Fate of compost nutrients as affected by co-composting of chicken and swine manures

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A b s t r a c t. Passive aeration co-composting using four mixtures of chicken manure and swine manure at 1:0, 1:1, 3:7 and 0:1 with sawdust and rice husk was carried out to study the effects of co-composting on the physicochemical properties of the organic materials. The experiment, which lasted 66 days, was carried out in bins equipped with inverted T aeration pipes. The results showed that nutrient losses decreased as the proportion of chicken manure in the mixtures decreased for saw dust and rice husk treatments. This indicates better nutrientst conservation during composting in swine than chicken manure. Manure mixtures with rice husk had higher pile temperatures (> 55°C), total carbon and total nitrogen losses, while manure mixtures with saw dust had higher total phosphorus loss and carbon to nitrogen ratio. Composts with rice husk demonstrated the ability to reach maturity faster by the rate of drop of the carbon to nitrogen ratio.

K e y w o r d s: co-composting, chicken manure, swine manure, bulking agent, nutrient loss

INTRODUCTION

Co-composting is the controlled aerobic degradation of organics using more than one material. The objective of co-composting is to integrate the various micro-organisms from the different organic materials with a view to optimizing the composting process and producing a useful and safe end product. Generally, co-composting of high nitrogenous organic materials (animal manure, kitchen waste) with low nitrogenous organic materials (dry leaves, newsprint, sawdust, straw, rice husk) otherwise known as bulking agents (BAs) to adjust the moisture content (MC), nitrogen content, carbon to nitrogen (C:N) ratio and void spaces between particles has been the trend. Poultry and swine manures, which have become environmental concern in Nigeria due to increased poultry and swine farming, have been difficult to apply in limited nearby land and are limited in agricultural use due to pathogens, weed seeds and unstable nutrients.

Several authors have reported the composting of these manures with different BAs: poultry manure (Ogunwande, 2011; Ogunwande and Osunade, 2011; Ogunwande *et al.*, 2008; Paredes *et al.*, 1996; Silva *et al.*, 2009; Tiquia and Tam, 2002) and swine manure (Changa *et al.*, 2003; Huang *et al.*, 2004; Zhu, 2007). It was observed that varying degrees of nutrient losses, depending on composting methods used and parameters controlled, were reported. The co-composting of poultry manure and municipal solid wastes has also been reported (Adewumi *et al.*, 2005; Lhadi *et al.*, 2006). However, information on the co-composting of chicken manure (CM) and swine manure (SM) which are both rich in nitrogen, at different ratios (w w^{-1} dry basis), with BAs is still sketchy. In the study, CM and SM were co-composted with sawdust (a commonly used BA), and rice husk (an uncommonly used BA) with a view to determining the effects of manure mixture (MM) on losses of compost nutrients for each of the BA.

MATERIALS AND METHODS

The co-composting study was conducted under a shed at the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. The raw chicken and swine manures used for the experiments were collected from the Teaching and Research Farm of the University, while the BAs – sawdust and rice husk – were collected from a sawmill and rice mill plants, respectively, in Ile-Ife. Plastic buckets and polyvinyl chloride (PVC) pipes used for the construction of the composting bins and aeration pipes were purchased from a plumbing materials dealer in Ile-Ife. The initial characteristics of the manures and BAs are presented in Table 1.

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T a b l e 1. Initial properties of composting materials

Property	Chicken manure	Swine manure	Sawdust	Rice husk
pH	6.95 (0.34)	6.46 (0.23)	7.03 (0.48)	7.32 (0.18)
EC (mS cm^{-1})	6.77 (0.83)	4.39 (0.03)	0.61 (0.06)	0.33 (0.01)
MC (%, wb)	80.90 (0.73)	74.20 (1.02)	15.00 (1.12)	11.30 (0.94)
Ash (%, db)	27.20 (2.19)	41.00 (1.94)	2.64 (0.98)	21.10 (1.66)
C_T (%, db)	40.40 (0.27)	32.80 (1.39)	54.10 (1.03)	43.80 (0.29)
N_T (%, db)	2.04 (0.26)	1.83 (0.21)	0.48 (0.08)	0.81 (0.43)
P_T (mg l^{-1}, db)	22.00 (2.11)	25.8 (0.92)	2.23 (0.10)	36.40 (0.38)
C:N ratio	19.9:1	17.9:1	113.8:1	54.1:1

Mean and standard deviation are shown in parenthesis (n = 3). EC – electrical conductivity, MC – moisture content, C_T – total carbon, N_T – total nitrogen, P_T – total phosphorus, wb – wet weight basis, db – dry weight basis.

An inverted T pipe was improvised according to Ogunwande *et al.* (2012) using 50 mm inner diameter PVC pipes. Eight holes of 15 mm diameters (four each on the horizontal and vertical arms) were drilled on the pipe for passive aeration. The perforations were covered with plastic mesh while the top of the vertical arm was blocked with a cap to prevent manures from dropping into the pipe. The composting bin was a plastic bucket with bottom and top dimensions of 340 and 450 mm diameters, respectively, and a height of 600 mm. Three holes of 15 mm diameters were drilled at the base of the bin for leachate drain. A 50 mm diameter hole was drilled at the centre of the bin cover for the escape of heat, water vapour and carbon dioxide. The inverted T pipe was fixed inside the bin, on top of 50 mm BA layer, with the open ends of the horizontal arm extending outside the bin for air supply. The bins were equipped with thermometer probes at heights of 265 and 450 mm from the base.

Two experiments of MMs of CM:SM (1:0, 1:1, 3:7 and 0:1) denoted by M1, M2, M3 and M4, respectively, were set up with the addition of BAs to adjust the mixtures C:N ratio: first, with sawdust (SD) and second, with rice husk (RH) (Table 2). The CM and SM were first mixed to the desired ratios, after which the C:N ratio of each mixture was raised to 25:1 (Wortmann *et al.*, 2006) through the addition of SD and RH. The mixture quantities were calculated on dry weight basis. Moisture addition was unnecessary as the initial MC of all the mixtures was not below the reasonable range (40-65%) for composting (Rynk *et al.*, 1992). The materials were mixed to uniformity using a hand shovel and stacked to a height of 550 mm in the composting bins. Each treatment was replicated three times. The ambient temperature and temperatures within each pile were measured between 06:00 and 08:00 a.m. when the ambient temperature was fairly stable. Samples were collected fortnightly for the first four weeks and weekly thereafter at three locations (200, 350, 475 mm from the top of the base material) in each bin. The collected samples were homogenized and analyzed

T a b l e 2. Manure mixtures with bulking agents

Name of manure mixture	Manure mixture ratio CM:SM	Bulking agent
M1SD	1:0	
M2SD	1:1	
M3SD	3:7	sawdust
M4SD	0:1	
M1RH	1:0	
M2RH	1:1	
M3RH	3:7	rice husk
M4RH	0:1	

CM – chicken manure, SM – swine manure.

at 105°C dry weight basis for the following parameters using standard methods: MC (105°C for 24 h), ash (expressed as a percentage of residues after combustion at 550°C for 5 h), total nitrogen (N_T) using regular-Kjeldahl method, total phosphorus (P_T) (after acid digestion) using ultra-violet visible, scanning spectrophotometer of wavelength 190-900 nm (Model Unicam Pye UV4-100 from LABEQUIP Limited, Canada), pH and electrical conductivity (EC) (1:10 w/v sample : water extract) using digital pH meter (Model 8000 from VWR Scientific Products, USA) and Conductivity/TDS meter (Model YK-22CT from Lutron Electronic Enterprise Company Limited, Taiwan). The total carbon (C_T) was estimated from the ash content according to the formula used by Ogunwande *et al.* (2012):

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

T a b l e 3. Effects of bulking agent on pooled means of manure mixture treatments during composting (Duncan multiple range test)

Bulking agent	Parameter							
	Temperature (°C)	MC (%)	pH	EC (mS cm^{-1})	C_T	N_T	P_T	C:N ratio
						(%)		
Sawdust	31.3a	65.3b	6.89b	3.10a	-14.6a	-3.25b	37.1a	28.2a
Rice husk	32.5b	55.5a	6.99a	3.37b	46.8b	23.2a	26.7a	17.8b
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

The same letter are not statistically different at p≤0.05. Explanation as in Table 1.

T a b l e 4. Effects of manure mixture on compost parameters for sawdust and rice husk treatments during co-composting (Duncan multiple range test)

Parameter	Manure mixture				
	M1	M2	M3	M4	p-value
	Sawdust				
Temperature (°C)	31.7a	32.8b	30.1c	30.8d	<0.0001
MC (%)	70.5a	64.9b	63.9b	61.9b	0.001
pH	6.96a	6.85a	6.87a	6.86a	0.335
EC (mS cm^{-1})	3.20c	2.82a	3.63b	2.73a	<0.0001
C_T (%)	10.5a	8.57a	-38.8b	-38.8b	0.002
N_T (%)	27.1c	24.5c	-23.3b	-41.3a	<0.001
P_T (%)	38.5b	36.7a	37.0a	36.1a	0.037
C:N ratio	30.4a	29.7c	27.7d	24.8b	<0.0001
	Rice husk				
Temperature (°C)	32.9a	33.5c	30.9b	32.8a	<0.0001
MC (%)	57.3a	53.8b	56.7a	54.3b	<0.0001
pH	7.04a	6.92c	7.13b	7.02a	<0.0001
EC (mS cm^{-1})	3.54c	3.43d	3.73b	2.79a	<0.0001
C_T (%)	76.3a	68.4a	22.0b	20.5b	<0.0001
N_T (%)	53.2c	43.1c	6.05b	-9.72a	<0.0001
P_T (%)	59.5a	52.5a	0.57b	-5.85b	<0.0001
C:N ratio	16.9b	15.1b	21.7a	17.5b	0.002

M1, M2, M3 and M4 – chicken manure to swine manure mixture of 1:0, 1:1, 3:7, and 0:1, respectively. Other explanations as in Table 1.

Loss of nutrients from the piles was calculated as a mass balance, taking into account the dry weight reduction of the pile. Hence, the initial (X_1) and final (X_2) ash concentrations were used to estimate the loss, according to the formula used by Ogunwande and Osunade (2011):

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

where: Y represents a nutrient, and Y_1 and Y_2 represent the initial and final concentrations of Y.

The data collected were subjected to statistical analyses. One-way analysis of variance (ANOVA) was performed to compare variations in compost properties for each BA and for pooled means of MMs. Where differences among treatments were significant at p≤0.05, means were separated using the Duncan multiple range test (DMRT). Correlation analysis was used to establish the relationships between compost properties. All analyses were performed using the Statistical Analysis Systems (SAS, 2002) software.

RESULTS AND DISCUSSION

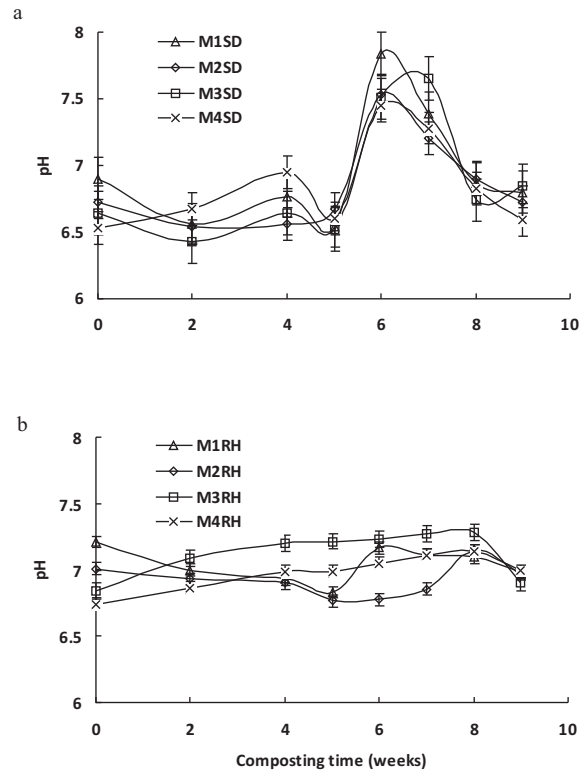Table 3 shows that BA had a significant (p≤0.05) effect on the pooled means of MM treatments in all the compost properties monitored. It is revealed in Table 4 that MM had a significant (p≤0.05) effect on the compost properties for each BA except for pH in SD treatments.

Pile temperature was used to assess the stability of the composts, which occurred within 66 days. This duration fell within the range of 15 and 180 days for converting manure into stabilised compost (Rynk *et al.*, 1992). The mean values showed that the temperatures of RH treatments were higher than those of SD treatments (Table 3). The temperature trend exhibited a sinusoidal curve as the proportion of CM decreased in the mixtures, for both BAs. The highest value was recorded in M2, while the least in M3. The average of the upper and lower temperatures within the piles was used to plot the temperature profiles shown in Fig. 1. The temperature evolution followed the ideal composting behaviour and it was the same pattern in all the piles: it started from mesophilic temperatures (25.5-38.6 and 27.5-38.5°C in SD and RH treatments, respectively), within 24 h to thermophilic temperatures (>42°C) within 6-16 and 2-8 days in SD and RH treatments, respectively, and dropped to mesophilic temperatures (<40°C) before stabilising at values close to ambient temperatures. Treatments manure mixture with: sawdust (M4SD) and rice husk (M4RH) of CM:SM – 0:1, were, however, distinct as they started with slightly higher temperatures (38.6 and 38.5°C). Observations from the temperature characteristics of each pile (Fig. 1) showed that the peak

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b
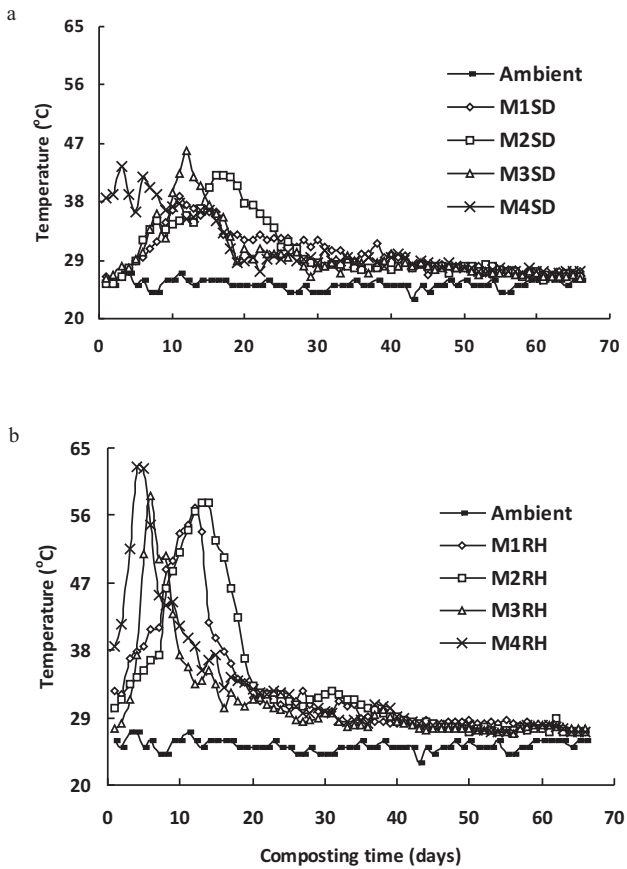
Fig. 1. Changes in air and pile temperatures during co-composting of chicken and swine manures with: a – sawdust, b – rice husk. M1SD, M2SD, M3SD, M4SD – with sawdust; M1RH, M2RH, M3RH, M4RH – with rice husk; chicken manure to swine manure mixture of 1:0, 1:1, 3:7 and 0:1, respectively.

a

b

Fig. 2. Changes in pH during co-composting of chicken and swine manures with: a – sawdust, b – rice husk. Error bars show standard errors of means (n = 3).

temperatures, which were attained at different days during composting, and the duration of thermophilic temperatures were much lower in SD treatments. None of the SD treatments met the sanitation requirement (temperatures >55°C for three consecutive days) for weed seeds and pathogens abatement (Zhu *et al.*, 2004). Similarly, manure mixture with rice husk (M1RH, M3RH) of CM:SM – 1:0 and 3:7, respectively, also failed to meet this requirement. The high temperature observed in RH treatments compared to SD treatments was attributed to low bulk density of rice husk (110-120 kg m^{-3}) compared to sawdust (190-210 kg m^{-3}) (Chang and Chen, 2010), which reflected high porosity (or free air space) and resulted in high air circulation within the RH treatments for efficient performance of the decomposing microorganisms. Generally, the low thermophilic temperatures and short thermophilic phase observed in all the treatments were probably a result of the high initial MC of the manures (74.2-80.9%) which may have impeded air supply to the piles for effective microbial activities. It was reported that excessive moisture can reduce free air space to the point where oxygen storage and transport through the void spaces

is reduced (Petric *et al.*, 2009). In spite of this shortcoming, the attainment of thermophilic temperatures by manure mixture with: sawdust (M2SD, M3SD) and rice husk (M2RH, M3RH) of CM:SM – 1:1 and 3:7, respectively; showed that co-composting of CM and SM had no negative effect on the temperature of the piles. Temperature data collected at the two levels within the piles showed no statistical difference (p values ranged from 0.330 to 0.964), implying that composting rates and compost quality within the levels were the same. Uniform composting rates are characteristic of an inverted T pipe (Ogunwande *et al.,* 2012).

The initial MC of the mixtures ranged from 69.1-77.4% (SD treatments) and 65.5-74.8% (RH treatments). The higher values for SD treatments were a result of the slightly higher initial MC of the SD (Table 1). Leachate from the piles was absorbed by the base material. The MC of the piles decreased by evaporation gradually as organic matter (OM) degradation occurred in the piles. The rate of moisture loss was higher in RH treatments (average of 2.40% week^{-1}, R^2 =0.960) than in SD treatments (average of 1.23% week^{-1}, R^2 =0.977) because SD has a higher water absorption capacity (430-450%) than RH (330-340%) (Chang and Chen, 2010). The mean values (Table 3) showed that MC of the piles decreased as the proportion of CM in the mixtures

decreased for SD treatments while a slight increase was observed in M3RH. The MC of the piles was not replenished throughout the experiment as no pile had below 45%.

The initial pH of SD treatments (6.53-6.90) was lower than that of RH treatments (6.84-7.21). This order was reflected during the composting (Table 2) and it was attributed to the high initial pH of RH (Table 1). The starting pH of the mixtures was within the reasonable range of 6.5-8.0 for rapid composting (Rynk *et al.*, 1992). The highest pH was observed in manure mixture with sawdust of CM:SM – 1:0 (M1SD), and M3RH. The changes in pH of composting piles are shown in Fig. 2. The pH of SD treatments followed the same trend. It showed slight variations from the initial values between week 0 and week 5 (Fig. 2a) before a steep increase to 7.45-7.84 by week 6 and a gradual drop to 6.59-6.85 by week 9. In RH treatments (Fig. 2b), the pH of M3RH and manure mixture with rice husk (M4RH) of CM:SM – 0:1, increased gradually from 6.84 and 6.93 to 7.29 and 7.22 by week 8 before decreasing to 6.91 and 6.94, respectively, by week 9. Conversely, M1RH and M2RH had their pH decreased from 7.21 and 7.01 to 6.83 and 6.77 by week 5 and increased to 7.10 and 7.15 by week 8 and again decreased to 6.98 and 6.97, respectively, by week 9. The pH rise was linked to the biodegradation of the organic acids, mineralisation of organic compounds, and the consequent release of volatile NH_3 (Paredes *et al.*, 2000). The temporary drops in pH noticed during composting were attributed to the production of organic acids during decomposition of OM contained in the mixtures (Charest and Beauchamp, 2002). The decrease in pH at the later stage of composting may be linked to the volatilisation of ammonia nitrogen and H^+ released as a result of microbial nitrification process by nitrifying bacteria (Eklind and Kirchmann, 2000). The final pH values of the compost ranged between 6.59 and 6.98. These values were within the limit of 7.2 recommended for the improvement of agricultural soils (Rynk *et al.*, 1992), 5.5-7.0 for optimum plant growth (Perry, 2003), and 6.0-8.5 for compatibility with most plants (Lasaridi *et al.*, 2006).

Electrical conductivity reflects the degree of salinity in the composting product, which indicates its possible phytotoxicity/phyto-inhibitory effects on the growth of plants (Lin, 2008). The EC of SD treatment was lower than that of RH treatment (Table 2). EC variation followed the same trend in both BA treatments (Table 3). The highest values were observed in M3. The changes in EC of composting piles are shown in Fig. 3. The EC variation followed the same pattern in SD treatments. It decreased gradually from initial values of 3.60-4.88 to 1.77-2.81 mS cm^{-1} by week 7, and increased afterward to final values of 2.21-3.02 mS cm^{-1}. M1RH and M3RH had their EC increased gradually from initial values of 3.16 and 3.24 mS cm^{-1} to peak values of 3.84 (by week 4) and 4.10 mS cm^{-1} (by week 2), and decreased to final values of 3.18 and 3.08 mS cm^{-1}, respectively. In M2RH, the EC decreased from 3.51 mS cm^{-1} to the lowest value of 2.77 mS cm^{-1} and increased
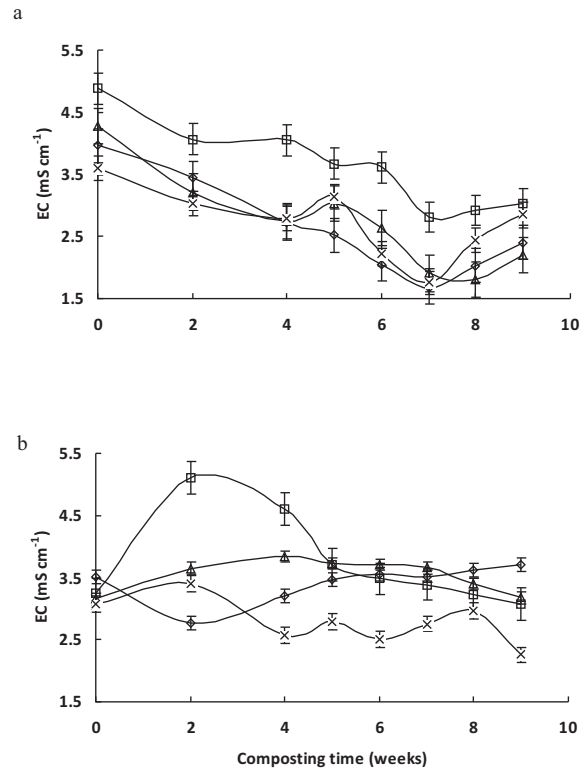
Fig. 3. Changes in electrical conductivity during co-composting of chicken and swine manures with: a – sawdust, b – rice husk. Error bars show standard errors of means (n = 3). Explanations as in Fig. 2.

gradually to the final value of 3.71 mS cm^{-1}. The EC of M4RH had repeated fluctuations throughout the experiment. It started with an initial value of 3.07 mS cm^{-1} and had a final value of 2.26 mS cm^{-1}. The increase in EC during composting could be due to the release of mineral salts through decomposition of OM, and the concentration effect due to net loss of dry mass (Silva *et al.*, 2009), whereas, the volatilization of ammonia and the precipitation of mineral salts could be the possible reasons for the decrease (Wong *et al.*, 1995). The final EC values (2.40-3.71 mS cm^{-1}) were below the upper limit of 4.0 mS cm^{-1} considered tolerable by plants of medium sensitivity (Lasaridi *et al.*, 2006).

The C_T contents showed an increase in the final values in SD treatments and a decrease in RH treatments. The C_T loss in RH treatments was greater than in SD treatments (Table 2). The C_T loss was attributed to bio-oxidation of OM resulting in the evolution of carbon dioxide and heat (Barrington *et al.*, 2002). It was observed that M1SD and M2SD had the same (p > 0.05) and higher losses than M3SD and M4SD which had the same (p > 0.05) and lower losses (Table 4). The high losses recorded in M1 treatments compared to those in M4 treatments showed that a higher level of OM biodegradation occurred in CM than in SM. The variation in losses showed high fluctuations in SD treatments (Fig. 4a). All treatments had gains in C_T by week 2.

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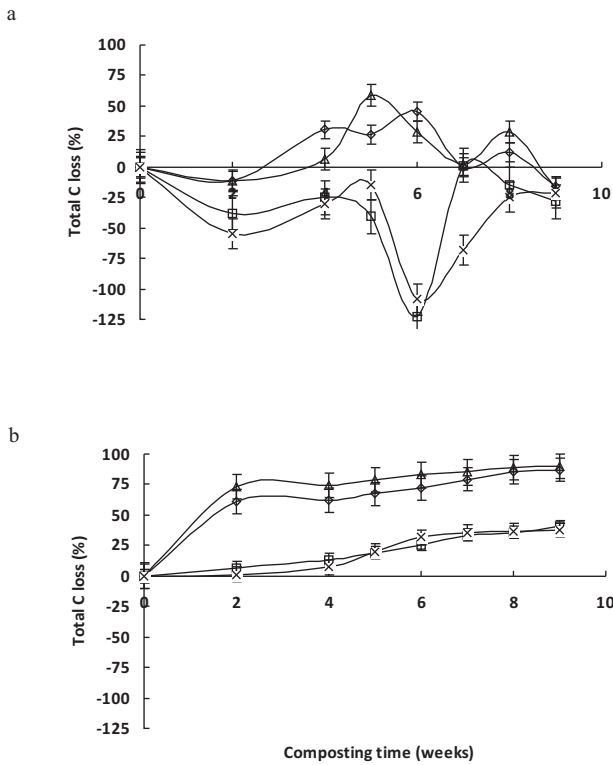
Fig. 4. Changes in total C losses during co-composting of chicken and swine manures with: a – sawdust, b – rice husk. Error bars show standard errors of means (n = 3). Explanations as in Fig. 2.

However, M1SD and M2SD lost varying proportions (0-59%) of C_T by week 4 to week 8 and had final gains of 18.5% and 15.8%, respectively (Table 5). M3SD and M4SD gained C_T throughout the composting experiment, with final values of 28.6 and 21.0%, respectively (Table 5). These gains corresponded to increase in C_T content of the piles. All the mixtures in RH treatments recorded C_T losses during composting (Fig. 4b). The losses were significantly (p≤ 0.05) correlated with MC ($R^2 = 0.943$), N_T ($R^2 = 0.865$) and C:N ratio ($R^2 = 0.935$). In RH treatments, M1 and M2 had consistently close and higher losses than M3 and M4 which had consistently close and lower losses. The losses increased gradually to final values between 37.7 and 89.9% (Table 4).

The N_T contents of RH treatments increased significantly during composting, from initial values of 1.18-1.5% to final values of 1.59-2.14%. The SD treatments recorded a decrease in N_T contents of M1SD and M2SD from 1.73 and 1.61% to final values of 1.49 and 1.30%, respectively, and an increase in M3SD and M4SD from 1.58 and 1.52% to final values of 1.72 and 1.71%, respectively. The N_T content increase was due to the net loss of dry mass in terms of carbon dioxide, as well as water loss by evaporation caused by heat evolved during oxidation of OM (Huang *et al.*, 2004). During composting, the average values showed that N_T losses from M1 and M2 were statistically the same

T a b l e 5. Final losses in compost nutrients

Parameter	Nutrients		
	C_T	N_T	P_T
	(%)		
Sawdust			
M1	18.5*,a,b	1.68b	51.7a
M2	15.8*,b	10.4b	52.0a
M3	28.8*,a	32.0*,a	55.0a
M4	28.8*,a	35.5*,a	51.1a
p-value	0.040	0.001	0.647
Rice husk			
M1	89.9a	58.7c	65.0d
M2	86.9b	54.2c	57.9a
M3	40.4c	15.9b	5.03*,c
M4	37.6d	7.51*,a	20.8*,b
p-value	<0.0001	<0.0001	<0.0001

Explanations as in Table 1.

a

b
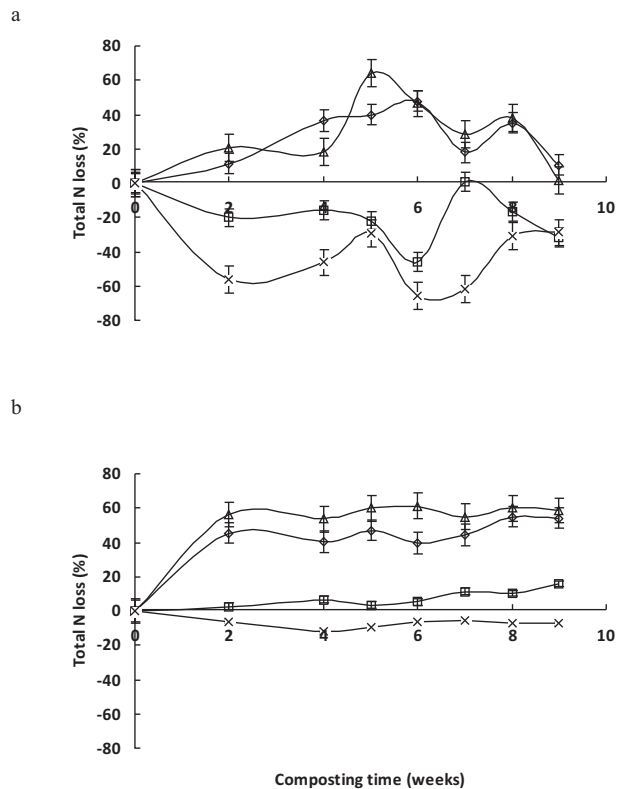
Fig. 5. Changes in total N losses during co-composting of chicken and swine manures with: a – sawdust, b – rice husk. Error bars show standard errors of means (n = 3). Explanations as in Fig. 2.

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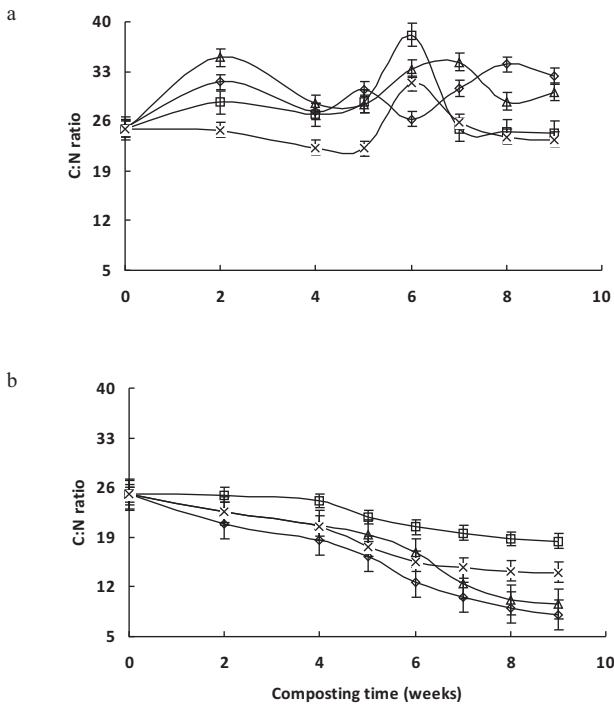
Fig. 6. Changes in C:N ratio during co-composting of chicken and swine manures with: a – sawdust, b – rice husk. Error bars show standard errors of means (n = 3). Explanations as in Fig. 2.

(p > 0.05) for both RH and SD treatments (Table 4). The variation of N_T loss during composting showed that SD treatments had fluctuating patterns (Fig. 5a), while M3SD and M4SD experienced gains throughout the experiment, and M1SD and M2SD recorded losses. The losses in M1SD and M2SD peaked at week 5 and week 6, respectively. All the RH treatments had relatively gradual variations (Fig. 5b). M1RH and M2RH recorded higher losses, M3RH recorded lower losses and M4RH recorded gains. At the end of composting, M3SD, M4SD and M4RH had gains in N_T (Table 5). Because of the low thermophilic temperatures and short thermophilic phase observed in this study compared to other passive aeration composting studies (Ogunwande, 2011; Ogunwande and Osunade, 2011), a significant part of the N_T losses observed during the early days of composting could therefore not be attributed to ammonia volatilization which has been found to occur at high temperatures (Barrington *et al.*, 2002; Liang *et al.*, 2006), but to denitrification (Liang *et al.*, 2006). The gain in N_T recorded in some piles may have been a result of the rise in N_T levels due to biological-N fixation (formation of NO_3-N) through microbial activities which can easily develop at moderate temperatures (Paredes *et al.*, 1996).

The C:N ratio of SD treatments decreased as the proportion of CM in the mixtures decreased (Table 4). However, for RH treatments, an increase in C:N ratio from

M2RH, M1RH, M4RH to M3RH was observed. During composting, the C:N ratio of SD treatments had an initial increase during week 2 and fluctuated thereafter (Fig. 6a). The C:N ratio of RH treatments (Fig. 6b) had a gradual decrease, with the highest rate of decrease in M2RH and the least in M3RH. Decrease in C:N ratio with composting time has been reported in previous studies (Charest and Beauchamp, 2002; Huang *et al.*, 2004; Ogunwande, 2011; Ogunwande and Osunade, 2011), and attributed to either the mineralisation of the substrates present in the initial composting materials or an increase in total N concentration resulting from the concentration effect as C is biodegraded. The final C:N ratios of M3SD and M4SD were less than the initial (24.4:1 and 23.4:1, respectively), while those of M1SD and M2SD were above (30.1:1 and 32.4:1, respectively). The composts with final C:N ratio less than 25:1 showed an indication of maturity (Bernal *et al.*, 2009). The RH composts demonstrated the ability to reach maturity faster by the rate of drop of the C:N ratio of the piles.

The losses of C_T, N_T and P_T followed the same trend, with losses decreasing as the proportion of CM in the mixtures decreased for both BAs (Table 4). From the mean values obtained during composting (Table 4) and the final values (Table 5), it was observed that for the individual manure treatments, M4 conserved nutrients better than M1, while M3 was better for nutrients conservation than M2 when co-composting. Generally, the final losses observed (Table 4) differ from values reported in previous composting studies (Changa *et al.*, 2003; Ogunwande *et al.*, 2008; Ogunwande *et al.*, 2012; Silva *et al.*, 2009; Tiquia and Tam, 2002), probably because of the:
– different composting method,
– BAs used,
– MM, or
– non-exposure of the piles to direct sunlight which may have accelerated the decomposition and loss of valuable nutrients (Kwakye, 1977).

CONCLUSIONS

1. Rice husk treatments had higher pile temperatures, total carbon and total nitrogen losses, while sawdust treatments had higher total phosphorus loss and C:N ratio.

2. Rice husk composts demonstrated the ability to reach maturity faster by the rate of drop of the C:N ratio of the piles.

3. Nutrient losses decreased as the proportion of chicken manure in the mixtures decreased. Hence, swine manure was better than chicken manure at nutrients conservation during composting while chicken manure to swine manure 3:7 was better than 1:1.

4. The composts had the potential to adequately attain optimum temperatures for pathogen and weed seeds abatement at reduced moisture content.

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