



Effects of initial C/N ratio on organic matter degradation of composting of rose oil processing solid wastes

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Abstract

This research study was aimed to investigate the degradability of organic substances of rose oil processing solid wastes mixed with separated dairy manure and straw. The experiment was conducted in 2014. Compost mixtures were prepared at five different C/N ratios of 16.52, 23.27, 27.48, 31.39, and 32.35 by keeping the moisture content (on a wet basis, %) between 67.76 and 74.87. Each mixture was replicated twice in composting reactors. To assess degradation rates changing with the initial C/N ratio, a first-order kinetic equation based on mass balance was utilized. Results showed that the highest decomposition rate was calculated as 0.03 kg kg⁻¹ day⁻¹. For each mixture, the compost mass ratio was also determined. The relationship between loss on dry matter and organic matter content and the initial C/N ratio were ascertained by using regression analysis applying Gaussian equation. According to the results, the maximum loss on dry matter and organic matter content was found to be 14.53 and 24.34%, while the corresponding initial C/N ratio was 29.50 and 24.25, respectively. It was concluded that the initial C/N ratio of the mixture could be greater than 30 in order to reduce nitrogen loss. Carbon loss was also expressed as a function of the initial C/N ratio by using regression analysis. An initial C/N ratio > 21.77 was suggested to reduce carbon loss for composting of rose oil processing solid wastes mixed with separated dairy manure and straw.

Keywords Dry matter loss · Organic matter decomposition · Rose oil processing solid wastes · Separated dairy manure

Introduction

Composting is biodegradation of organic substance and a process of which physical, chemical, and biological factors interact simultaneously (Keener et al. 1993) and is considered as an alternative management method for the valorization of rose oil processing solid wastes (ROPSW), which is a by-product of rose oil producing industry (Tosun 2003; Onursal 2006). At the final stage of composting, the new and economic products (humus-like materials, also known as compost) are produced. Compost is used in open

fields, orchards, vineyards, urban landscapes, and nursery to improve soil fertility, to increase water holding capacity of soils, and to prepare potting mixes (Keener et al. 2000). Michel et al. (2004) highlighted that the utilization of compost obtained from dairy manure composting with sawdust or straw as fertilizer to meet the need of organic matter of lands is the most beneficial solution.

Proper composting management is required to acquire a high-quality compost. Therefore, various airflow management strategies (Ekinci et al. 2004, 2005), mixing ratio-feedstock formulation (Ekinci et al. 2002a), bulking agents (Onursal 2006), and process control options (Keener et al. 2005) have been used in optimization of composting process in terms of time, costs, and compost quality. Likewise, Ekinci et al. (2002a) studied composting of paper mill sludge with broiler litter at different initial moisture and temperature conditions and reported that the maximum decomposition occurred approximately at 44% (ash-free moisture of 62% on a wet basis) and 58 °C, respectively. They also showed that operational cost of the process at 60 °C would require 31% less energy than that of operated at 50 °C. In another study, Ekinci et al. (2002b) examined the impact of

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initial carbon/nitrogen (C/N) ratio on the degradation rate of composting of short paper fiber with broiler litter. It was found out that the highest degradation, based on dry matter loss (DML), was obtained as $0.11 \text{ kg kg}^{-1} \text{ day}^{-1}$ when C/N ratio was in the range of 30–38. This result was used in the study to optimize the system in terms of initial C/N ratio. Haug (1993) emphasized that degradability of organic matter affects its conversion during the composting process. Petric et al. (2012) pointed out that a high decomposition rate leads to possible lower operational costs of composting operations. Finstein et al. (1986a) stated that decomposition rate is an overriding determinant of composting process performance. The absence of a decomposition rate measure in composting leads to process design and control failure, inconsistent operational performance, odor problems, and proliferation of proprietary processes, and the associated claims are usually untested and sometimes extravagant.

Although the influence of the initial C/N ratio, moisture, and temperature on degradation rates was well studied (Ekinici et al. 2002a); impact of the initial C/N ratio on organic matter degradation in composting process has been rarely examined. The results of the earlier studies showed that decomposition of organic matter through composting could be approximated with DML (Ekinici et al. 2002a), organic matter loss (OML) (Onursal 2006), or carbon loss (C -loss) (Bernal et al. 2009). The aim of this work is, therefore, (1) to assess the parameters describing the mixture of composting of rose oil processing wastes with separated dairy manure and straw, (2) to investigate the effects of initial C/N ratio on decomposition kinetics of composting, and to identify the C -loss and nitrogen loss (N -loss) as a function of the initial C/N ratio.

Materials and methods

In all experimental studies, ROPSW, separated dairy manure (SDM) and straw samples were used as raw materials and they were collected from organically certified farms. The ROPSW was collected from Rose Oil Factory of Başmakçı Agricultural Development Cooperative Limited in Afyon province. SDM was received from Arif Gürdal Dairy farm in Aydın province, and straw was obtained from a farm located in Konya province. The properties of the raw materials are presented in Table 1.

Composition of each reactor fed at the beginning of the experimental stages is given in Table 2. Mixing ratios for ROPSW, SDM, and straw were calculated on a dry weight basis. Straw was used to balance the C/N ratios and to form free air space in the mixture. Two different initial C/N ratio parameters were evaluated during the study. They were

Table 1 Initial values for physical and chemical properties of feedstocks

Parameters	ROPSW	SDM	Straw
Moisture ^a , %	6.17 ± 0.08	74.76 ± 0.50	0.72 ± 0.02
Organic matter ^a , %	91.74 ± 0.08	84.93 ± 0.16	94.46 ± 0.61
EC ^b , dS/m	0.82 ± 0.03	2.95 ± 0.05	1.09 ± 0.03
pH	4.75 ± 0.20	8.81 ± 0.33	6.4 ± 0.40
Total C ^a , %	26.73 ± 0.53	44.79 ± 0.10	44.64 ± 1.75
Total N ^a , %	2.89 ± 0.13	1.16 ± 0.03	0.26 ± 0.06
C/N	9.25	38.61	175.04

^aExpressed on a dry weight basis

^bElectrical conductivity

(1) $[C/N]_{ia}$, where a is the calculated C/N ratio in compost based on mixing ratios and laboratory analysis of individual component at time = 0 prior to the mixing process, and (2) $[C/N]_{ib}$, where b is the measured C/N ratio in compost at time = 0 based on laboratory analysis of blended ingredients after the mixing process.

Ten identical reactor vessels of 100 L volume, which had perforated stainless steel floors with a hole size of 4 mm (diameter) to maintain air space for better air distribution at the bottom, were used in the experiments (Fig. 1). Air flow was provided to the reactors through PVC pipes having 50 mm of diameter. Compost temperature was measured at three different depths (10.5, 27.5 and 44.1 cm above the perforated floor) with K type thermocouples. Control of aeration fans (0.25 kW) were maintained by a PLC system (Schneider M258). Hot wire anemometers attached to the PVC pipes were employed to determine air velocity for the calculation of air flow.

Management of aeration fans was performed through temperature feedback control. Fans were operated intermittently (on/off mode) when temperature of compost bed was less than or equal to set point temperature ($T_{sp} = 60 \text{ }^\circ\text{C}$). Air-flow at this stage (Q_{min} , $\text{m}^3 \text{ h}^{-1}$) was supplied to meet the minimum oxygen requirement of the composting process. When $T > T_{sp}$ (Q_{max}), fans run continuously to lower temperature of the compost bed.

O_2 and CO_2 concentration measurements were taken with an analyzer (Quantek Model 902P). Gas measurements were taken twice a day drawing the compost exhaust air by internal pump passing through a trap containing drierite as a desiccant. To determine O_2 and CO_2 concentrations, air samples were withdrawn for 5 min after the fans were shut off.

Triplicate samples were analyzed to characterize the composting process. Moisture content and organic matter content of dry samples were determined as explained by (USCC 2002). pH and EC of the samples were measured at a solid:

Table 2 Compositions of feedstocks and amendments used to formulate reactor feed and initial chemical analysis of mixtures in reactors

Mixes	Reactors	ROPSW (kg/kg)	SDM (kg/kg)	Straw (kg/kg)	[C/N] _{ia}	[C/N] _{ib}
1	R1, R2	0.65	0.25	0.10	15.06	16.52 ± 0.64
2	R3, R	0.44	0.46	0.10	20.12	23.27 ± 0.48
3	R5, R6	0.29	0.61	0.10	25.16	27.48 ± 2.53
4	R7, R8	0.18	0.72	0.10	30.07	31.39 ± 1.37
5	R9, R10	0.09	0.81	0.10	35.22	32.35 ± 1.71

**Fig. 1** View from Composting Laboratory

water ratio of 1:10 (w/v) using pH and EC meters (WTW pH 720 and WTW Multi 340i, respectively). Total C and N contents of the mixtures were analyzed using the elemental analyzer (Vario MACRO CN Elemental analyzer).

Determination of decomposition rate

Finstein et al. (1986b) highlighted that information on the principles of process design and operation that lead to odor control and cost-effectiveness are currently available and would be useful to decision makers. Both odor control and cost-effectiveness necessarily result from rapid decomposition. Rate of change of compost dry matter is a function of compost temperature, oxygen concentration, microbial population, etc. Degradation of dry matter was modeled taking into account of oxygen consumption/carbon dioxide evolution and heat generation (Mohee and White 1997). In this study, a first-order kinetic model based on material mass balance (Keener et al. 1993; Marugg et al. 1993) was used as described by the following:

$$\frac{dm_c(\theta)}{d\theta} = -k(m_c(\theta) - m_e) \quad (1)$$

where θ = time, day; k = decomposition rate, $\text{kg kg}^{-1} \text{day}^{-1}$; $m_c(\theta)$ = compost dry mass, kg; m_e = equilibrium mass evaluated as $m_e = \beta m(0)$, kg; $m_c(0)$ = initial compost dry mass, kg.

The parameter m_e presumes the portion of the organic matter that can be decomposed by microorganisms. The expression $m_e/m_c(0)$, named β , defines the proportion of compost left after a long composting period (6 months to 1 year). β is assigned a value greater than ash content as some organic fractions stay undecomposed in the stabilized final product. Assuming that k is constant, the compost mass ratio, mR , can be expressed as the following:

$$mR = \frac{m(\theta) - m_e}{m(0) - m_e} = e^{-k\theta} \quad (2)$$

mR is a dimensionless number (between 0 and 1). It is accepted 1 when $\theta=0$, and it takes 0 when θ goes to ∞ . It is a valuable parameter as it is an indication of the degree of advancement of the composting process (Keener et al. 1993). The procedure to obtain decomposition rate (k) and mR was described elsewhere (Keener et al. 1993; Ekinici 1997).

Chowdhury et al. (2013) emphasized that the assessment of organic matter loss necessitates the use of mass balance of the compost based on dry weight instead of only considering the difference in concentration of organic matter or organic carbon in the composting material. The mass balance approximation is preferable since organic matter is a fraction of dry mass. DML, OML, C-loss, and N-loss were calculated based on the initial and final values of the corresponding loss.

$$\text{DML} (\%) = \left(1 - \left[\frac{m_d(\theta)}{m_d(0)} \right] \right) 100 \quad (3)$$

$$\text{OML} (\%) = \left(1 - \left[\frac{m_o(\theta)}{m_o(0)} \right] \right) 100 \quad (4)$$

$$\text{C-loss} (\%) = \left(1 - \left[\frac{m_c(\theta)}{m_c(0)} \right] \right) 100 \quad (5)$$

$$\text{N-loss} (\%) = \left(1 - \left[\frac{m_n(\theta)}{m_n(0)} \right] \right) 100 \quad (6)$$

where $m_d(\theta)$, $m_o(\theta)$, $m_c(\theta)$, and $m_n(\theta)$ are dry mass of the compost, mass of the organic fraction, total carbon mass, and total nitrogen mass (kg) at a given time, respectively. $m_d(0)$, $m_o(0)$, $m_c(0)$, and $m_n(0)$ are the dry mass of the compost, mass of the organic fraction, total carbon mass, and total nitrogen mass (kg) at the initial stage, respectively.

Results and discussion

Temperature, O₂, and CO₂ profiles

During composting experiment, Q_{\min} was adjusted from 1 to 1.2 m³ h⁻¹ to meet the oxygen requirement. The purpose of this manual adjustment is to meet the maximum O₂ requirement at the initial stage of the composting process, although heat management strategy using ventilation generally supplies adequate O₂ in the composting bed. In this study, aeration was manually controlled when temperature of compost bed was less than or equal to T_{sp} and temperature feedback control system with aeration fans was employed when temperature was greater than T_{sp} of 60 °C (Harper et al. 1992).

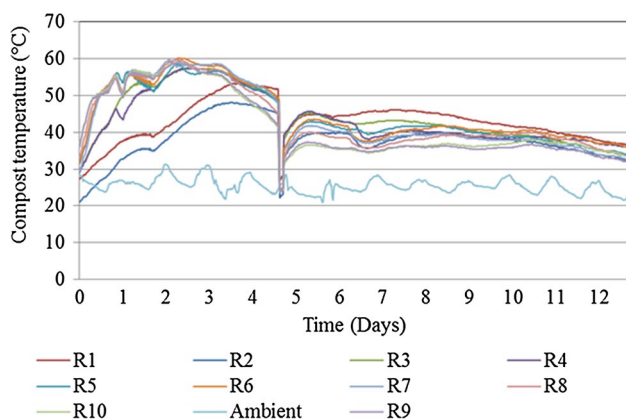


Fig. 2 Compost temperature as a function of time for all reactors

Q_{\max} was applied in the range of 2–3.5 m³ h⁻¹ to cool down compost mass by evaporative cooling.

Change in compost temperature for each reactor as a function of time is shown in Fig. 2. Although temperature was measured at three different depths in any reactor, only the temperature measured at the middle point was reported here. The initial compost temperature in R1 and R2 was 27.4 °C and 21 °C, respectively, while those of the other reactors ranged from 29.1 to 37.1 °C. These initial temperature differences may be resulted from the difference in time of the material loading to the reactors. As a consequence of decomposition of organic matters, temperature in Mix-1 (R1 and R2), where C/N ratio was measured as 16.0, increased to 42 °C at 2.5–3.2 days. On the other side, it took 0.5–1.5 days to reach to 42 °C for the other reactors. The existing delay in the temperature increase in R1 and R2 could be attributed to the lower initial C/N ratio in these reactors. The highest temperature measured in R1 and R2 was 53.2 and 48 °C, respectively, while temperature in R3 and R4 reached to > 55 °C, and these reactors were operated at this temperature only for 2 days. The temperature in R5, R6, R7, R8, R9, and R10 reached to > 55 °C, and these reactors were operated at this temperature for three days for the elimination of the pathogens (Lopez and Foster 1985). Feedback control system did not allow the temperature to exceed T_{sp} of 60 °C in these reactors due to evaporative cooling of compost mass. Compost materials in reactors were turned manually on the 4.5th days and never reached to level of 50 °C again due to depletion of the easily degradable compounds.

The oxygen level in compost bed influences the microbial degradation and is guaranteed when aeration based on heat management is performed (Haug 1993). According to the results, it can be estimated that high initial moisture content of > 67.67% (Table 2) in each of R6–R10 reactors adversely affected oxygen movement within compost bed in these reactors. Oxygen levels in R1–R3 reactors were over 14% during composting process. Similarly, the lowest O₂ concentrations in R4–R5 reactors were 5.4 and 5.8%, respectively, which are higher than reasonable level (> 5%). Nonetheless, the O₂ concentrations at the initial stage of composting measured from R6 to R10 reactors were lower than reasonable levels (> 5%) because of high respiration rate of the microorganisms (Villaseñor et al. 2011). However, after 4.5th days of composting, the oxygen levels in all reactors were higher than 10%, which is a possible consequence of decrease in microbial activity (Petric et al. 2012). After this period, the oxygen content returned near to ambient level.

The CO₂ concentration fluctuated in all reactors and was inversely related to concentrations of O₂ (Sommer and Möller 2000). Organic matter was degraded and converted into CO₂ in all reactors. At the onset of the process, CO₂

emission profile of the reactors showed the similarity with the temperature and O₂ concentration profiles. As composting proceeded, while the temperature elevation started, the corresponding CO₂ concentration was measured as 10–11% in R6–R10 approximately at 2.5th days of composting due to high microbial activity. Increased CO₂ concentrations in the reactors could be due to microbial degradation of compounds such as sugars and proteins. The highest CO₂ concentrations measured in R4 and R5 (8.3 and 9.2%, respectively) were usually higher than that of R1, R2, and R3 (3.2, 3.7 and 3.5%, respectively).

Physical and chemical properties

Compost moisture content is one of the most influential parameter that has an impact on oxygen supply, thereby affecting microbial activity (Jolanun and Towparyoon

2010). In the current study, the initial moisture contents of composts in all reactors were higher than that of reasonable limits (Rynk 1992) due to the initial moisture contents of SDM used in the mixture (Table 1). The lowest initial moisture content of compost mixture without addition of water was around 70% (Mix-5). Therefore, water was supplemented to the other mixtures to bring out the same level. The initial moisture level of the mixtures ranged from 67.76 ± 1.46 to 74.87 ± 0.54 (w.b., %) (Table 3). This result indicated the variability of the initial moisture levels. Generally speaking, the aeration system was not able to completely remove water from compost matrix by evaporative cooling process but accumulated at the top of reactors. Eventually, moisture contents of all composts increased slightly except for R2 (Table 4).

Variation in the initial and final pH by mixtures is given in Table 3 and Table 4. The pH of the mixtures decreased

Table 3 Mean values for chemical properties of initial mixtures (Values are calculated based on dry weight, excluding moisture content, which is wet weight basis)

Mixes	Reactors	Moisture (w.b.,%)	pH -	EC (dS/m)	Organic matter (%)	C (%)	N (%)	[C/N] _{ib} (-)
Mix-1	R1	68.45 ± 6.68	8.72 ± 0.02	1.58 ± 0.36	55.75 ± 0.3	29.92 ± 2.58	1.86 ± 0.01	16.07 ± 1.27
	R2	74.87 ± 0.54	8.74 ± 0.03	1.84 ± 1.15	57.30 ± 2.49	27.80 ± 2.83	1.64 ± 0.04	16.98 ± 1.36
Mix-2	R3	73.80 ± 0.13	9.03 ± 0.01	3.19 ± 1.12	69.66 ± 3.09	33.75 ± 4.23	1.47 ± 0.01	22.93 ± 2.66
	R4	67.76 ± 1.46	8.93 ± 0.04	2.75 ± 3.86	66.28 ± 5.64	34.03 ± 1.62	1.44 ± 0.01	23.61 ± 0.89
Mix-3	R5	68.88 ± 0.38	9.10 ± 0.05	2.24 ± 0.96	76.07 ± 1.86	36.87 ± 2.11	1.27 ± 0.09	29.26 ± 3.79
	R6	71.39 ± 1.42	9.12 ± 0.04	2.20 ± 0.39	77.24 ± 3.24	35.86 ± 0.80	1.40 ± 0.04	25.69 ± 0.07
Mix-4	R7	72.19 ± 0.38	9.27 ± 0.06	2.55 ± 0.87	76.08 ± 2.62	37.29 ± 0.52	1.23 ± 0.02	30.43 ± 0.95
	R8	69.64 ± 0.49	9.2 ± 0.00	2.42 ± 0.59	80.49 ± 1.63	39.02 ± 0.92	1.21 ± 0.01	32.36 ± 0.96
Mix-5	R9	71.08 ± 0.31	9.34 ± 0.13	2.81 ± 1.90	85.83 ± 0.46	40.16 ± 2.63	1.20 ± 0.07	33.56 ± 4.17
	R10	70.49 ± 0.59	9.29 ± 0.06	2.79 ± 1.45	85.85 ± 0.02	38.62 ± 2.18	1.24 ± 0.03	31.15 ± 2.47

Table 4 Mean values for chemical properties of final mixtures (values are calculated based on dry weight, excluding moisture content, which is wet weight basis)

Mixes	Reactors	Moisture (w.b., %)	pH (-)	EC (dS/m)	Organic matter (%)	C (%)	N (%)	[C/N] _{ib} ^a (-)
Mix-1	R1	69.83 ± 2.54	8.54 ± 0.06	2.00 ± 0.20	51.11 ± 0.65	19.93 ± 0.16	1.42 ± 0.11	14.11 ± 1.17
	R2	71.56 ± 1.20	8.61 ± 0.01	2.36 ± 0.40	47.13 ± 8.96	21.97 ± 1.31	1.59 ± 0.04	13.84 ± 0.51
Mix-2	R3	74.03 ± 0.60	8.89 ± 0.06	3.09 ± 2.14	57.45 ± 4.25	25.59 ± 8.50	1.56 ± 0.35	16.24 ± 1.85
	R4	73.89 ± 0.71	8.99 ± 0.16	3.27 ± 1.14	57.92 ± 0.84	26.46 ± 1.55	1.59 ± 0.02	16.67 ± 0.75
Mix-3	R5	72.36 ± 0.60	8.91 ± 0.07	2.19 ± 1.40	65.04 ± 4.59	26.38 ± 1.42	1.43 ± 0.06	18.43 ± 0.26
	R6	73.08 ± 1.71	8.91 ± 0.01	2.28 ± 1.53	64.24 ± 7.86	28.20 ± 5.71	1.47 ± 0.13	19.14 ± 2.14
Mix-4	R7	72.75 ± 0.31	9.11 ± 0.11	2.29 ± 4.25	72.82 ± 7.09	31.53 ± 1.35	1.42 ± 0.01	22.28 ± 0.85
	R8	72.82 ± 0.40	9.11 ± 0.22	2.29 ± 1.55	74.73 ± 0.66	34.67 ± 0.24	1.38 ± 0.01	25.22 ± 0.30
Mix-5	R9	72.65 ± 0.09	8.97 ± 0.07	2.41 ± 1.44	78.55 ± 0.24	37.12 ± 0.90	1.35 ± 0.07	27.52 ± 0.77
	R10	72.42 ± 0.63	8.99 ± 0.16	1.65 ± 3.77	80.27 ± 5.23	38.42 ± 0.99	1.44 ± 0.01	26.68 ± 0.42

^af stands for “final”

from 0.09 to 0.37 units in all reactors except for R2. The pH of composts in the reactors was finalized at values around 8.5–9.1. The pH values were finalized at slightly higher levels in the mixtures owing to probably ammonium formation and N-losses (Nakasaki et al. 1993).

EC of R1, R2, R4, and R6 increased somewhat as reported by Sánchez-Monedero et al. (2001) probably due to the increment in either of ion concentration, which occurs when the weight of compost mass decreases, or of nutrients (Table 3 and 4). The EC of the rest of the mixtures in reactors decreased at the end of the process probably due to the volatilization of ammonia and the precipitation of mineral salts (Montemurro et al. 2009).

The organic matter content of compost declined in all mixtures during microbial decomposition (Tables 3 and 4). Furthermore, studies showed that the temperature evolution, O₂ consumption, and CO₂ production as a function of time yield information about organic matter degradation due to microbial activity. The organic matter degradation of the five examined mixtures showed some differences. The highest change was measured for Mix-3 having the $[C/N]_{ib}$ ratio of 27.48 ± 2.53 . This situation can be explained as the mineralization of labile organic compounds that exist primarily in the thermophilic phase (Montemurro et al. 2009).

The initial CN values of the mixtures calculated were slightly different than those of the measured (Table 1). Changes in the initial and final C/N ratios are given in Tables 3 and 4. As a result of the change in C and N in all mixtures, the C/N ratio declined in each mixture (Paredes et al. 2002; Montemurro et al. 2009). The lowest change in C/N ratio was found for Mix-1 due to probably the excess of N. The highest change was measured for Mix-3 having the $[C/N]_{ib}$ ratio of 27.48 ± 2.53 .

Effects of initial C/N ratio on decomposition rate and compost mass ratio

Keener et al. (1993) and Marugg et al. (1993) showed that the decomposition rate of compost mass can be expressed as a first-order kinetic equation for the active stage of composting, i.e., the first stage. The high-rate stage is crucial for design and sizing of equipment as the highest rates of heat generation and aeration requirements occur during this period. To describe decomposition rate as a function of $[C/N]_{ib}$, Gaussian equation was applied to experimentally determine decomposition rates at five different initial ratios of $[C/N]_{ib}$. The fitted regression equation ($R^2 = 0.84$) is:

$$k = a_1 e^{-0.5 \left[\frac{[C/N]_{ib} - [C/N]_{ib}^0}{b_1} \right]^2} \quad (7)$$

with $a_1 = 0.03$, $b_1 = 9.44$, and $[C/N]_{ib}^0 = 26.54$.

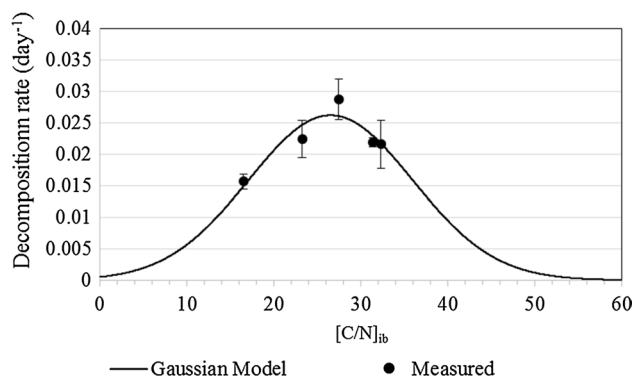


Fig. 3 Decomposition rate changing with $[C/N]_{ib}$ with standard deviations

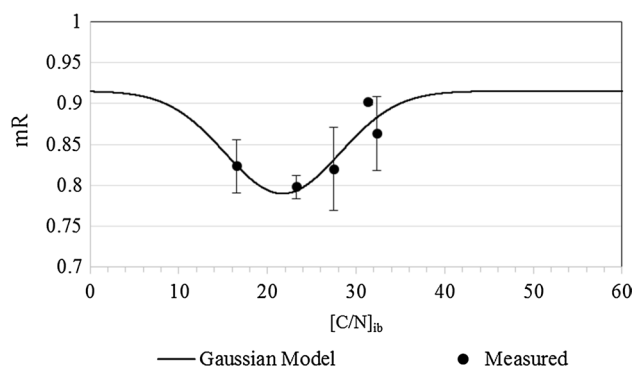


Fig. 4 mR as a function of $[C/N]_{ib}$ with standard deviations

Figure 2 shows the decomposition rate changing with $[C/N]_{ib}$ with the standard deviation. To describe the process, curve fitting was done by using the Gaussian equation because it would not predict negative k values at low or high $[C/N]$ s. Additionally, the Gaussian equation can be used to predict the $[C/N]_{ib}$ where the maximum decomposition rate existed. Results from Eq. 7 and Fig. 3 indicated that k peaked at a value of $[C/N]_{ib} = 26.54$. However, Ekinci et al. (2002a) reported that the highest degradation rate occurred at the initial $[C/N]_{ib}$ of 35.94 for composting of short paper fiber with broiler litter. Onursal (2006) found that the highest decomposition rate occurred at the initial $[C/N]_{ib}$ of 30.39 for composting of ROPSW with caged layer and straw.

The initial C/N ratio is one of the most crucial parameters influencing composting process since it directly affects microbial degradation of materials. It is also interrelated with mR described by Keener et al. (1993). Furthermore, mR is also function of physical and chemical conditions such as temperature, O₂ consumption, EC, pH. To reach a certain mR , all physical and chemical conditions should be balanced. Therefore, functional relationship between mR and

initial $[C/N]_{ib}$ was sought in the current study. mR at five different initial ratios of $[C/N]_{ib}$ is plotted in Fig. 4 and is presented as a function of $[C/N]_{ib}$ using regression analysis with Gaussian model.

$$mR = y_{01} + a_2 e^{-0.5 \left[\frac{[C/N]_{ib} - [C/N]_{ib}^0}{b_2} \right]^2} \tag{8}$$

with $y_{01} = 0.92$, $a_2 = -0.13$, $b_2 = 6.45$, and $[C/N]_{ib}^0 = 21.70$.

Regression analysis yielded a coefficient of determination of 0.81 indicated relatively strong relationship between mR and $[C/N]_{ib}$. However, there is uncertainty that the lowest mR value occurred at the $[C/N]_{ib}$ of 21.70, since high variations were calculated in the standard deviation of mR values corresponding $[C/N]_{ib}$, especially, 27.48 and 32.35.

Effects of initial C/N ratio on dry matter and organic matter loss

Degradation of organic matter, which is necessary for the estimation of decomposition rate required to size and design composting equipment, can be approximated using DML and OML, which should be calculated based on as a mass balance (Bernal et al. 2009; Chowdhury et al. 2013). Bernal et al. (2009) also reported that loss of organic matter decreases the weight of the composting material and reduces the C/N ratio. Ekinici et al. (2002a) implied that the higher organic matter loss leads to achieve a better mR value (decrease in mR value), thereby yielding more mature compost. Likewise, Ekinici et al. (2002a) and Onursal (2006) indicated that the degree of degradation of organic matter closely linked to mR value and showed the mR as a function of both dry matter and organic matter loss for composting of ROPSW with caged layer and straw. It is reasonable to say that the higher dry matter and organic matter loss are, the lower mR value indicating more advanced and mature compost. Furthermore, dry matter and organic matter losses based on organic matter degradation give the idea about the advancement of the composting process. In this study, the relationship was established by a Gaussian equation with R^2 of 0.93 indicating that DML had a peak value at $[C/N]_{ib}$ of 29.50.

$$DML = a_3 e^{-0.5 \left[\frac{[C/N]_{ib} - [C/N]_{ib}^0}{b_3} \right]^2} \tag{9}$$

with $a_3 = 14.53$, $b_3 = 12.29$, and $[C/N]_{ib}^0 = 29.50$.

Applying regression analysis by using Gaussian equation resulted in R^2 of 0.88. It can be said that the highest OML value existed at the CN ratio of 24.25. The fitted equation was:

$$OML = a_4 e^{-0.5 \left[\frac{[C/N]_{ib} - [C/N]_{ib}^0}{b_4} \right]^2} \tag{10}$$

with $a_4 = 24.34$, $b_4 = 12.15$, and $[C/N]_{ib}^0 = 24.25$. It should be noted that the peak value of DML and OML is slightly different.

Effects of initial C/N ratio on C-loss and N-loss

Initial C/N ratio of compost mixtures exerts a great impact on decomposition of organic material since nutritional balance is primarily expressed by C/N ratio (Ekinici et al. 2002a). The C/N range of 25–40:1 promotes decomposition of organic material, thereby yielding high growth rates with restricted odor generation (Keener et al. 2000). This recommendation is due to the carbon being readily available to microorganisms. $C/N > 40$ usually retards decomposition due to availability of nitrogen for microbial activity. On the other hand, Bernal et al. (2009) stated that a low C/N ratio indicates abundance of nitrogen per carbon, which may lead to loss of inorganic nitrogen through emission of ammonia or leaching from the composting mass. Larney et al. (2006) reported that composting causes more carbon or nitrogen losses than bulk storage or direct application to the field. Likewise, Michel et al. (2004) stated that nitrogen concentration increases, whereas organic matter, total C and C/N ratio are reduced at the end of composting process. Hao et al. (2004) also stated that the most important aspect of manure composting is to control C- and N-losses as the composting reduces its agronomic value and leads to greenhouse gas emissions. Bicudo et al. (2002) pointed out that nitrogen

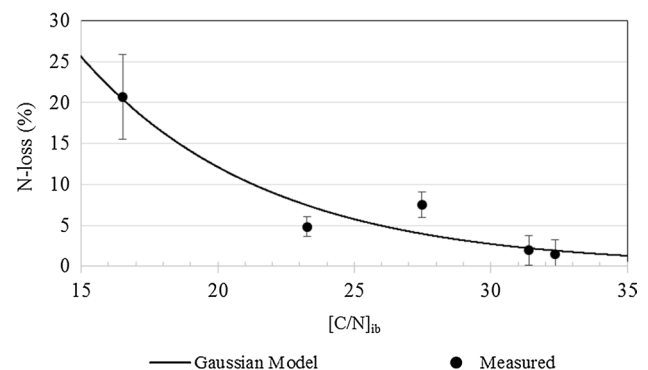


Fig. 5 N-loss as a function of C/N ratio with standard deviations

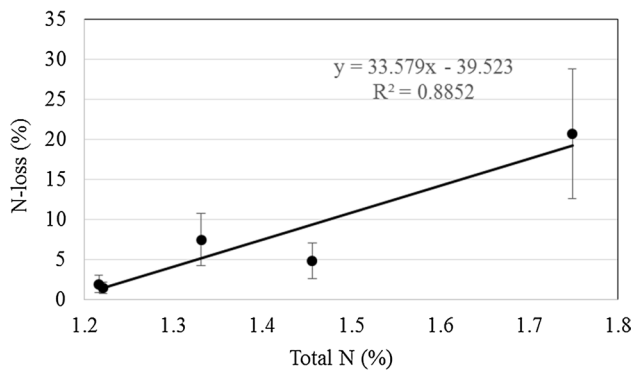


Fig. 6 N-loss as a function of initial total N with standard deviations

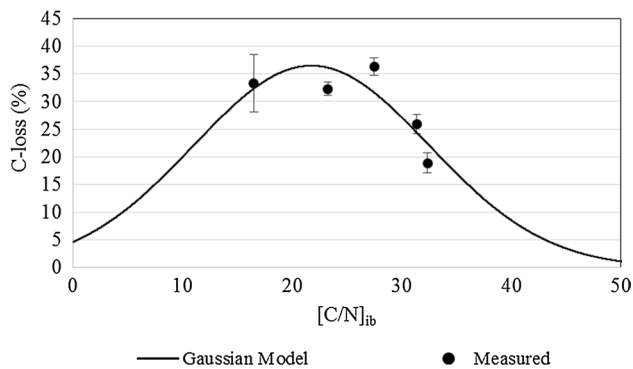


Fig. 7 C-loss as a function of C/N ratio with standard deviations

loss is an important aspect of composting in terms of protection of nutrients as atmospheric ammonia and nitrogen oxides may lead to various detrimental environmental and health problems. Furthermore, Ekinci et al. (2002a) indicated that manipulation of C/N ratios in composting reduces nitrogen volatilization substantially during manure composting.

Results showed that there was a significant negative correlation (exponential decay curve) between C/N ratio and N -loss ($R^2 = 0.92$) during composting (Fig. 5). To reduce nitrogen loss during ROPSW composting with separated dairy manure and straw, a C/N ratio of > 30 is recommended. Likewise, Larsen and McCartney (2000) suggested that practically all the N is retained in the compost at initial C/N ratios above 40 or an initial N concentration below 1%. Retention of the N is desirable since this would result in less odor, less nutrient loss, and less corrosion of equipment during composting. However, this situation may influence the degradation rate and the time required

for stable and mature compost production. Furthermore, in this study, the initial manure N concentration was the important factor controlling N -loss as the amount of N lost was linearly related ($R^2 = 0.89$) to the initial manure N concentration (Fig. 6).

Bernal et al. (2009) stated that composting comprised of a partial mineralization of the organic material, causing C -loss during the process. C -loss during composting was substantial, where somewhat more loss of carbon (18.91–36.37%) was observed in this study. The experimental results for C -loss at five different initial ratios of $[C/N]_{ib}$ are plotted in Fig. 7. Regression analysis with Gaussian equation was applied to C -loss as a function of $[C/N]_{ib}$. The fitted equation is:

$$C - \text{loss} = a_5 e^{-0.5 \left[\frac{[C/N]_{ib} - [C/N]_{ib}^0}{b_3} \right]^2} \quad (11)$$

with $a_5 = 36.50$, $b_5 = 10.72$, and $[C/N]_{ib}^0 = 21.77$.

Result of regression analysis yielded a value of $R^2 = 0.73$ indicating a moderate relationship between C -loss and $[C/N]_{ib}$. According to the results, it can be pointed out that the highest C -loss occurred at the $[C/N]_{ib}$ of 21.77. Therefore, an initial C/N ratio > 21.77 is suggested to reduce C -loss during ROPSW composting with separated dairy manure with straw amendment.

Conclusion

Rose oil processing wastes were mixed with separated dairy manure and straw at five different proportions to investigate the effects of C/N ratio on organic matter degradation. Composting process was monitored by temperature, O_2/CO_2 concentrations, moisture and organic matter, content, pH, EC, and total C and N contents. Maximum decomposition ($0.03 \text{ kg kg day}^{-1}$) occurred at the initial C/N ratio of 26.54 based on the first-order kinetic model. Results showed that the more mature compost was obtained when the compost mixture was prepared at the initial C/N ratio of 21.70. However, there is the uncertainty on the result since high variations were calculated in the standard deviation of compost mass ratio values corresponding to the initial C/N ratios of 27.48 and 32.35. The highest dry matter loss (14.53%) and organic matter loss (24.34%) closely related to compost mass ratio existed at the initial C/N ratio of 29.50 and 24.25, respectively.

To lessen nitrogen loss during composting, a C/N ratio of > 30 is preferable due to the inverse relationship (exponential decay curve) between initial C/N ratio and N -loss.



The initial total nitrogen content of compost mixtures affected *N*-loss significantly implying that the lower initial nitrogen content led to lower *N*-loss. To avoid high *C*-loss, composting operation should be performed at an initial *C/N* ratio of > 21.77 .

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