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Short Communication

Composting of Greenhouse Tomato Plant Residues, Wheat Straw, and Separated Dairy Manure, and the Effect of Free Air Space on the Process

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Abstract

This study investigated the optimum mixture ratio of greenhouse tomato plant residues, wheat straw, and separated dairy manures for composting. Five 127-L laboratory-scale bioreactors were used to investigate the effect of separated dairy manure addition on the composting process of a tomato plant residues-wheat straw mixture. The wastes were mixed at 5 different ratios during the trials and were then placed in the reactor. Whereas the C/N ratios of the material mixtures placed in the reactors were fixed at a level of about 31, the FAS values ranged between 24.56% and 32.64%. Temperature and CO_2 measurements were made from the reactors during the trials along with organic matter and moisture content analyses.

According to the results, the optimum mixture ratio for composting the experimental materials was found to be 60% tomato waste, 10% wheat straw, and 30% separated manures on a dry basis. The FAS ratio of this mixture was 30.22%.

Keywords: composting, greenhouse tomato residues, separated dairy manure, free air space (FAS)

Introduction

There has been a continuous increase in the world's agricultural production and consumption. The growing demands for feedstuffs to be produced and consumed have brought about various problems throughout the world, yielding a significant amount of wastes in agricultural, municipal, and industrial sectors on a global scale. Landfilling, incineration, pyrolysis, anaerobic digestion, and composting are the methods that are used to dispose of organic wastes [1].

Composting, which can be defined as aerobic biological treatment, is sustainable management of wastes. Compost can be used to improve soil structure and can act as a soil conditioner [2]. In the process of decomposing organic wastes, microorganisms use oxygen in the environment and then decompose the organic structure; at the end of the reaction, CO_2, water, and heat are generated [3-6]. The main factors influencing the composting process are temperature, water content, oxygen/carbon dioxide concentration in the composting matrix, porosity, and free air space (FAS) [7-9]. The carbon/nitrogen (C/N) ratios of mixtures directly affect the microbiological activity during the process. N is the building block for microorganisms, whereas C is the energy source. Hence, a C/N ratio of about 30 is preferred for mixtures that will be used in composting processes. The FAS value represents the air:space ratio in compost mixtures. The proper aeration of the composting material will only be possible if enough porosity and FAS are provided. Low FAS decreases the degradation rate [10]

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Table 1. Physical and chemical analysis of raw materials used in the study.

Material	C/N (%)	N (%)	P (%)	K (%)	EC (dS/cm)	pH	OM (%)	MC (%)	FAS (%)
Separated Dairy Manure	27.47	1.44	0.18	0.76	2.46	8.02	71.21	65.24	14.15
Tomato Residues	29.22	1.62	0.16	4.22	0.36	7.62	85.21	64.22	37.56
Wheat Straw	176.48	0.29	0.34	0.27	10.45	6.80	92.12	6,11	32.01

EC – electrical conductivity, MC – moisture content, OM – organic matter, and FAS – free air space

and may lead to anaerobic conditions with gaseous and odorous emissions [11].

When the FAS value is high, heat transfer in bulk increases, and not enough heat is provided. The FAS value is especially important for static composting systems. The best FAS value varies according to the physical properties of the materials used in the composting processes. Researchers have carried out studies to determine the best FAS value for different wastes. Jeris and Regan [12] examined the effects of FAS on the oxygen consumption rates of mixed refuse samples. Approximately 67% moisture and 30% FAS were found to be optimum. About 95% of the maximum oxygen consumption rate was maintained when the FAS was between about 20% and 35%. Working with garbage and sludge mixtures, Schultz [13] concluded that a minimum of 30% FAS should be maintained. Kulcu and Yaldiz [14] found the optimum FAS value to be 33.62% for grass and leaf wastes. Kulcu and Yaldiz [15] stated that the optimum FAS value was 32.8% for goat manure, wheat straw, and pine cone mixtures. Ruggieri et al. [16] studied the levels of FAS during three co-composting experiments of biosolids plus different biochemical amendments and one composting control experiment (biosolids alone). The initial FAS was adjusted to 40% for all runs and was found to be a good compromise value for the correct performance of all processes. Maulini-Duran et al. [17] adjusted the FAS to 41.8% for raw sludge to obtain stabilized compost. Jolanun and Towprayoon [18] created 5 different FAS ratios in compost mixtures that were prepared using clay residues and food waste, and they examined the effect of the FAS value by carrying out experiments in compost reactors. During their experiments, they prepared mixtures with FAS values of 22.5%, 26.8%, 31.6%, 37.2%, and 43.3%, and they determined that the most successful composting process was actualized at an FAS value of 31.6%.

Tomato production of Turkey was reported as 11.35 million tons in the year 2012 [19]. Tomato is the most commonly grown vegetable crop in greenhouses. Greenhouse tomato production represented 55% of total vegetable production in Turkey. Although residues or wastes of tomato production are appropriate for composting because of their high organic matter content, they are burned or dumped in open areas in Turkey. Alkoaik and Ghaly [20] stated that the addition of manure to the greenhouse tomato residues–wood shaving mixture is a good source of macro- and micronutrients that are required to support the composting microorganisms. Because the particle size is large when tomato wastes are coarsely ground, the FAS values are also high. Greenhouse tomato wastes can be used as a bulking agent to adjust the FAS values of compost mixtures.

The objective of this study is to determine the optimum mixture ratio of tomato residues, wheat straw, and separated dairy manure for composting. In mixtures, separated dairy manure was used as an inoculum and a nitrogen source, greenhouse tomato residues were used as bulking agent and nitrogen source, and wheat straw was used as a carbon source in this study.

The C/N levels for the mixtures in the trial were fixed at the interval of 31-32, which is the optimum level. Greenhouse tomato plant wastes and separated dairy manure ratios were changed in the mixtures to adjust the FAS levels. Mixtures that were prepared at 5 different FAS ratios were composted to determine the mixing ratio that yields the best FAS value for the composting of the wastes used in the trial.

Materials and Methods

The physical and chemical properties of separated dairy manure, tomato residues, and wheat straw used in this study are given in Table 1. The N contents of wastes ranged from 0.29% to 1.62%. Tomato wastes and wheat straw are rich in organic matter. Separated dairy manure and tomato wastes are rich in N. The FAS values of the wastes used in the trials are quite different. Whereas the highest FAS value was measured as 37.56% for tomato wastes, this value was measured as 32.01% and 14.15% for wheat straw and separated dairy manure, respectively.

These wastes were mixed at 5 different ratios based on the dry matter content of materials for composting (Table 2). C/N ratios and FAS values of each mixture are listed in Table 2.

The wheat straw ratio of the mixtures was fixed at 10% dry basis. The FAS values of the mixtures were changed without changing the C/N ratios. The C/N levels for the mixtures in the trial were fixed at approximately 31, which is the optimum level. Greenhouse tomato plant wastes and separated dairy manure ratios were changed in the mixtures to adjust the FAS levels. Mixtures that were prepared at 5 different FAS ratios were composted to determine the mixing ratio that yields the best FAS value for the composting of the wastes used in the trial.

Table 2. Properties of the mixtures in the composting reactors.

Reactor No.	Separated Dairy Manure (%)	Tomato Residues (%)	Wheat Straw (%)	FAS (%)	C/N
R1	60	30	10	24.56	31.06
R2	50	40	10	26.32	31.37
R3	40	50	10	28.49	31.52
R4	30	60	10	30.22	31.22
R5	20	70	10	32.64	31.67

FAS values increase as the tomato wastes amount used in the reactors increases. While the lowest FAS value was measured in the R1 reactor where 30% tomato waste was used, the highest FAS value was measured in the R5 reactor as 32.64% when 70% tomato waste was used.

The composting process was carried out in laboratory-type composting reactor systems. Composting reactors were made of a plastic material that was insulated against heat transfer and had an effective volume of 127 L. The aeration inside the reactors was performed by 3-phase radial fans. The temperature was measured at 3 different points inside the reactors on a vertical axis passing through the central point (Fig. 1). The location of thermocouples is depicted in Fig. 1.

The management and monitoring of the process in the composting system were carried out by a programmable logic controller (PLC)-based process control device. The flow rate of the air blown into the reactor by fans was measured by a flow meter, and the result of the measurement was transmitted to the PLC unit. Using the aeration value that was entered to the interface, the PLC unit determined the optimum air flow rate and altered the frequency to provide the optimum flow rate according to the data obtained from the flow meter. The frequency tuner adjusted the frequency of the electric current that was conveyed to fans and enabled them to perform aeration at the adjusted flow rate. The aeration ratio was adjusted to 0.4 L air·min^{-1}·kgom^{-1} in the tests [1, 21]. Furthermore, the aeration period in these experiments was adjusted to 15 min/h. The PLC unit also measured the temperature of the piles. The temperature during composting was measured and recorded every 15 min. The CO_2 concentrations of the air within the pile were measured daily during the composting process by a digital gas analyzer with an infrared CO_2 sensor. Composting experiments were conducted for 21 days. The moisture content of the experimental materials was analyzed by a drying oven method at 105ºC for 24 hours (22). The organic matter (*OM*) content of the material was measured by a burning oven at 550ºC for 5 h [22]. The *OM* was calculated according to the following equation [23]:

$$OM(\%) = ((W_{105} - W_{550}) / W_{105}) \tag{1}$$

...where W_{105} is the oven dry weight of the mass at 105ºC and W_{550} is the furnace dry weight of the mass at 550ºC.

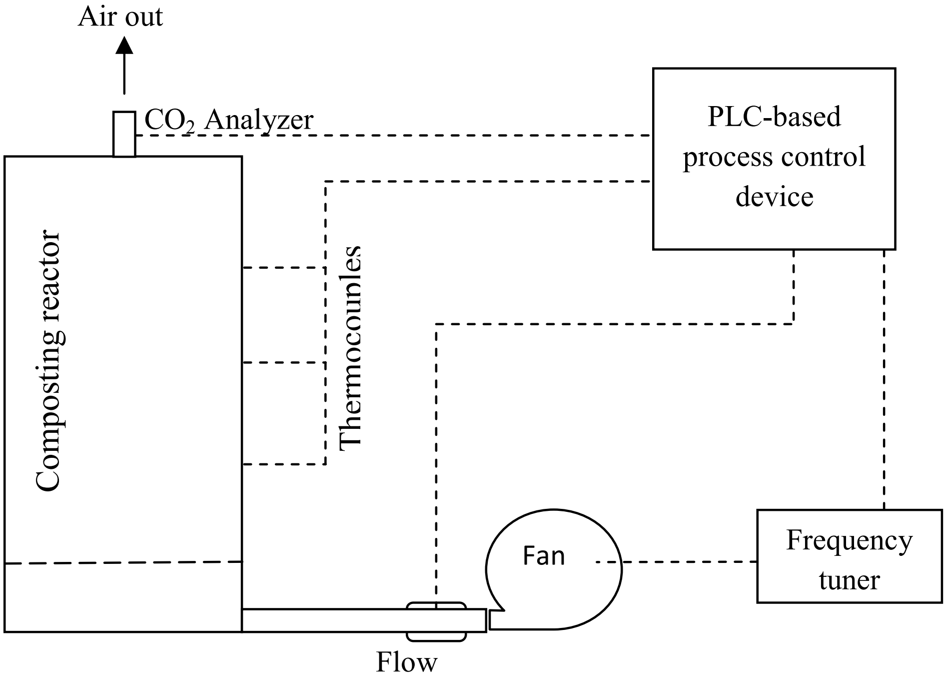

Fig. 1. Schematic of a laboratory-type composting reactor system.

The loss of organic matter (k) was calculated from the initial and final volatile solid contents as follows [24]:

$$k = \frac{\left[OM_m(\%) - OM_p(\%)\right] \cdot 100}{OM_m(\%) \cdot \left[100 - OM_p(\%)\right]} \qquad (2)$$

...where OM_m is the OM content at the beginning of the process and OM_p is the OM content at the end of the process.

The bulk density (BD) and specific gravity (SG) of compost were determined using a weight-per-hectoliter tester that was calibrated as kilogram per hectoliter. *FAS* values of materials were calculated based on the equation given by Epstein [25].

$$FAS(\%) = 100 \cdot \left(1 - \frac{BD}{SG}\right) \qquad (3)$$

Statistical Analysis

The normality of k values was tested using the Anderson-Darling procedure, and the homogeneity was tested using the Bartlett procedure. The k values were subjected to one-way analysis of variance to test differences, and Duncan's multiple range test was used to establish the significance of differences among treatments. All analyses were performed using the SAS statistical package [26].

Results and Discussion

The profiles of the average temperatures of the reactors are presented in Fig. 2. The temperatures of all mixtures reached the thermophilic phase (>55ºC) after 3-4 days of composting, which reflected active microbial decomposition in the composting mixtures. The rapid rise in temperature was due to the breakdown of the easily decomposable fractions of the mixtures. According to data in Fig. 2, the temperature in reactors R2, R3, R4, and R5 stayed at 56ºC for at least 3 days. Then the temperature level in these reactors gradually decreased with time. However, the temperature in the R1 reactor increased only to 55ºC on the third day and then decreased rapidly. The temperatures of reactors R3 and R5 were similar throughout the process. The process temperatures in these reactors increased to 57-62ºC on the 4th and 5th days, and then the temperature started to decrease. The temperature in the R4 reactor rapidly increased to 64ºC in the first 5 days and then decreased gradually. The temperature data indicates a relationship between the FAS values and microbiological activity. The process temperatures were low in reactors where the FAS values were around 24.56-26.32%. It was determined that the composting temperatures were high when the FAS values of the mixtures increased above 28%. The highest process temperature was observed for the mixture with the FAS value of 30.22%. The temperature was affected adversely when the FAS value exceeded 30%.

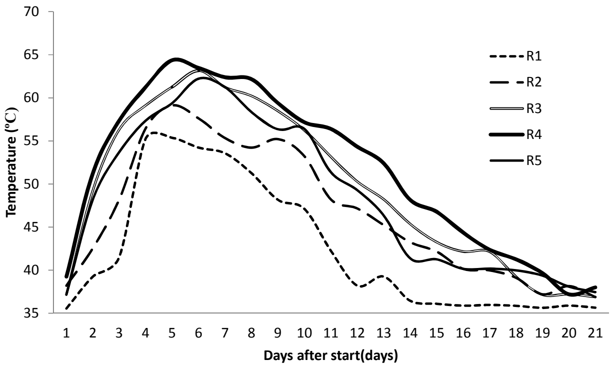

Fig. 2. Temperature changes in all reactors during the composting process.

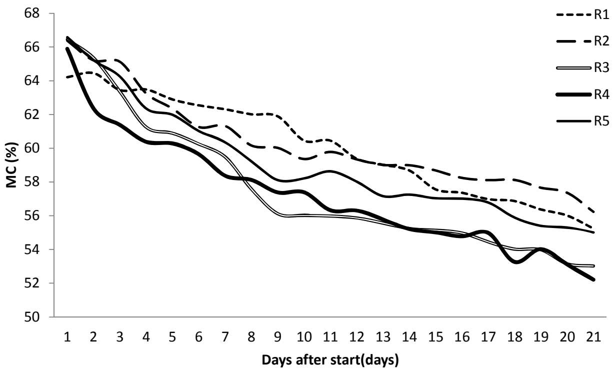

Fig. 3. Moisture content (MC) as a function of time for all reactors during composting.

The initial moisture content of all compost mixtures was 64-66%. Water is necessary for microorganisms to utilize dissolved nutrients. The moisture contents of compost materials declined gradually in all reactors during the composting process (Fig. 3). The moisture content was the lowest in R4 (52.21%) and the highest in R2 (55.24%) after 21 days of composting. There was not a linear relationship between compost temperatures and moisture losses. The moisture loss was high in reactors R4 and R3, which had high composting temperatures. Moisture losses were less in other reactors with lower process temperatures.

Many researchers have emphasized the importance of the moisture content, and they stated that 50-70% moisture content is suitable for efficient composting [27, 10]. In this study, the moisture content (52-66%) was not a limiting factor for microbial growth, and it was in the optimum range at all times.

The decomposition of organic matter is directly related to microbial respiration [28]. The OM content decreased in all reactors during composting (Fig. 4), and this decrease was more pronounced during the first stages of the process. A relationship was observed between the FAS values of mixtures and organic substance degradation rates. The organic substance degradation was higher in reactor R4, which had an FAS value of 30.22%, relative to the other reactors.

Table 3 presents the k values that were calculated from the decomposition of organic material at the end of com-

Table 3. The loss of organic matter (*k*) of composting mixtures at the end of the experiment and statistical analysis ($P < 0.01$).

	R1	R2	R3	R4	R5
k (%)*	61.75±2.38c	63.75±2.38c	69.87±2.80b	72.87±2.01a	69.20±1.59b

*There are no statistically significant differences between the values that are categorized with the same letter, while the differences between the values that are categorized with different letters are statistically significant.

posting. Our results showed that the highest level of decomposition occurred in the R4 reactor, which was followed by the R3, R5, R2, and R1 reactors. The R4 reactor was considered class "A" based on the results of the statistical analyses, and it had the highest *k* value.

CO_2 production was caused by the mineralization of OM in the substrate [29]. Fig. 5 shows the mean changes in CO_2 concentration as a function of time inside each reactor. The CO_2 concentration increased in all reactors in proportion to microorganism activity during the process. The CO_2 concentration was the highest in reactor R4. The high CO_2 level in the R4 reactor indicates a high microbiological activity. We observed that the composting temperature, CO_2 level, and *k* value were greater in the R4 reactor than in the other reactors. The FAS value of the mixture that was composted in this reactor was around 30.22%. The CO_2 concentration increased after the first 2 days and decreased after 10 days in all the aerated reactors.

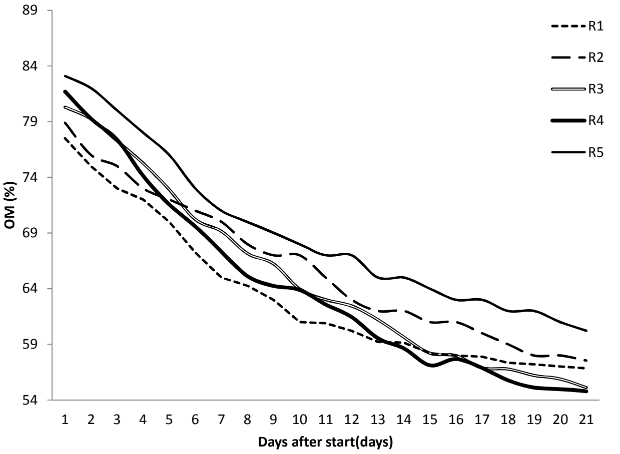

Fig. 4. Organic matter (OM) content changes in mixtures during composting.

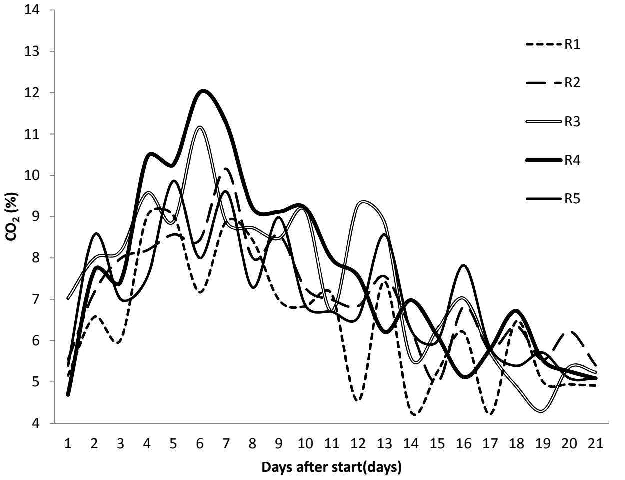

Fig. 5. Carbon dioxide (CO_2) concentration as a function of time during composting.

According to a survey of the available literature, the best FAS ratio for the composting process was between 30% and 41.8%. It was suggested that the composting process was adversely affected by the negative effects on aeration when the FAS value decreased below 30%. Our results agree with the data reported in the literature.

Conclusions

The composting process was adversely affected when the FAS value decreased below 30%. Results indicate that problems related with aeration in terms of penetration of air in the composting matrix occur when FAS values decrease below 30%. According to our results, the composting process was the most successful in the R4 reactor, which had an FAS value of 30.22%. The composting process was adversely affected when the FAS value was increased to 32.64%. This is thought to be due to the increased heat transfer as a result of the high FAS level, thereby decreasing the compost temperature. Therefore, the mixture in the R4 reactor (FAS 30.22%) was more successful than the other mixtures for composting. Thus, 60% greenhouse tomato wastes, 30% separated dairy manures, and 10% wheat straw could be applied for the composting process.

Acknowledgements

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