Effects of Carbon to Nitrogen Ratio and Turning Frequency on Composting of Chicken Litter in Turned-Windrow Piles

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ABSTRACT

Raw chicken manure was co-composted with sawdust in turned-windrow piles to understand the effects of carbon to nitrogen (C:N) ratio and turning frequency (TF) on composting. Carbon to nitrogen ratios of 20:1, 25:1 and 30:1, and turning frequencies of every 2 days and every 6 days were experimented. Properties of the chicken litter (chicken manure + sawdust) periodically monitored during the composting process were moisture content (MC), temperature, pH, total nitrogen (TN), total carbon (TC) and C:N ratio while dry matter (DM), total phosphorus (P) and total potassium (K) were examined at the end of composting. During composting, MC of the piles was periodically replenished to 55%. The results showed that C:N ratio had significant ($p \leq 0.05$) effect on pile temperature, TN, TC, C:N ratio, DM, P and K while TF had significant ($p \leq 0.05$) effect on pile temperature, pH, TC, C:N ratio and K. A significant part of the TN losses were attributed to NH_3 volatilization while that of the TC losses were attributed to OM degradation. It was observed that moisture loss increased as C:N ratio and TF increased. All treatments reached stability at about 87 days as indicated by the decline of pile temperatures to values close to ambient temperature.

Keywords: Composting, chicken litter, C:N ratio, turning frequency, Nigeria

1. INTRODUCTION

The use of raw manure as a soil amendment has increased over the years since the use contributes to the disposal of wastes and enhances the preservation of the environment. However, such practices could lead to serious environmental problems such as increased nutrient loss through leaching, erosion, and runoff from agricultural fields. Composting has received increasing interest as a method for handling various types of animal manures. It 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 (Tiquia *et al.*, 2000), and destroys most parasites, pathogens, and viruses contained in the wastes. 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 nitrogen (N) through ammonia (NH_3) volatilization which reduces the fertilizer value of the manure, and constitutes an important economic loss. Hence, composting changes the nature of the waste and can affect its usefulness as a soil amendment (Tiquia and

Tam, 2000). Ammonia emissions result from aerobic or anaerobic bacteria activities in manure (Zhang *et al.*, 1991). Several studies have shown that NH_3 volatilization increases with an increase of pH, MC, aeration, NH_3 concentration, or temperature (Bishop and Godfrey, 1983). Apart from N, carbon (C) is another element that is most likely to be lost during the composting process. Carbon may be lost due to either bio-oxidation, in which carbonaceous materials are lost as CO_2 (Bishop and Godfrey, 1983; Eghball *et al.*, 1997) or mineralization of C, in which inorganic C are converted to organic C (Bernal *et al.*, 1998). The most widely used parameter for composting is the C:N ratio of the initial composting material; high initial C:N ratio will cause a slower beginning of the process and the required composting time to be longer than usual (Tuomela *et al.*, 2000) while low initial C:N ratio results in high emission of NH_3 (Tiquia and Tam, 2000). If the water content of the composting litter is not maintained at a proper level, undesirable factors may arise such as, a longer composting period (Eghball, 1997). Brake (1992) reported that with too little water, the heat required for proper composting will not be attained while anaerobic conditions may set in with too much water. 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 is commonly believed to be a factor which affects the rate of composting as well as compost quality (Tiquia, 1996). Near-neutral pH is preferred for most efficient microbial activity during composting. Moore *et al.* (1997) found that NH_3 volatilization from poultry litter increases once pH rises above 7.0. Temperature is a simple and excellent indicator of how well the composting process is progressing and how much O_2 is being used (Walker, 2004). Misra *et al.* (2003) reported that high temperatures during composting contribute to the killing of weed seeds and pathogenic organisms.

According to Stephenson *et al.* (1990), raw poultry manure contains higher concentrations of N, Ca, and P than manure from other livestock, hence its importance as fertilizer and soil amendment. A considerable body of literature exists concerning the effects of different C:N ratios (Hansen *et al.*, 1989; Eghball *et al.*, 1997) and turning frequencies (Tiquia *et al.*, 1997; Wong *et al.*, 2001) on composting properties, however, the combined effects of these composting factors on composting of poultry litter in turned-windrow piles are not well understood. Therefore, the present study aims to: (1) assess the effects of C:N ratio on composting of chicken litter in turned-windrow piles; (2) assess the effects of turning frequency (TF) on composting of chicken litter in turned-windrow piles; and (3) assess the combined effects of C:N ratio and TF on composting of chicken litter in turned-windrow piles.

2. MATERIALS AND METHODS

2.1 Composting in Turned-windrow Piles

The experiment was conducted during the dry season on an open site at the back of Agricultural Engineering building, Obafemi Awolowo University, Ile-Ife, South-West of Nigeria, between the months of December, 2005 and March, 2006. Fresh chicken manure used in the study was collected in batches from a poultry farm in Ile-Ife, South-West of Nigeria, within 4 days prior to composting. The bulking material (sawdust) mixed with the manure was collected from a sawmill plant, also in Ile-Ife. Sawdust was used because of its low MC, high porosity and C:N ratio. The initial properties of the chicken manure and sawdust are summarized in Table 1. The

TN, P and K contents of the sawdust were assumed to be negligible as various authors (Galler and Davey, 1971; Eghball, 1997) have reported these elements as traces.

Table 1. Initial properties of the chicken manure and sawdust

	Concentration (dry weight basis)	
Parameter	Manure	Sawdust
Total N (%)	2.10 ± 0.11	nd
Ash (%)	52.34 ± 1.20	3 ± 0.17
Total C (%)	26.47 ± 1.13	53.89 ± 1.71
C:N ratio	13:1	nd
Potassium (ppm)	203.90 ± 4.10	nd
Phosphorus (ppm)	2.70 ± 0.10	nd
pH	8.34 ± 0.04	7.60 ± 0.10
Moisture content (%)	54.0 ± 2.48*	30.0 ± 1.10*

* Value on wet weight basis.
Mean and standard error are shown (n = 3); ppm = parts per million; nd = not determined

The concentration of ash, TC, TN, C:N ratio, total P, total K, and moisture content (MC) of the initial composting mixture was theoretically calculated based on the results of the initial analyses. The C:N ratio of the raw 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. The MC of the litter was adjusted to 55% (wet basis) at the beginning of composting by the method given by Brake (1992).

The experimental set up was a 3 × 2 factorial design with C:N ratios at 20:1, 25:1 and 30:1, and with turning frequencies at every 2 days and every 6 days. Six 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 was 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

During the composting process, ambient temperature and temperatures within each pile were measured daily using a digital thermometer. Temperature measurements were taken at two locations (0.25 m from the top and 0.25 m from the bottom) within the pile between the hours of 06:00 am and 08:00 am when the ambient temperature was fairly stable. Sampling was done every two weeks from the start to the end of the experiment. Three samples each were collected at three locations in a pile (0.25 m from the top, the middle and 0.25 m from the bottom) and composited. Samples were analyzed for the following parameters: moisture content (105 ^{o}C for 24 h); ash content (expressed as a percentage of residues after ignition at 600 ^{o}C for 5 h); TN 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 TC was estimated from the ash content according to the formula (Mercer and Rose, 1968):

$$C(\%) = [100 - Ash(\%)]/1.8 \tag{1}$$

Samples were analyzed for total P and total K at the start and at the end of the process while TC, TN and pH were analyzed fortnightly. All mass measurements (except MC) were expressed on 105 ^{o}C dry weight basis.

Losses of TC, TN, DM, P and K from the pile during composting were calculated based on the initial (X_1) and final (X_2) ash contents, according to the formula (Sanchez-Monedero *et al.*, 1996):

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

where Y represents TC, TN, DM, P and K, and Y_1 and Y_2 represent the initial and final concentrations of Y.

2.3 Statistical Analyses

The data were subjected to statistical analyses, using statistical analysis system procedure (SAS, 2002). Two-way analysis of variance (ANOVA) was performed to compare variations in compost properties. Where significance was indicated, Duncan's multiple range tests was used to establish which treatment(s) was significantly different.

3. RESULTS AND DISCUSSION

The results of this study have shown that composting duration was 87 days and within the range of 15 and 180 days reported by Rynk *et al.* (1992) and Michel *et al.* (1996) for converting manure into stabilized compost. It was observed that moisture loss increased as the TF and C:N ratio increased. This was revealed by the cumulative percent MC added to the piles during composting (Table 2). Table 3 presents the loss in compost elements for each treatment by the end of composting. The increases that were observed in the ash concentration of all the treatments by the end of composting revealed that effective OM degradation occurred during the composting process. C:N ratio had significant ($p \leq 0.05$) effect on DM, P and K losses while TF affected ($p \leq 0.05$) K loss. The Duncan's multiple range tests showed the treatment(s) that was significantly different for each of the measured parameters (Table 4 & 5).

3.1 Temperature Profiles

The mean temperatures at the upper and lower locations within the piles were not significantly ($p > 0.05$) different. The results of the ANOVA test revealed that C:N ratio and TF had significant ($p \leq 0.05$) effect on pile temperature. The temperature values showed that temperature increased as C:N ratio and TF increased (Table 4).

Table 2. Cumulative percent MC (wet basis) added during composting

Day	T_2R_{20}	T_2R_{25}	T_2R_{30}	Day	T_6R_{20}	T_6R_{25}	T_6R_{30}
8	20.9	21.9	27.4	6	7.6	11.2	16.0
14	45.7	48.6	57.5	12	14.5	19.4	28.2
20	57.1	60.8	71.5	18	31.7	35.8	46.1
28	81.0	83.4	96.4	30	45.8	52.9	65.5
38	111.7	115.4	129.2	36	58.7	66.4	79.8
48	143.1	145.9	160.8	48	75.0	93.6	104.3
58	179.6	182.8	199.7	60	96.2	124.0	133.2
68	201.6	214.1	236.3	72	109.0	146.4	160.4
78	224.9	243.8	274.5	84	122.9	171.9	190.2
86	241.3	265.6	304.8				

Data under the treatment column represent the cumulative % MC (wet basis)

Table 3. Loss in compost elements

Treatment	TN loss (%)	TC loss (%)	Total P loss (%)	Total K loss (%)
T_2R_{20}	88.17 ± 0.28	79.98 ± 0.71	62.78 ±1.51	85.78 ± 0.17
T_2R_{25}	82.85 ± 0.42	80.45 ± 1.08	57.22 ± 1.48	70.89 ± 0.54
T_2R_{30}	87.12 ± 1.06	83.52 ± 0.13	53.66 ± 0.11	85.60 ± 0.15
T_6R_{20}	86.80 ± 0.32	63.12 ± 0.92	53.96 ± 0.48	82.10 ± 0.12
T_6R_{25}	87.42 ± 0.67	69.28 ± 0.96	50.97 ± 1.21	50.61 ± 0.46

Mean and standard error are shown (n = 3)

Table 4. Duncan's multiple range tests on the effect of C:N ratio and TF on compost parameters

Parameter	C:N ratio			TF	
	20:1	25:1	30:1	2	6
Temperature	36.46^{b}	52.52^{a}	53.98^{a}	49.34^{b}	45.96^{a}
pH	ns	ns	ns	9.69^{b}	4.35^{a}
Total N	87.49^{a}	85.14^{b}	84.23^{b}	ns	ns

Total C	71.55^{a}	74.87^{b}	82.34^{c}	81.40^{a}	71.11^{b}
C:N ratio	45.27^{a}	45.01^{a}	34.74^{b}	33.90^{b}	49.45^{a}
DM	15.64^{b}	13.19^{a}	20.41^{c}	ns	ns
Total P	58.37^{a}	54.10^{b}	60.41^{a}	ns	ns
Total K	83.94^{a}	60.75^{c}	80.87^{b}	80.76^{a}	69.61^{b}

Superscripts with the same letter indicate no significant difference among mean values; ns = mean value not significant at $p \leq 0.05$

Table 5. Duncan's multiple range tests on the interaction (C:N*TF) effect on compost parameters

Parameter	C:N*TF2			C:N*TF6		
	20:1	25:1	30:1	20:1	25:1	30:1
Temperature	ns	ns	ns	29.51^{c}	54.93^{a}	53.44^{b}
pH	ns	ns	ns	7.36^{a}	7.41^{a}	1.73^{b}
Total N	88.17^{a}	82.85^{c}	87.12^{b}	86.81^{a}	87.42^{a}	81.34^{b}
Total C	79.97^{b}	80.45^{b}	83.76^{a}	63.12^{c}	69.28^{b}	80.91^{a}
C:N	$34.26^{a,b}$	28.97^{a}	38.47^{b}	56.29^{a}	61.04^{a}	31.01^{b}
DM	ns	ns	ns	15.18^{b}	10.02^{c}	22.86^{a}
Total P	62.78^{a}	57.22^{b}	53.66^{b}	53.96^{b}	50.97^{c}	67.16^{a}
Total K	85.78^{a}	70.89^{b}	85.61^{a}	82.10^{a}	50.61^{c}	76.14^{b}

Superscripts with the same letter indicate no significant difference among mean values; ns = mean value not significant at $p \leq 0.05$

The interaction of C:N ratio with TF (C:N*TF) was significant ($p \leq 0.05$) on pile temperature among the treatments with 6 days TF. Both the C:N ratio and TF affected ($p \leq 0.05$) the thermophilic phase. Pile temperature was significantly ($p \leq 0.05$) correlated with pH and TC, according to the regression equation:

$$Temperature = -29.59 + (5.84 \times pH) + (0.92 \times TC); \; R^2 = 0.73 \qquad (3)$$

This confirms the findings by Tiquia *et al.* (1998) on the correlation of temperature with compost properties. The temperatures during composting ranged between 28 ^{o}C and 71 ^{o}C. All the composting treatments started with thermophilic temperatures (58 ^{o}C to 71 ^{o}C) that lasted for about 17 days to 22 days (Fig. 1a & b). This was an indication that the C:N ratios were ideal, and also, that the pathogens and weed seeds would have been destroyed (Misra *et al.*, 2003). The short thermophilic phase is associated with turned windrow method (Diaz *et al.*, 2002), but also, likely related to the small size of piles involved. There were slight increases in pile temperatures immediately after each turning operation in the early days of the experiment. This was responsible for the rise and fall pattern of the temperature profile which has been reported as the re-activation of the composting process by the incorporation of external material into the pile, providing degradable substrate for the microbial biomass (Gracia-Gomez *et al.*, 2003).

3.2 pH

Turning frequency affected ($p \leq 0.05$) pH change. Decrease in pH values (which signified increase in the acidity of the piles) was associated with decrease in TF (Table 4). The increase in acidity may have been caused by the production of short-chain organic acids as a result of decrease in TF.

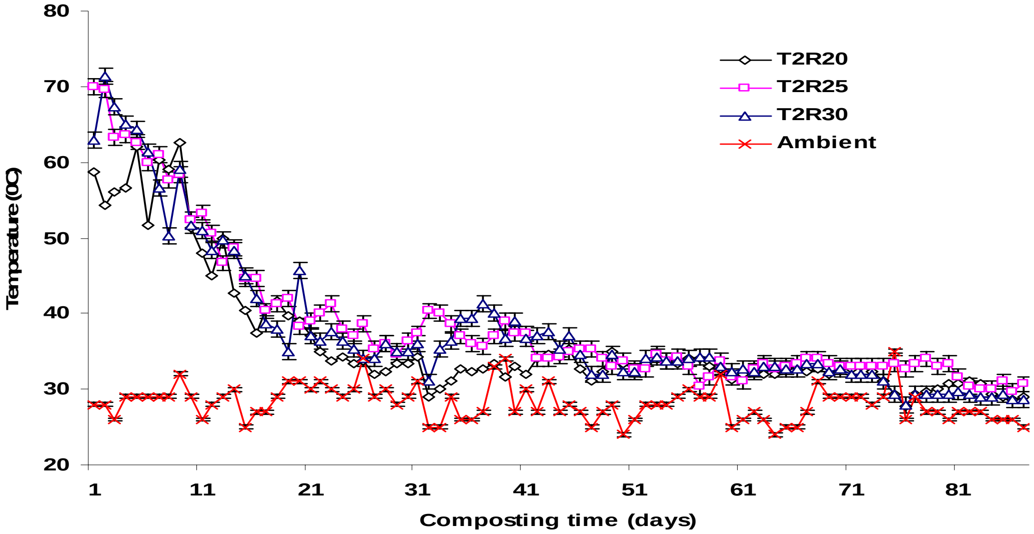

Figure 1a. Changes in air and pile temperatures of composting piles with 2 days TF. Error bars show standard errors of means (n = 3)

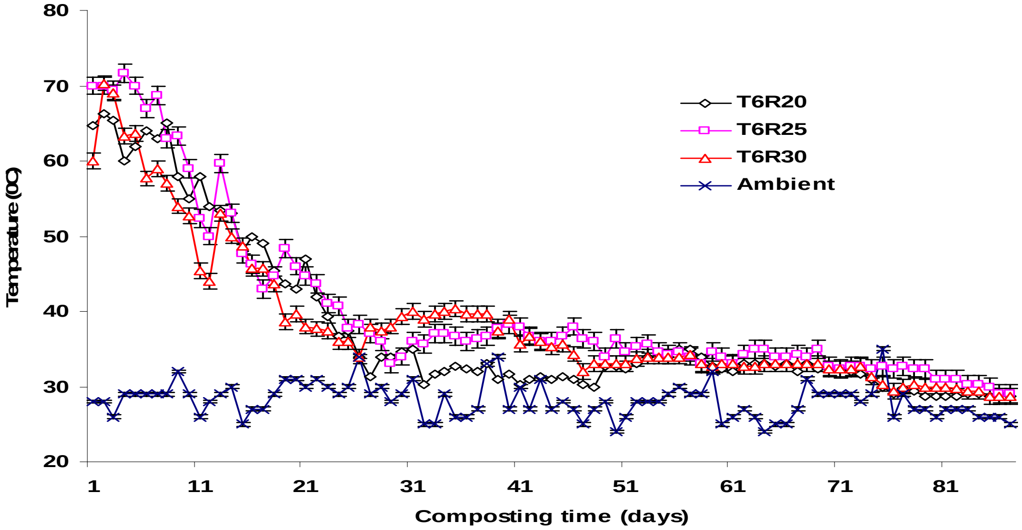

Figure 1b. Changes in air and pile temperatures of composting piles with 6 days TF. Error bars show standard errors of means (n = 3)

The interaction between C:N ratio and TF (C:N*TF) affected ($p \leq 0.05$) acidity of treatments with 6 days TF. The initial values of pH were alkaline within the range of 8.13 and 8.63. The pH values rose to between 8.82 and 9.34 within two weeks of composting (Fig. 2a & b) and decreased to final values between 7.53 and 7.83. The reduction in acidity values observed during the second week in all the treatments were probably brought about by the decomposition of OM in the piles (Baeta-Hall *et al.*, 2005) due to the high pile temperatures (> 45 ^{o}C) and microbial activities.

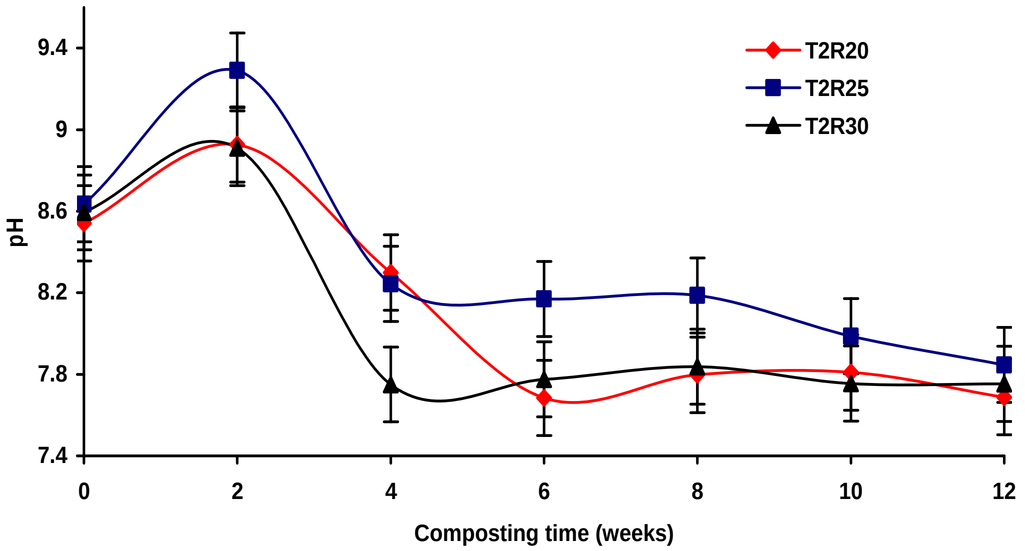

Figure 2a. Changes in pH of composting piles with 2 days TF due to C:N ratio effect. Error bars show standard errors of means (n = 3)

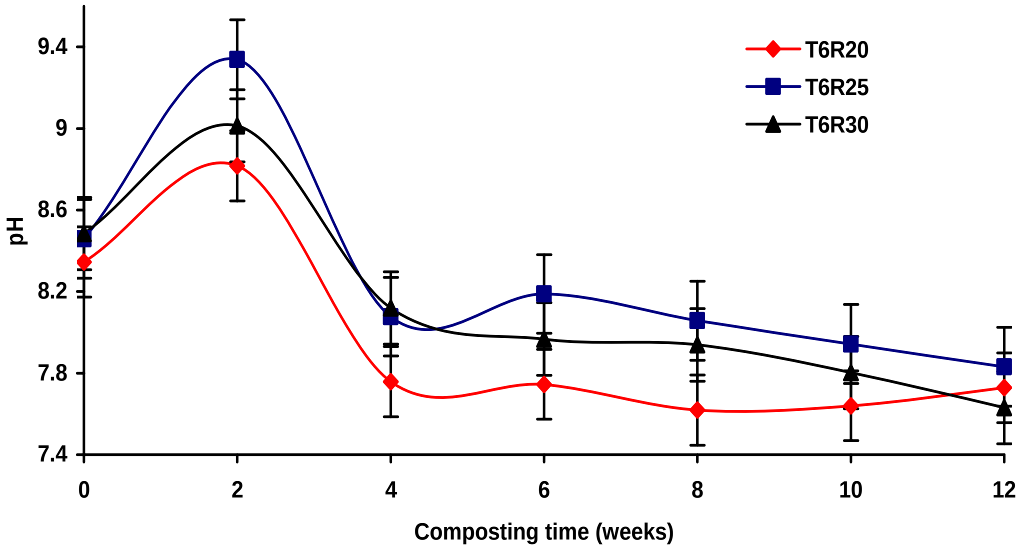

Figure 2b. Changes in pH of composting piles with 6 days TF due to C:N ratio effect. Error bars show standard errors of means (n = 3)

The attainment of pH values of between 8.0 and 9.0 indicated that the composting process was successful and fully developed (Sundberg *et al.*, 2004). Also, the final values of pH were an indication of stabilized OM (Sesay *et al.*, 1997).

3.3 Total Nitrogen

C:N ratio and the interaction of C:N ratio with TF (C:N*TF) were significant ($p \leq 0.05$) on TN loss. The final TN losses revealed that TN losses decreased as C:N ratio increased (Table 4). The final TN losses ranged between 81.34% and 88.17% of the initial TN concentration in all the treatments (Table 3), with the least loss (81.34%) observed in treatment T_6R_{30}. The pooled estimates of all the treatments showed that TN was significantly ($p \leq 0.05$) correlated with TC and C:N ratio, according to the regression equation:

$$TN = 0.62 + (0.04 \times TC) - (0.02 \times C : N\ ratio);\ R^2 = 0.93 \qquad (4)$$

This implied that TC and C:N ratio significantly contributed to TN loss. A further investigation of treatment T_6R_{30} revealed that in addition to TC and C:N ratio, temperature also contributed significantly ($p \leq 0.05$, $R^2 = 0.99$) to TN loss in this treatment. The TN losses were greater than losses reported by Kirchmann and Witter (1989) and Hansen *et al.* (1989) during composting of poultry manure. High proportions (71.42% to 99.18%) of the final TN losses occurred within the first six weeks of composting in all the treatments (Fig. 3a & b) when pile temperatures and pH values were above 33 ^oC and 7.7, respectively. The increase in TN losses as C:N ratio decreased was probably due to increase in TN content (associated with decrease in C:N ratio) of the litter which was transformed to ammonium by micro-organisms and lost to the atmosphere in form of NH_3. The TN losses may also have been due to the small size of piles involved, mineralization of OM by micro-organisms (Grigatti *et al.*, 2004), or exposure of the piles to direct sunlight which may have accelerated the decomposition and loss of valuable nutrients (Kwakye, 1977). The increase in TN content (as observed in treatments T_2R_{20}, T_2R_{25} and T_6R_{20} during week 4, and treatment T_6R_{30} during week 8) (Fig. 3a & b) during composting may be attributed to increase in organic N due to a concentration effect as a consequence of strong degradation of organic C compounds (Tiquia and Tam, 2000).

3.4 Total Carbon

C:N ratio, TF and the interaction (C:N*TF) were significant ($p \leq 0.05$) on TC loss. Increase in TC loss was associated with increase in C:N ratio and TF (Table 4). Total C was significantly ($p \leq 0.05$) correlated with temperature, TN and C:N ratio according to the regression equation:

$$TC = -12.10 + (0.20 \times temperature) + (19.09 \times TN) + (0.38 \times C : N\ ratio);\ R^2 = 0.91 \qquad (5)$$

This implied that temperature, TN and C:N ratio contributed significantly ($p \leq 0.05$) to TC losses. The final TC losses ranged between 63.12% and 83.52% in all the treatments, with the least loss (63.12%) recorded in treatment T_6R_{20}. Interestingly, only pH and TN contributed

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significantly ($p \leq 0.05$, $R^2 = 0.97$) to TC loss in treatment T_6R_{20}. Figures 4a & b showed the variation of TC content with composting time. The high TC losses were an indication that the chicken litter contained high degradable OM (Fang *et al.*, 1999). High TC losses (65.20% to 97.07% of the final TC losses) occurred during the first six weeks of composting when the pile temperatures and pH values were above 33 °C and 7.7, respectively. The increase in TC losses associated with increase in TF indicated that aeration had effect on TC losses. As a result of this, it was possible that with increased air supply to the piles, TC served as a source of energy for the micro-organisms and was burnt up and respired as CO_2, or TC was mineralized, in which inorganic C was converted to organic C (Bernal *et al.*, 1998). The decrease in TC content of the compost with time synchronized with an increase in mass ash of the piles.

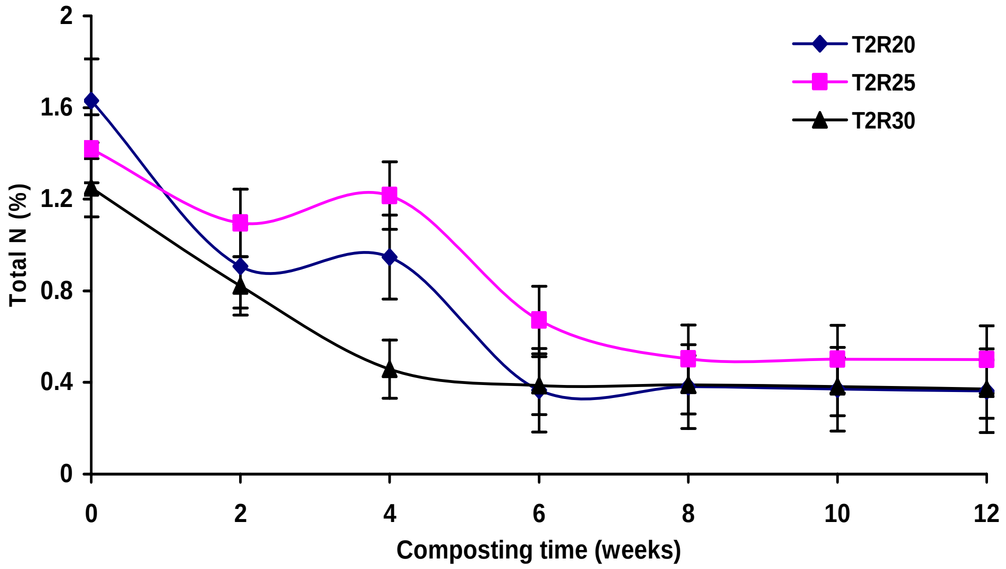

Figure 3a. Variation of total N in composting piles with 2 days TF due to C:N ratio effect. Error bars show standard errors of means (n = 3)

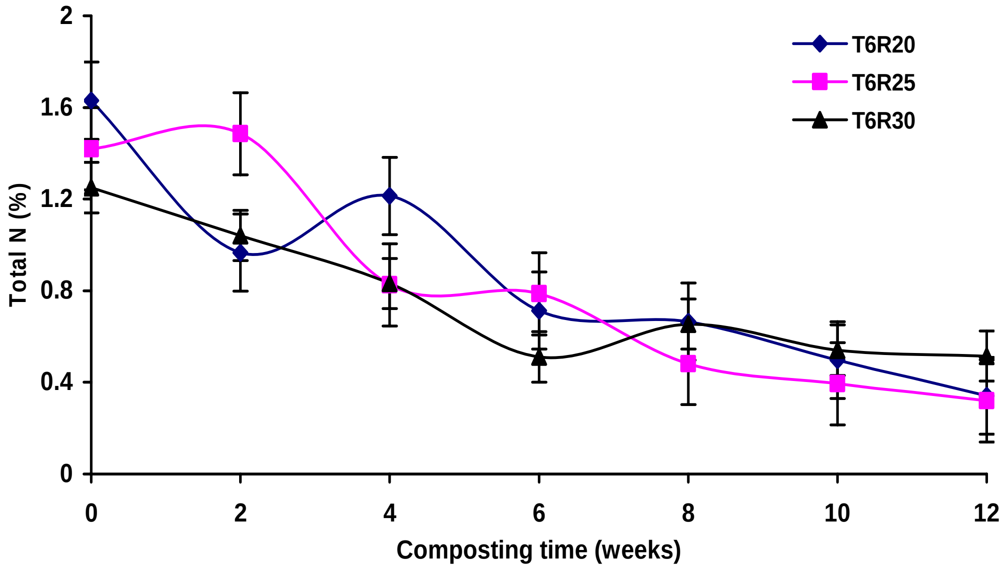

Figure 3b. Variation of total N in composting piles with 6 days TF due to C:N ratio effect. Error bars show standard errors of means (n = 3)

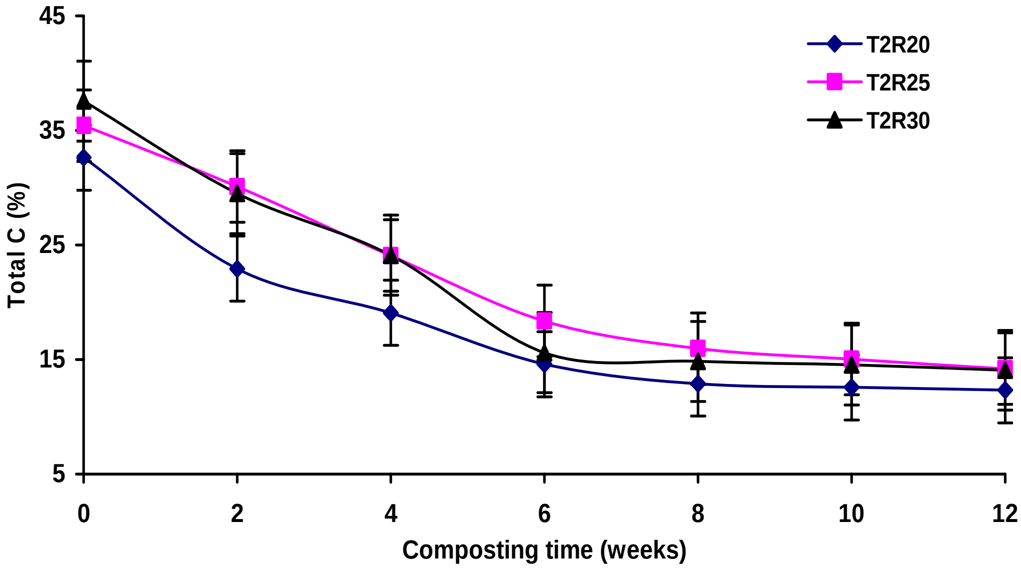

Figure 4a. Variation of total C in composting piles with 2 days TF due to C:N ratio effect. Error bars show standard errors of means (n = 3)

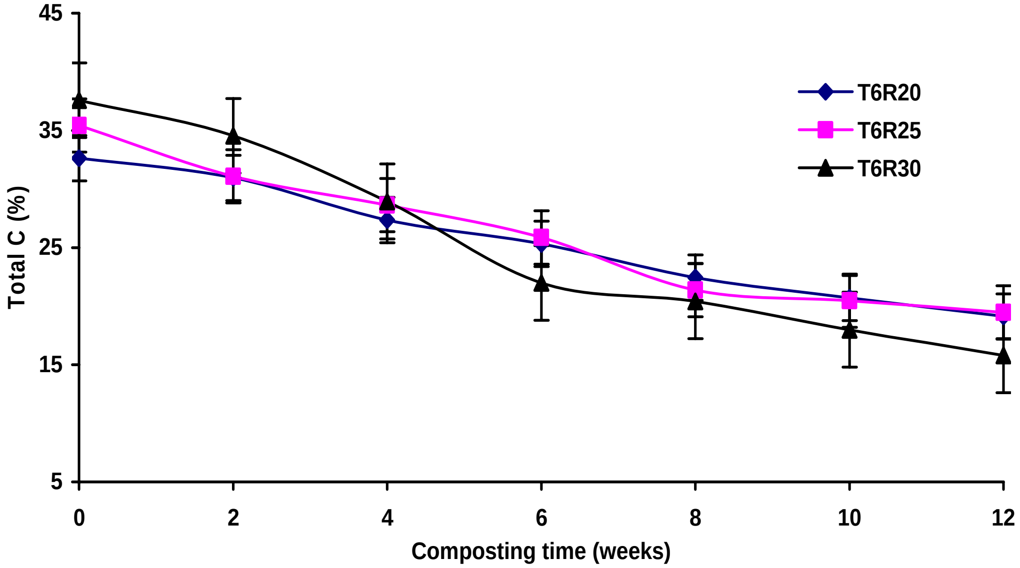

Figure 4b. Variation of total C in composting piles with 6 days TF due to C:N ratio effect. Error bars show standard errors of means (n = 3)

3.5 Carbon to Nitrogen Ratio

C:N ratio, TF and the interaction (C:N*TF) affected ($p \leq 0.05$) the C:N ratio values of the treatments. By the end of composting, all the treatments had increased C:N ratios (Fig. 5a & b). This may have been due to vigorous NH_3 volatilization during composting. Increase in the C:N ratios as observed in this study have been reported in previous composting (Eghball *et al.*, 1997; Tiquia and Tam, 2000).

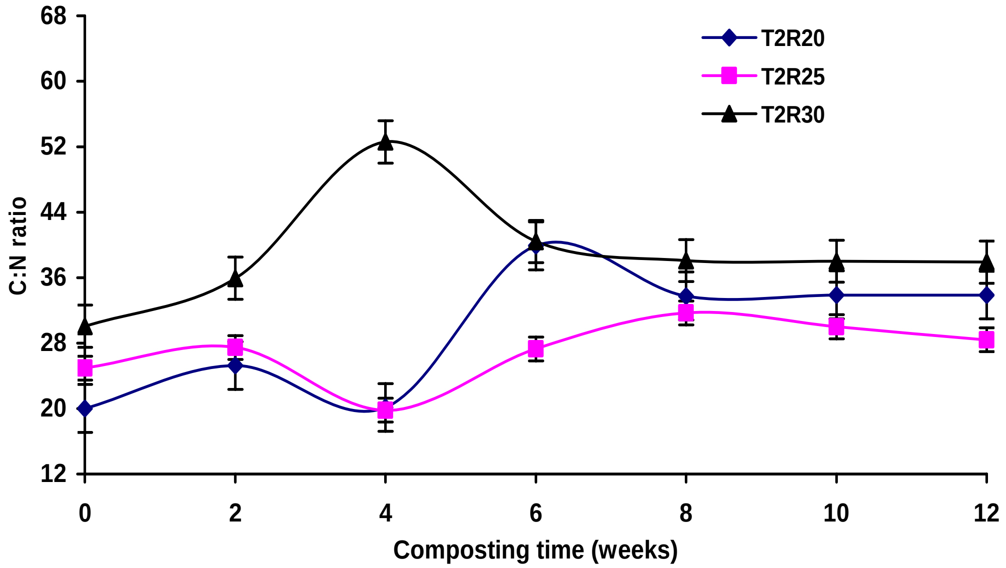

Figure 5a. Variation of C:N ratio in composting piles with 2 days TF due to C:N ratio effect. Error bars show standard errors of means (n = 3)

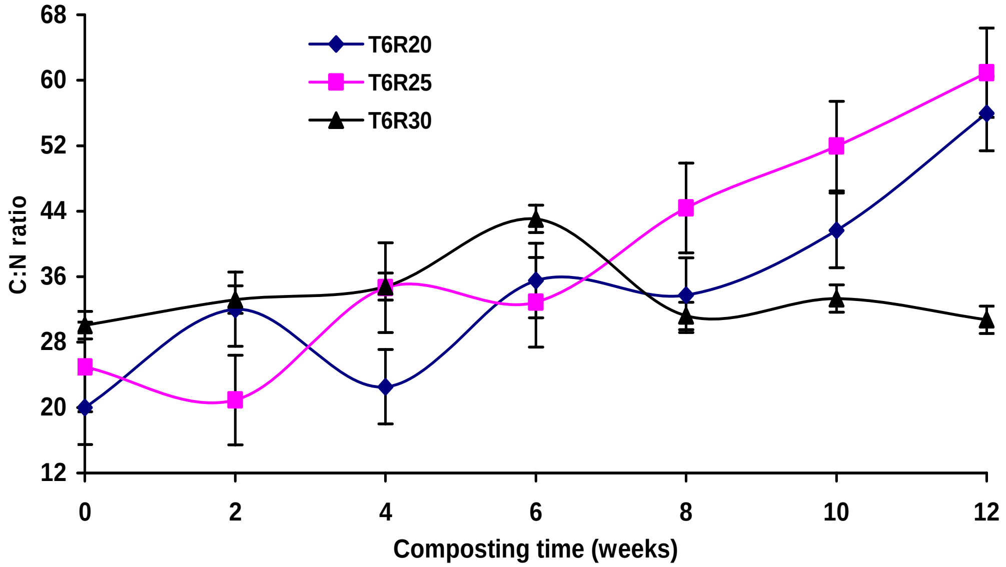

Figure 5b. Variation of C:N ratio in composting piles with 6 days TF due to C:N ratio effect. Error bars show standard errors of means (n = 3)

However, decrease in C:N ratios of treatments T_2R_{20}, T_2R_{25} and T_6R_{20} in week 4, and T_6R_{30} in week 8 may have been as a result of increase in organic N due to a concentration effect as a consequence of strong degradation of organic C compounds (Tiquia and Tam, 2000)

4. CONCLUSIONS

The following conclusions can be drawn from the study:

- The maturation of chicken litter compost was accompanied by a decline of compost temperatures to ambient level within a period of 87 days.
- Moisture loss increased as C:N ratio and TF increased.
- Both C:N ratio and TF had significant ($p \leq 0.05$) effect on pile temperature, TC, C:N ratio and K while only C:N ratio had significant ($p \leq 0.05$) effect on TN, DM and P, and pH was affected ($p \leq 0.05$) only by TF.
- A significant part of the TN losses were attributed to NH_3 volatilization while that of the TC losses were attributed to OM degradation.

For future experiment, it is suggested that chicken litter be composted under a shed to prevent exposure of the piles to direct sunlight in order to reduce nutrients loss.

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Nomenclature

T_2R_{20}	treatment with a combination of 2 days TF and C:N ratio 20:1
T_2R_{25}	treatment with a combination of 2 days TF and C:N ratio 25:1
T_2R_{30}	treatment with a combination of 2 days TF and C:N ratio 30:1
T_6R_{20}	treatment with a combination of 6 days TF and C:N ratio 20:1
T_6R_{25}	treatment with a combination of 6 days TF and C:N ratio 25:1
T_6R_{30}	treatment with a combination of 6 days TF and C:N ratio 30:1
C:N*TF	interaction of C:N ratio with turning frequency
