectively in C/N 16, 22 and 30. Solvita® results proved the composts from all C/N ratios inter into the well stable condition after the 15 days. In the work of

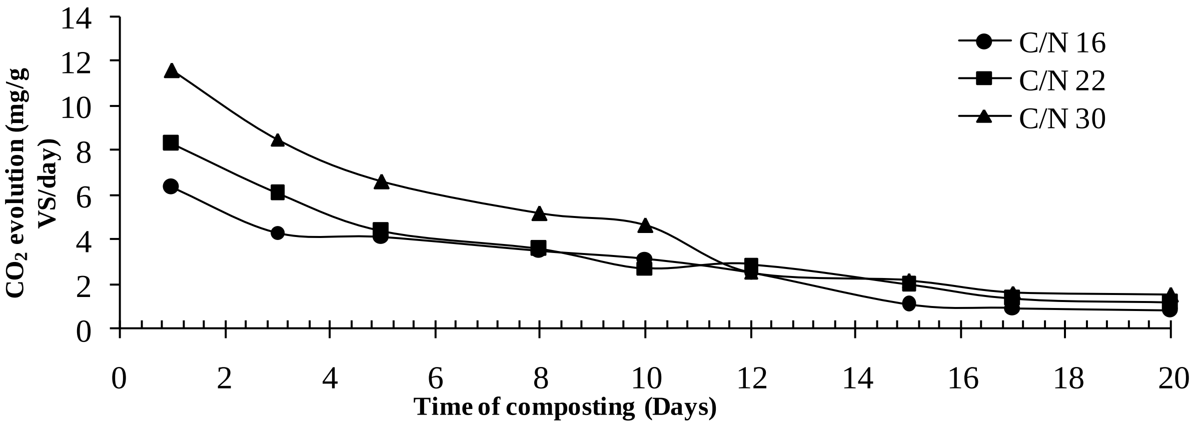

Figure 3. CO_2 evolution of composting materials over time

Changa et al. [19] and Cabanas-Vargas et al. [8] observed that, the Solvita® CO_2 index of less than 6 of finished windrow type compost. In our case, more than 7 Solvita® CO_2 index proved the rotary drum is the good and viable technique for composting of various kinds of waste. However, due to variation in compost feedstock in different C/N ratios, stable compost especially from C/N 16 and 30 containing larger amount of cellulosed or fibers contents may need more time to break down the phytotoxic substances [11]. Authors suggested the Solvita® maturation index is a good indicator for compost

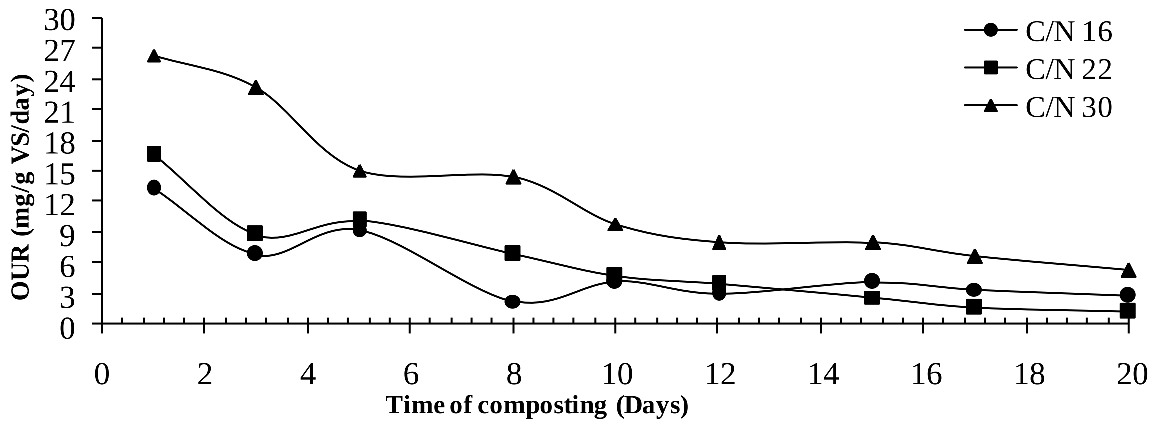

Figure 4. OURs of composting materials over time

stability and were more useful at the later stage of the composting process.

3.4 Oxygen Uptake Rate (*OUR*)

The higher OUR was observed in the beginning of the composting in all C/N ratios especially in C/N 30, constituently paper waste, saw dust and vegetable waste **(Figure 4)**. Similar phenomenon has been observed by other researchers [20]. Iannotti et al. [20] found OURs to be high in raw material, as microbes grow rapidly from digesting readily biodegradable substrate. During the active phase the composting mixture contains organic compounds that support microbial respiration thus resulting in high oxygen consumption rates that confer instability [12].

As composting begins, large organic molecules are broken down to smaller, soluble ones and temporarily more substrate may become available. In fact, the microbial activity decreases with composting time as evidenced by the decrease in the values of OURs of all C/N ratios. A sharp decrease (40 to 55%) observed after the initial one week could be due to a considerable drop in temperature and moisture content. The smaller decrease observed in C/N 22 comparing to C/N 16 and 30, indicated the poor decomposition during one week of composting in C/N 22. Although the maximum decrease of 92% observed in C/N 22 for the 20 days of composting period against almost 80% in remaining two C/N ratios. Result indicated the higher decomposition in C/N 22 could be due to large amount of cattle dung, which provided a favorable condition for the growth and biological activity of microorganisms. On analyzing the results by ANOVA, decrease in OUR varied significantly among the waste mixtures of C/N ratios ($P<0.0001$). The OUR dropped steadily after the initial sharp decrease in the all C/N ratios, while after the 13^{th} day of composting the drop is much temperate indicating the compost approaches the maturation period. OUR dropped up to 2.8 mg O_2 /g VS/day in C/N 16, while in C/N 22 and 30 OUR reduced up to 1.21 and 5.32 mg O_2/g VS/day, respectively after the 20 days of composting period in the rotary drum. According to the National Standard of Canada (BNQ 0413-200 and CCME guidelines), California Compost Quality Council (CCQC-US standard) along with Wood End Research Laboratory [21], the compost contain the OUR of 0.15 mg O_2/g VS/hr (3.6 mg O_2/g VS/day) considered as mature compost. Results indicated the compost of C/N 22 considered as the very stable compost and compost had a Solvita® index (based on OUR) of 8, which indicated that compost was ready for usage of soil conditioner [8]. Similarly, C/N 16 had a Solvita® maturity index of 7 which can be considered as finished compost. Conversely, the compost from C/N 30 had a Solvita® maturity index of 6, indicated immaturity and compost was ready for maturation. Especially C/N 30 depicted higher OUR required more time for maturity compare to C/N 16.

3.5 BOD and COD

The anaerobic condition brought about by the respiration of biodegradable organic matter in the compost, is measured as BOD and COD. As the biological organic content is diminished, BOD and COD are decreased, resulting in decreased emission of carbon dioxide, ultimately indicating stabilization of the compost. BOD and COD values decreased from 412 to 210 mg/l (4.12 to 2.1 mg/g) and 790 to 515 mg/l (7.9 to 5.15 mg/g) in C/N 16 and 580 to 107 mg/l (5.8 to 1.07 mg/g) and 1512 to 458 mg/l (15.12 to 4.58 mg/g) in C/N 22, while in C/N 30 830 to 358 mg/l (8.3 to 3.58 mg/g) and 943 to 546 mg/l (9.43 to 5.46 mg/g) respectively within 20 days of composting period.

Figure 5 shows that the BOD and COD removal of 82 and 70% respectively observed in C/N 22 after 20 days of composting indicated the higher decomposition throughout the

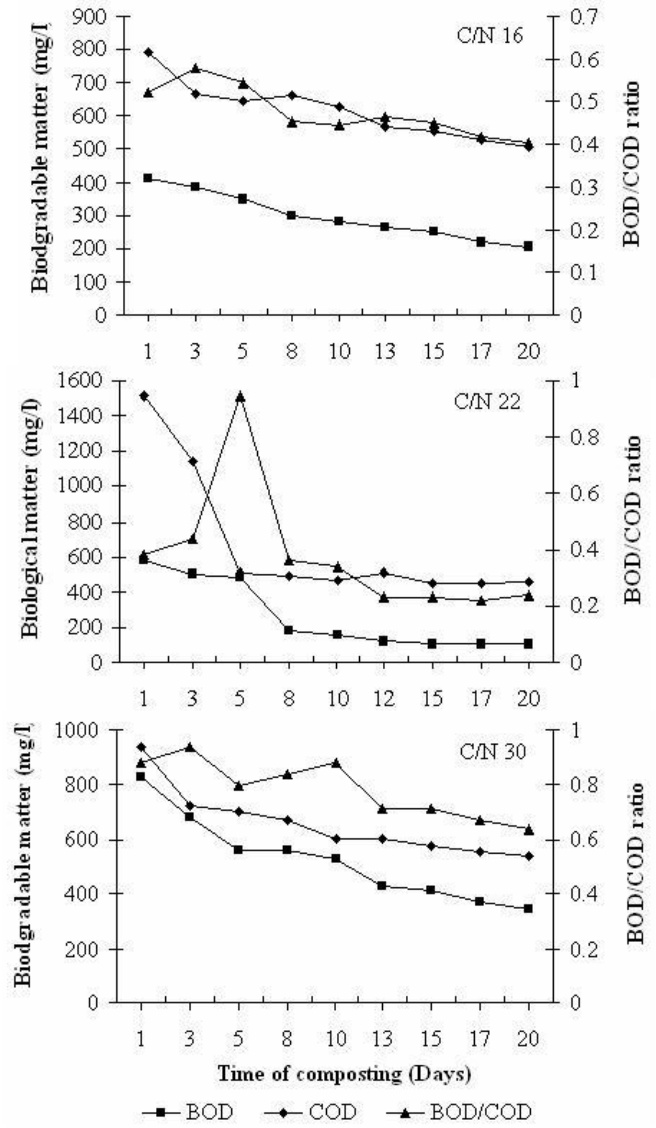

Figure 5. **BOD, COD and BOD/COD ratios of composting materials over time**

composting period in contrast poor reduction (less than 50%) depicted in C/N 16 and 30. Similarly, BOD/COD ratio decreased to 0.23 by the end of C/N 22, while in C/N 16 and 30 observed the final BOD/COD ratio of 0.41 and 0.63, required longer time for degradation and stabilization. This final decrease in the BOD/COD ratio indicates the stabilization of the compost as only the non-biodegradable parts remains. ANOVA results showed significant variation in BOD/COD ratio between the C/N ratios. Results indicated that more degradation of organic matters taken place in C/N 22 compare to C/N 16 and 30 within the composting period of 20 days.

3.6 Correlation between respiration rates

The CO_2 evolution and OUR values as well as the derived Solvita maturity index from CO_2 value were correlated to volatile solid, BOD, COD and BOD/COD ratio of the individual compost samples for all three C/N ratios. The correlation matrices are prepared, as a result of r-values and p-values denoted to each correlation.

Simple linear correlation between the OUR and changes in several individual compost characteristics showed a significant correlation except a few correlations **(Table 2)**. The OUR strongly correlated (P<0.0001) positively with CO_2 evolution, volatile solids (indicated the optimal conditions for degradation of VS) and BOD and COD (indicated the decrease in rate of oxygen uptake as a result of reduction in oxygen demand) in C/N 16, 22 and 30. Correlation between OUR and BOD/COD ratio showed less significant with the maximum positive r value of 0.82 (P = 0.0062) in C/N 30, while C/N 22 observed poor correlation (r = 0.53) as compare to C/N 16 (r = 0.71). On the whole, C/N 30 showed the highly significant correlation between OUR and other compost characteristics indicated the optimal conditions achieved during the composting for microbial activities. Results suggested the BOD and COD reduction highly depend upon the initial material used for composting. The correlation between the CO_2 evolution and changes in several individual compost characteristics showed a highly significant correlation in all C/N ratios **(Table 3)**. As discussed earlier the CO_2 evolution strongly correlated to the OUR in all three C/N ratios. Correspondingly, CO_2 evolution positive correlated with volatile solids, BOD and COD. Overall, all C/N ratios showed the significant correlation between CO_2 evolution and other compost parameters.

Table 2. Correlation between OUR and various characteristics

Characteristic	C/N = 16			C/N = 22			C/N = 30		
	r	n	P	R	n	P	R	n	P
CO_2 evolution	0.81	32	0.0086	0.96	32	<0.0001	0.98	32	<0.0001
VS	0.87	32	0.0023	0.84	32	0.0046	0.97	32	<0.0001
BOD	0.83	32	0.0051	0.84	32	0.0042	0.97	32	<0.0001
COD	0.79	32	0.0105	0.84	32	0.005	0.93	32	0.0002
BOD/COD ratio	0.71	32	0.033	0.53	32	0.1441	0.82	32	0.0062

r = Correlation coefficient; n = Number of samples; P = Probability

Table 3. Correlation between CO_2 evolution and various characteristics

Characteristic	C/N = 16			C/N = 22			C/N = 30		
	r	n	P	R	n	P	R	n	P
OUR	0.81	32	0.0086	0.96	32	<0.0001	0.98	32	<0.0001
VS	0.93	32	0.0002	0.84	32	0.0048	0.97	32	<0.0001
BOD	0.96	32	<0.0001	0.94	32	0.0001	0.99	32	<0.0001
COD	0.98	32	<0.0001	0.93	32	0.0003	0.96	32	<0.0001
BOD/COD ratio	0.78	32	0.0133	0.4	32	0.2921	0.83	32	0.0052

r = Correlation coefficient; n = Number of samples; P = Probability

4) CONCLUSIONS

1. Compost stability studies carried out for rotary drum under various C/N ratios reveals that compost of initial C/N 22 became very stable with the wastes combinations of cattle dung, vegetable wastes and saw dust. C/N 22 showed lower final OUR of 1.21 mg O_2/g VS/day and Solvita® index of 8, which indicated that compost was completely stable.
2. Lower final CO_2 evolution proved the rotary drum is the excellent and viable technique for composting of various combinations of different kinds of wastes. All C/N ratio especially C/N 30 depicted a highly significant positive correlation (p<0.0001) between OUR and VS indicated the optimal conditions in rotary drum for degradation of VS. However, due to variation in waste materials in different C/N ratios, stable compost especially from C/N 16 and 30 containing larger amount of cellulosed or fibers contents may need more time to break down the phytotoxic substances.
3. On analyzing the results by ANOVA significant variation observed in stability parameters (OUR and CO_2 evolution) among the waste mixtures of different C/N ratio (P<0.0001).This study demonstrate that compost OUR and CO_2 evolution provided additional information about the effectiveness of the rotary drum that was not clearly reflected in measurement of compost physico-chemical parameters.
4. Even though, the conditions of pilot scale and full scale are different as heat losses in both cases are different, nevertheless, the results of this study would be very useful in selecting the best possible waste composition (C/N 22) for a full scale rotary drum composter to achieve stable compost.

5. Conversion of the organic wastes into valuable compost is believed to bring many environmental and public health benefits.

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