Full Paper

Carbon Loss in Chicken Litter Compost As Affected By Carbon to Nitrogen Ratio and Turning Frequency

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ABSTRACT

Raw chicken manure was co-composted with sawdust in turned-windrow piles to study the effects of carbon to nitrogen (C:N) ratio and turning frequency (TF) on the loss of total carbon (C) during composting. Three levels of C:N ratio (20:1, 25:1 and 30:1) and TF (2, 4 and 6 days) were experimented in a two-factor completely randomized block design. During the composting process, temperature, pH, moisture content (MC), total C, phosphorus (P), potassium (K) and nitrogen (N), dry matter (DM) and C:N ratio were monitored. Also, MC of the piles was periodically replenished to 55%. The results showed that both C:N ratio and TF had significant ($p \leq 0.05$) effect on temperature, pH, total N, C, P and K losses and C:N ratio of the piles while only C:N ratio affected ($p \leq 0.05$) DM losses. It was observed that moisture loss increased as C:N ratio and TF increased. The decline of pile temperatures to near ambient temperature occurred at about 87 days in all treatments. The final total C losses ranged between 63.1 and 83.8%, with 65.2-97.1% occurring within the first six weeks when the pile temperatures and pH values were above 33 °C and 7.7, respectively. The total C losses were largely attributed to organic matter degradation and increased as C:N ratio and TF increased. The combined effects of C:N ratio and TF showed that treatment with 6 days TF and C:N ratio of 20:1 had the minimum total C loss (63.1%).

Keywords: *Composting, C:N ratio, Turning frequency, Total C loss.*

NOMENCLATURE

T_2R_{20}	composting pile with 2 days TF and C:N ratio 20:1
T_2R_{25}	composting pile with 2 days TF and C:N ratio 25:1
T_2R_{30}	composting pile with 2 days TF and C:N ratio 30:1
T_4R_{20}	composting pile with 4 days TF and C:N ratio 20:1
T_4R_{25}	composting pile with 4 days TF and C:N ratio 25:1
T_4R_{30}	composting pile with 4 days TF and C:N ratio 30:1
T_6R_{20}	composting pile with 6 days TF and C:N ratio 20:1
T_6R_{25}	composting pile with 6 days TF and C:N ratio 25:1
T_6R_{30}	composting pile with 6 days TF and C:N ratio 30:1

1. INTRODUCTION

Application of raw manure to agricultural soils could lead to serious environmental problems such as increased nutrient loss through leaching, erosion, and runoff from agricultural fields. These problems could be mitigated by chemically and biologically stabilizing the soluble nutrients in raw manure to more stable organic forms by composting before application to agricultural soils. Composting is viewed as a viable means of producing environmentally friendly humus-like material, and an important way of protecting ground and surface waters from excessive loading of litter nutrients. Composting stabilizes organic wastes and destroys most parasites, pathogens, and viruses contained in the wastes (Tiquia *et al.*, 2000). It also considerably reduces odour emissions by reducing levels of biodegradable hydrocarbons and dries up the waste making it unattractive to insects (Barrington *et al.*, 2002). However, one of the most negative effects of composting animal manures is the loss of valuable nutrients which reduces the fertilizer value of the manure and constitutes an important economic loss. During composting, nitrogen (N) is largely lost through ammonia (NH_3) volatilization. Ammonia emissions can result from aerobic or anaerobic bacteria activities in manure (Zhang *et al.*, 1991). Apart from N, carbon (C) is another key element of animal manure that is lost during the composting. Carbon may be lost due to either bio-oxidation, in which carbonaceous materials are lost as carbon dioxide (CO_2) (Eghball *et al.*, 1997) or mineralization of C, in which inorganic C are converted to organic C (Bernal *et al.*, 1998). Total C loss during composting varies depending on the composting method used. Nutrients that plants need in large amounts, called macronutrients, include oxygen, hydrogen, carbon and an array of minerals (Hynes, 2008). Carbon is what most of the plant is made of. It forms the backbone of many plant biomolecules, including starches and cellulose. Therefore, minimization of C loss during composting process should also be a research focus.

The control of parameters such as C:N ratio, temperature, moisture content (MC), bulk density, aeration, particle size and pH have demonstrated to be key for composting optimization since they determine the optimal conditions for microbial development and organic matter (OM) degradation (Haug, 1993). The initial C:N ratio of composting materials should be within 20:1-40:1 for rapid composting (Rynk *et al.*, 1992). Lower values could cause high emissions of NH_3 (Tiquia and Tam, 2000) while higher values could cause a slower beginning of the process and longer than usual composting time (Tuomela *et al.*, 2000). Turning is often cited as the primary mechanism of aeration and temperature control during windrow composting (Michel *et al.*, 1996; Tiquia, 1996), while turning frequency (TF) is commonly believed to be a factor which affects the rate of composting as well as compost quality (Tiquia, 1996).

Most composting studies have focused on N losses from manure during composting while C losses have been less investigated. For instance, the effects of C:N ratio (Hansen *et al.*, 1989; Eghball *et al.*, 1997; Huang *et al.*, 2004) and TF (Tiquia *et al.*, 1997; Wong *et al.*, 2001) on N losses during composting have been studied while information regarding the effects on C losses are rather scarce. As a result, the present study aims to: (1) investigate the effects of C:N ratio and TF on the changes in total C during composting of chicken litter in turned-windrow piles and (2) assess the combined effects of C:N ratio and TF with a view to determining the optimum combination that will minimize total C loss during composting.

2. MATERIALS AND METHODS

2.1. Composting Set Up

The experiment was conducted during the dry season on an open site at the Department of Agricultural Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. The ambient temperatures during the period ranged from about 22-35 °C. The raw chicken manure and sawdust used in the study were collected from a poultry farm and sawmill plant in Ile-Ife, respectively. The initial properties of the chicken manure and sawdust are summarized in Table 1. The total N, total phosphorus (P) and total potassium (K) contents of the sawdust were assumed to be traces (Eghball, 1997), hence they were not determined. The experimental set up was a 3 × 3 completely randomized block design with C:N ratios at 20:1, 25:1 and 30:1, and with TFs at every 2, 4 and 6 days. The C:N ratio of the chicken manure was raised to 20:1, 25:1 and 30:1 through the addition of sawdust (Brake, 1992), and in accordance with the recommendations of (Rynk *et al.*, 1992) on rapid composting. Sawdust was used because of its low MC, high porosity and C:N ratio. The initial concentrations of ash, total C, total N, C:N ratio, total P, total K, and MC of the composting mixture were theoretically calculated based on the results of the analyses.

Nine piles of chicken litter were built in pits of size 1.2 m × 1.2 m square base and a height of 0.3 m, which each pile having a pyramidal shape with a square base of 1.2 m × 1.2 m and a height of about 0.76 m. Each pile was replicated three times and turned manually using a hand shovel. The MC of the litter was adjusted to 55% (wet basis) at the beginning of composting, as described by Brake (1992), measured periodically (precisely a day to turning operation) and replenished to 55% (wet basis) during turning operation such that every part received moisture.

2.2. Sampling and Analytical Procedures

Pile temperatures were measured daily, using a digital thermometer, at two levels (0.25 m and 0.50 m from the base of the pile) within the pile between the hours of 06:00 am and 08:00 am when the ambient temperature was fairly stable. Sampling was done fortnightly from the start to the end of the experiment. Three samples each were collected at three locations in each pile (0.25 m from the top, at the middle and 0.25 m from the base) and composited. Samples were analyzed at 105 °C dry weight basis for the following parameters: moisture content (105 °C for 24 h); ash content (expressed as a percentage of residues after ignition at 600 °C for 5 h); total N using regular-kjeldahl method (Bremner, 1996); total K (after acid digestion) using atomic absorption spectrophotometer (Alpha 4 model); total P (after acid digestion) using ultra-violet visible spectrophotometer (UNICAM UV1 model) of wavelength 660 nm; pH (1:10 w/v sample: water extract) using a pH meter with a glass electrode. The total C was estimated from the ash content according to the formula (Mercer and Rose, 1968):

$$Total\,C\,(\%) = [100 - Ash\,(\%)]\,/\,1.8 \qquad (1)$$

Initial and final concentrations of total N, P and K were determined while total C and pH determined fortnightly. Losses of dry matter (DM), total C, total N, total P and total K from the pile during composting were calculated according to the equation (Sanchez-Monedero *et al.*, 1996):

$$Y\,loss\,(\%) = 100 - 100\left[\frac{X_1 Y_2}{X_2 Y_1}\right] \qquad (2)$$

where X_1 and X_2 represent the initial and the final ash concentrations, Y represents DM, total C, N, P and K, and Y_1 and Y_2 represent the initial and final concentrations of Y.

2.3. Statistical Analysis

The data obtained were subjected to statistical analyses, using Statistical Analysis System (SAS, 2002) procedure. *T*-test was used to compare the upper and lower temperature readings within the piles. Regression analysis was used to determine the relationship among compost properties. Two-way analysis of variance (ANOVA) was performed to compare variations in compost properties, and where significance was indicated, Least Significant Difference (LSD) test was used to establish which treatment was significantly different.

Table 1: Initial properties of the composting materials

Property	Concentration (dry weight basis)	
	Chicken manure	Sawdust
MC (%)	54.0 ± 2.48*	30.0 ± 1.10*
pH	8.34 ± 0.04	7.60 ± 0.10
Ash (%)	52.3 ± 1.20	3.00 ± 0.17
Total C (%)	26.5 ± 1.13	53.9 ± 1.71
Total N (%)	2.10 ± 0.11	nd
Total K (ppm)	203.9 ± 4.10	nd
Total P (ppm)	2.70 ± 0.10	nd
C:N ratio	13:1	nd

Mean and standard error are shown (n = 3).

nd - not determined; ppm - parts per million.

**Value on wet weight basis.*

3. RESULTS AND DISCUSSION

3.1. Physico-Chemical Changes during Composting

The pile temperatures stabilized about the 87th day of composting. This duration was within the range of 15 and 180 days reported for converting manure into stabilized compost (Rynk *et al.*, 1992; Michel *et al.*, 1996). It was observed that moisture addition during composting increased from 161.67% to 270.57% (of total pile weight) as TF increased from 6 to 2 days, and increased from 176.90% to 248.37% (of total pile weight) as C:N ratio increased from 20:1 to 30:1. The final losses in compost elements are presented in Table 2. The increases observed in the ash concentrations of all the treatments revealed that effective OM degradation occurred during the composting process. Seepage losses were considered insignificant as the piles were not wet enough to drain water. Total P and K concentrations were significantly ($p \leq 0.05$) affected by both C:N ratio and TF. Table 3 shows the LSD test on compost properties. The final C:N ratios showed that, except for T_4R_{25}, all other treatments had increase in C:N ratio. This development could be attributed to vigorous NH_3 volatilization during composting, as reported by Eghball *et al.* (1997) and Tiquia and Tam (2000).

Table 2: Final loss in compost elements

Treatment	Dry matter loss (%)	Total N loss (%)	Total P loss (%)	Total K loss (%)
T_2R_{20}	16.1 ± 1.01	88.2 ± 0.28	62.8 ± 1.51	85.8 ± 0.17
T_4R_{20}	18.4 ± 1.71	82.7 ± 0.45	4.60* ± 9.16	79.6 ± 0.28
T_6R_{20}	15.2 ± 0.24	86.8 ± 0.32	53.9 ± 0.48	82.1 ± 0.12
T_2R_{25}	16.4 ± 1.50	82.9 ± 0.42	57.2 ± 1.48	70.9 ± 0.54
T_4R_{25}	7.72 ± 2.14	70.7 ± 0.80	1.77* ± 2.29	57.2 ± 0.62
T_6R_{25}	10.0 ± 0.80	87.4 ± 0.67	50.9 ± 1.21	50.6 ± 0.46
T_2R_{30}	17.9 ± 0.86	87.1 ± 1.06	53.7 ± 0.11	85.6 ± 0.15
T_4R_{30}	18.0 ± 2.15	83.9 ± 2.44	55.7 ± 3.55	82.8 ± 0.16
T_6R_{30}	22.9 ± 1.21	81.3 ± 1.10	67.2 ± 0.49	76.1 ± 0.27

Mean and standard error are shown (n = 3).

**Percent gain.*

3.1.1. Temperature

The pile temperatures during composting ranged between 28 °C and 71 °C. Both the C:N ratio and TF had significant ($p \leq 0.05$) effect on pile temperature (Table 3). The results of the *t*-test showed no significant ($p > 0.05$) difference between the two temperature readings within the piles. This was as a result of the mixing effect and it

Table 3: Least significant difference (LSD) test on the compost properties

Property	C:N ratio				TF (days)			
	20:1	25:1	30:1	LSD	2	4	6	LSD
Temperature (°C)	42.39^{b}	52.49^{a}	53.57^{a}	2.57	49.34^{a}	53.14^{b}	45.96^{c}	2.57
pH	8.03^{b}	8.26^{a}	8.09^{b}	2.45	8.17^{c}	8.09^{b}	8.12^{a}	2.45
DM (%)	16.55^{a}	11.36^{b}	19.61^{a}	2.44	ns	ns	ns	-
Total N (%)	85.90^{a}	80.33^{b}	84.13^{a}	1.80	86.05^{a}	79.13^{b}	85.19^{a}	1.80
Total C (%)	71.77^{a}	74.04^{b}	82.21^{c}	1.76	81.40^{a}	75.51^{b}	71.11^{c}	1.76
C:N ratio	40.89^{a}	37.85^{a,b}	34.74^{b}	3.28	33.90^{a}	30.14^{b}	49.45^{c}	3.28

Superscripts with the same letter are not statistically different at $p \leq 0.05$; ns - mean value not significant at $p \leq 0.05$.

implied that the composting rates and compost quality within the piles would be the same. The regression analysis performed on the pooled means showed that pile temperature had a significant ($p \leq 0.05$) correlation with pH and total C, according to the relationship:

$$Temperature = -29.49 + (1.02 \times total\,C) + (5.60 \times pH); \quad R^2 = 0.76 \tag{3}$$

This confirms the findings by Tiquia *et al.* (1998) on the correlation of temperature with compost properties. Thermophilic temperatures (56.3-70.7 °C) were attained within 24 h of composting (Figure 1a-c), an indication that the initial C:N ratios and MC were ideal for composting. The short thermophilic phase (17-22 days) observed is associated with turned windrow method (Diaz *et al.*, 2002), likely related to small size of piles involved (Ogunwande *et al.*, 2008) and also, as a result of the TFs ($p \leq 0.05$). The duration of temperatures > 55 °C (9-11 days, 10-11 days and 7-8 days in piles with C:N ratios 20:1, 25:1 and 30:1, respectively) indicated that the pathogens and weed seeds would have been abated during composting (Misra *et al.*, 2003). The slight increases noticed in the pile temperatures after each turning operation in the early days of composting were as a result of the re-activation of microbial activities. This could be explained by the incorporation of external material into the pile, providing degradable substrate for the microbial biomass (Gracia-Gomez *et al.*, 2003).

3.1.2. Dry Matter and Total Nitrogen

Dry matter loss ranged between 7.72% and 22.9% (Table 2) and was affected ($p \leq 0.05$) by C:N ratio (Table 3). These losses were lower than the range (35-50%) reported by Kithome *et al.* (1999) during composting of poultry manure. Both the C:N ratio and TF had significant ($p \leq 0.05$) effect on the final total N losses which ranged between 70.7% and 88.2% (Table 2).

3.1.3. pH

The initial pH values (8.35-8.63) (Table 4) were within the reasonable range (5.5-9.0) recommended for rapid composting (Rynk *et al.*, 1992). The pH values remained on the alkaline side throughout the composting process (Table 4). Both the C:N ratio and TF had significant ($p \leq 0.05$) effect on the alkalinity of the piles (Table 3). High pH values (8.73 to 9.34) observed during the second week in all the treatments (Table 4) was attributed to intense OM degradation in the piles and the consequent release of volatile NH_3 (Paredes *et al.*, 2000). The decrease in pH values after the second week was attributed to the production of organic acids during decomposition of OM contained in the chicken litter (Charest and Beauchamp, 2002). The final values (7.53-7.83) were close to 7.2 recommended for the improvement of agricultural soils (Rynk *et al.*, 1992) and for optimum plant growth (Campbell *et al.*, 1997).

3.1.4. Total Carbon

Total C concentration decreased gradually with composting time in all the piles due to OM degradation. The decrease synchronized with an increase in ash content of the chicken litter piles. It was observed that C:N ratio and TF had significant ($p \leq 0.05$) effect on total C loss, which increased as C:N ratio and TF increased (Table 3). Increase in C:N ratio is associated with increase in porosity of the piles, hence increase in air supply to the piles. Similarly, increase in TF increases air supply to the piles. Therefore, it can be concluded that total C loss was related to the air supplied to the piles. In view of these facts, with increased air supply, total C may have served as a source of energy for the micro-organisms and been

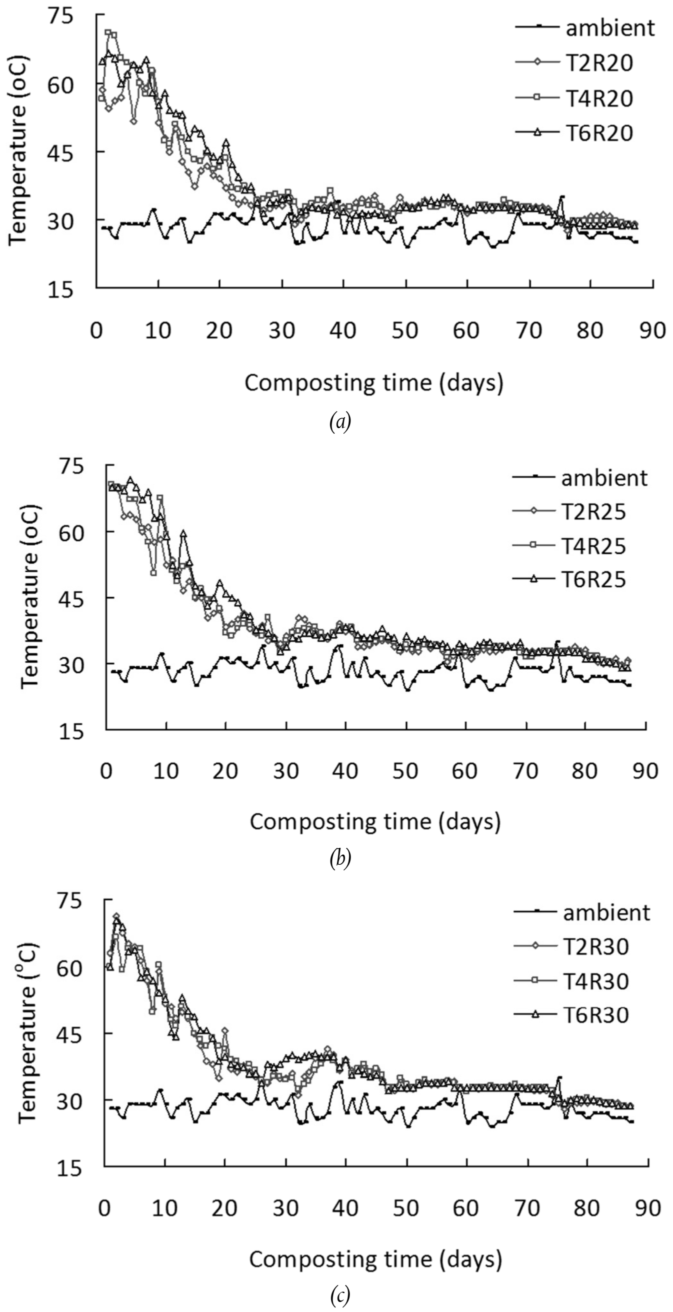

Figure 1: Changes in air and pile temperatures of composting piles with (a) C:N 20:1, (b) C:N 25:1, and (c) C:N 30:1

burnt up and respired as CO_2, or may have been mineralized, in which inorganic C would have been converted to organic C (Bernal *et al.*, 1998). The regression analysis showed that as TF decreased from 2 to 6 days, the rate of total C loss (% total C/day) was highest in treatment with C:N 20:1 (4.21, R^2=0.99), followed by treatment with C:N 25:1 (2.80, R^2=0.94) and then, treatment with C:N 30:1 (0.70, R^2=0.98). Also, it was shown that total C had a significant ($p \leq 0.05$) correlation with total N and C:N ratio, according to the relationship:

$$Total\ C = -11.54 + (0.21 \times temperature) + (17.59 \times total\ N) + (0.39 \times C:N\ ratio);\ R^2 = 0.9 \quad (4)$$

Table 4: Changes in pH of composting piles during composting

Treatment	Composting time (weeks)						
	0	2	4	6	8	10	12
T_2R_{20}	8.54	8.93	8.30	7.68	7.90	7.81	7.69
T_4R_{20}	8.49	8.87	7.87	7.65	7.72	7.76	7.74
T_6R_{20}	8.35	8.82	7.76	7.75	7.62	7.64	7.73
T_2R_{25}	8.63	9.29	8.24	8.17	8.19	7.99	7.82
T_4R_{25}	8.60	9.07	8.15	7.96	7.91	7.90	7.63
T_6R_{25}	8.46	9.34	8.08	8.19	8.06	7.94	7.83
T_2R_{30}	8.59	8.91	7.75	7.78	7.84	7.76	7.75
T_4R_{30}	8.43	8.73	8.02	7.96	7.95	7.76	7.80
T_6R_{30}	8.48	9.01	8.12	7.97	7.94	7.80	7.63

Figure 2a-c showed the changes in total C losses with composting time. It was shown that total C loss increased gradually in all the piles. The final total C loss ranged between 63.1% and 83.8% in all the treatments. This was an indication that the chicken litter contained high degradable OM (Fang *et al.*, 1999). Treatment T_6R_{20}, which had the least loss in total C, had pH and total N significantly ($p \leq 0.05$) correlated with total C. This implied that pH and total N contributed to the total C loss in the treatment. The final losses were higher than the range (44.5-61.5%) reported by Eghball *et al.* (1997), probably due to the higher initial C:N ratios or composting method used in this study. It was observed that 65.2-97.1% of the final losses occurred within the first 42 days of composting when the pile temperatures and pH values were above 33 °C and 7.7, respectively. This indicated that maximum OM degradation occurred within this period.

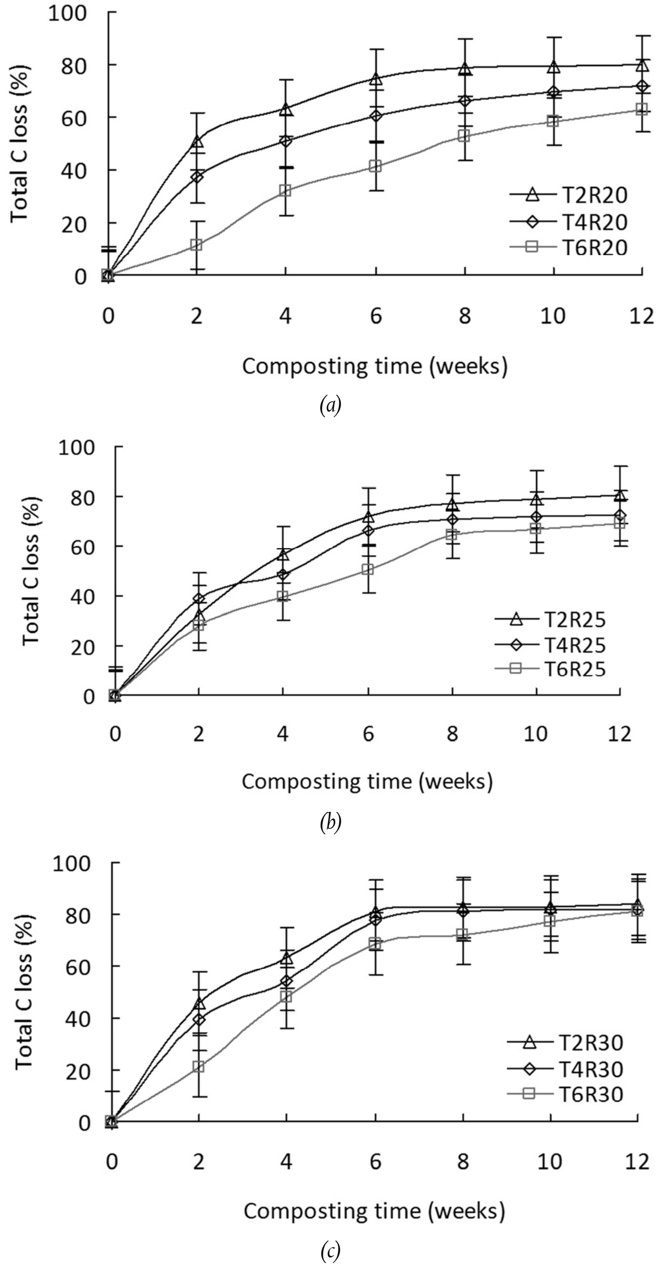

Figure 2: Changes in total C losses of composting piles with (a) C:N 20:1, (b) C:N 25:1, and (c) C:N 30:1. Error bars show standard errors of means (n = 3).

4. CONCLUSIONS

The main conclusions of the study are summarized as follows:

i. The stability of chicken litter compost was accompanied by a decline of compost temperatures to temperature near ambient level within a period of 87 days.
ii. Both C:N ratio and TF were significant ($p \leq 0.05$) on pile temperature, pH, total C, N, P and K losses and C:N ratio while DM was only affected ($p \leq 0.05$) by C:N ratio.
iii. The highest losses of total C occurred during the period of maximum OM degradation when the pile temperatures and pH values were above 33 °C and 7.7, respectively, and increased as C:N ratio and TF increased.
iv. Moisture loss increased as C:N ratio and TF increased.
v. A combination of 6 days TF and initial C:N ratio 20:1 (T_6R_{20}) produced the least total C loss.

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