PERFORMANCE EVALUATION OF INVERTED T AND V-SHAPED PIPES WITH DIFFERENT PERFORATIONS ON COMPOSTING PROCESS

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ABSTRACT

Inverted T (IT) and V-shaped (Vs) pipe configurations were perforated at three different sizes (15, 25 and 35 mm diameter) in a two-factor passive aeration composting experiment using chicken litter. The results showed that thermophilic temperatures (42-69 ºC) for effective composting were attained in all the piles. However, pile with IT15 failed to meet the sanitation requirements for hygienic compost. Both pipe configuration and perforation size had significant ($p \leq 0.05$) effect on pile temperature, pre-replenishment moisture content and electrical conductivity. Pipe configuration affected ($p \leq 0.05$) total carbon while perforation size affected ($p \leq 0.05$) pH and total phosphorus. Both pipe configurations were effective for uniform composting rate, although Vs pipe was more. Summarily, the results showed that IT15 was not promising for passive aeration composting while Vs35 was the most effective for uniform composting rate. IT35 and Vs25 were the most suitable for minimizing total nitrogen and total phosphorus losses, respectively.

KEYWORDS: Passive aeration composting, pipe configuration, perforation size, chicken litter, composting rate

1. INTRODUCTION

Composting is the aerobic decomposition of organic wastes in the thermophilic temperature range (40-65 ºC) (Wortmann et al., 2006) to stabilize and transform the wastes into an aesthetic soil amendment (Barrington et al., 2003) free of phytotoxicity and pathogens and with certain humic properties (Zucconi and de Bertoldi, 1987). Based on the method of aeration, composting technologies can be classified as turned windrow, in-vessel system, natural aeration, passive aeration, and forced aeration. However, the acceptance of composting technology depends on how well the operating strategies being employed are developed for product quality (Tiquia et al., 2000) and environmental protection (Savage, 1996). Passive aeration composting is a promising technique as it is more economical (Barrington et al., 2003) and effective in conserving nitrogen (Sartaj et al., 1997) than forced aeration composting, and as efficient (Patni et al., 2001; Solano et al., 2001). It involves fewer on-going labour and equipment costs compared to forced aeration and turned-windrow methods, and has a higher process rate than natural aeration system (Sartaj et al., 1997). As a result, different pipe orientations: horizontal (Fernandes et al., 1994; Lyncht and Cherry, 1996; Sartaj et al., 1997; Solano et al., 2001) and vertical (Sylla et al., 2003a,b; Sylla et al., 2006), and different pipe configurations: V-shaped (Ogunwande, 2011) and inverted T (Ogunwande et al., 2012) have been developed to aid the distribution of air to the composting piles. Studies have also shown that vertical pipe (Sylla et al., 2006; Ogunwande et al., 2012), inverted T pipe (Ogunwande et al., 2012) and V-shaped pipe (Ogunwande, 2011) improved air delivery and produced uniform composting rate within the pile than horizontal pipe. Also, the effects of pipe orientation and perforation size on compost elements were studied (Ogunwande and Osunade, 2011).

This study was therefore a follow-up to the recently developed V-shaped pipe and inverted T configurations (Ogunwande, 2011; Ogunwande et al., 2012) with the aim of (1) investigating the effects of configuration and perforation size on some physico-chemical properties of chicken litter during passive aeration composting and (2) determining the optimum combination of pipe configuration and perforation size that will minimize compost elements losses.

2. MATERIALS AND METHODS

2.1 Materials Collection and Pile Construction

The experimental set up was a 2 × 3 completely randomised block design with pipe configurations (PCs) of IT and Vs and perforation sizes (PSs) of 15, 25 and 35 mm diameters. Polyvinyl chloride pipes of 76.2 mm inner diameters used for the construction of the APs were purchased from a plumbing materials dealer in Ile-Ife town, South-West of Nigeria. The fresh chicken manure and sawdust were collected from a poultry farm and a sawmill plant, respectively also in Ile-Ife town. The design of the PCs had been presented in Ogunwande (2011) and Ogunwande et al. (2012). Three of each PC had 8 perforations of 15, 25 and 35 mm diameters. Fig. 1a,b show the side view of the APs. The perforations were covered with plastic mesh to prevent chicken litter from dropping into the pipes. The initial properties of the manure and sawdust were determined and a chicken litter of C:N ratio 32:1 was obtained by mixing calculated quantities of manure and sawdust, according to Wortmann et al. (2006).

The initial moisture content (MC) of the chicken litter was adjusted to and replenished fortnightly to 60% (wet basis) through the addition of tap water (Brake, 1992) with pH of about 7.6. The initial properties of the composting materials are shown in Table 1. Each of the six chicken litter piles, pyramidal in section, with bottom and height dimensions of 1.2 m × 1.1 m and 0.72 m, respectively, was built on top of 100 mm thick sawdust base and an AP. A 40 mm layer of sawdust was added to the outside of the piles to reduce moisture loss and conserve heat in the piles. Each treatment was replicated three times.

2.2 Sampling and Analytical Methods

The ambient temperature and temperatures within each pile were measured daily, using a K-type digital thermometer with thermocouple probe, at two levels (0.21 m and 0.42 m from the top of the base material). The temperatures were measured between the hours of 06:00 am and 08:00 am when the ambient temperature was fairly stable. Samples were collected fortnightly at three levels (170 mm, 340 mm and 510 mm from the top of the base material) in each pile. A total of three samples were collected at each of the levels, homogenized and ground. Samples were analyzed at 105 ºC dry weight basis for the following parameters: MC (105 ºC for 24 h); ash (expressed as a percentage of residues after combustion at 550 ºC for 5 h); total nitrogen (N_T) using regular-Kjeldahl method (Bremner 1996); total phosphorus (P_T) (after acid digestion) using ultra-violet visible, scanning spectrophotometer of wavelength 190-900 nm (Model Unicam Pye UV4-100) (APHA 1995); pH and electrical conductivity (EC) (1:10 w/v sample: water extract) using digital pH meter (Model 8000) and Conductivity/TDS meter (Model YK-22CT), respectively. The total carbon (C_T) was estimated from the ash content according to the formula (Mercer & Rose 1968):

$$TC\,(\%) = [100 - Ash\,(\%)]/1.8 \quad (1)$$

Loss of elements from the piles was calculated as a mass balance, taking into account the dry weight reduction of the pile, instead of only the difference in concentrations of the elements in the composting mass. Hence, the initial (X_1) and final (X_2) ash concentrations were used to estimate the losses, according to the formula by Sanchez-Monedero et al. (1996):

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

where Y represents an element, and Y_1 and Y_2 represent the initial and final concentrations of Y.

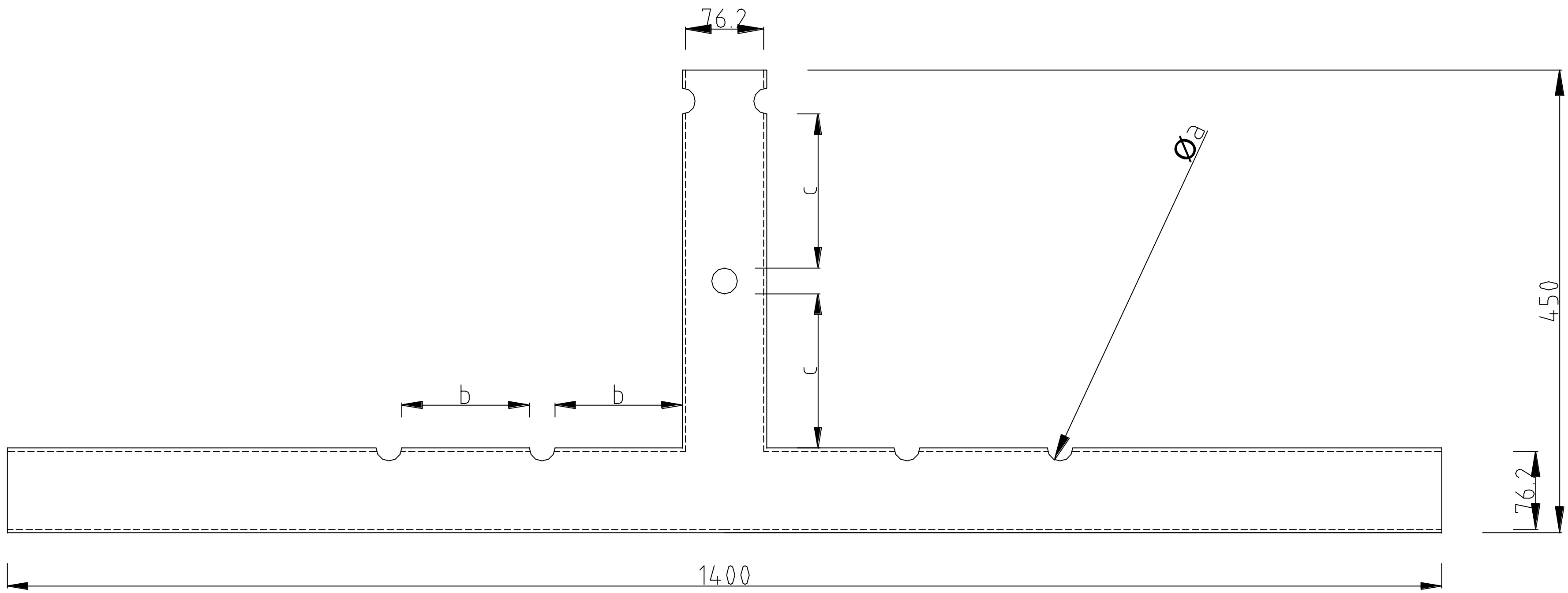


Fig. 1a. Side view of a perforated inverted T pipe (All dimensions in mm): For 15 mm diameter perforation, a = 15, b = 134.45, c = 160; For 25 mm diameter perforation, a = 25, b = 124.45, c = 150; For 35 mm diameter perforation, a = 35, b = 114.45, c = 140

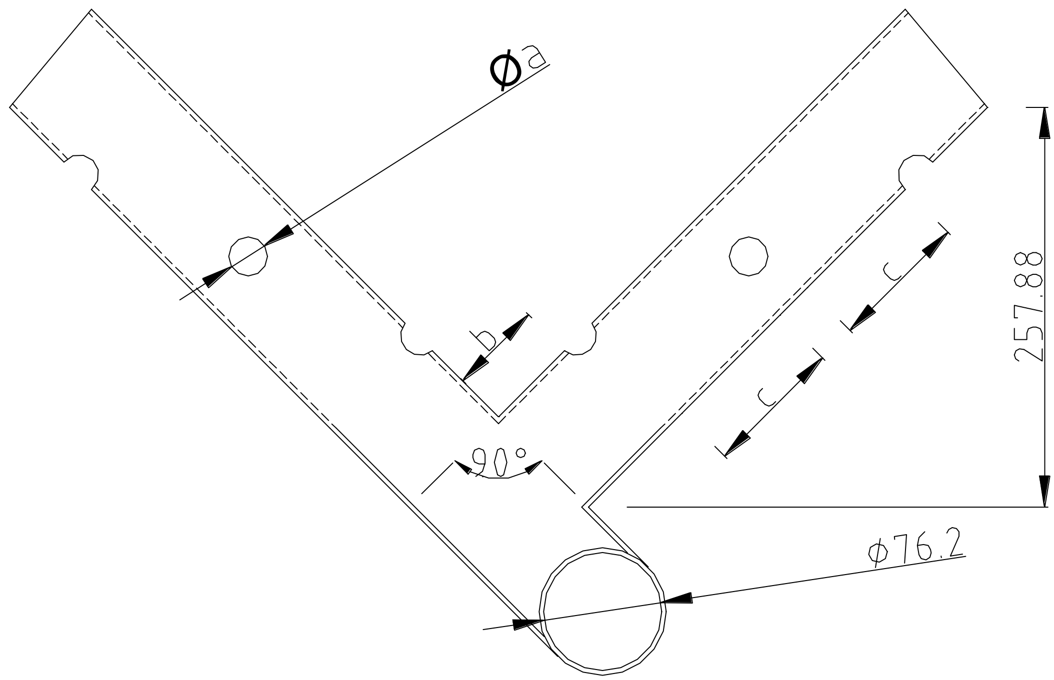


Fig. 1b. Side view of a perforated V-shaped pipe (All dimensions in mm): For 15 mm diameter perforation, a = 15, b = 65.04, c = 105.98; For 25 mm diameter perforation, a = 25, b = 60.01, c = 89.6; For 35 mm diameter perforation, a = 35, b = 56.01, c = 80.47

Table 1. The initial concentrations of the composting materials

Parameter	Composting material		
	Sawdust	Chicken manure	Chicken litter
MC* (%)	31.7 ± 0.58	71.8 ± 0.87	49.6 ± 1.13
Ash (%)	2.31 ± 0.06	33.9 ± 2.65	32.8 ± 7.65
Total C (%)	54.3 ± 0.05	36.7 ± 1.47	37.3 ± 4.25
Total N (%)	0.21 ± 0.03	2.24 ± 0.17	1.15 ± 0.05
C:N ratio	259:1	16:1	32:1
Total P (%)	0.08 ± 0.03	0.82 ± 0.92	0.53 ± 0.17
pH	7.82 ± 0.01	7.62 ± 0.04	7.84 ± 0.04
EC (mS/cm)	0.51 ± 0.02	5.74 ± 0.55	2.24 ± 0.48

Mean ± standard deviation are shown (n = 3).
* MC was measured on wet weight basis.

2.3 Statistical Analysis

The data obtained were subjected to statistical analyses using the GLM procedure of Statistical Analysis System software (SAS, 2000). Two-way analysis of variance (ANOVA) was performed to compare variations in compost properties. Where significance was indicated at $p \leq 0.05$, Least Significant Test (LSD) was used to establish which treatment(s) was significantly different. Multiple regression analysis with stepwise selection of variables was used to establish relationships among compost properties.

3. RESULTS AND DISCUSSION

The piles stabilized within 115 days of composting; a duration which fell within the range of 90 and 168 days reported for converting poultry manure into stabilized compost (Fernandes et al. 1994, Tiquia and Tam 2002, Silva et al. 2009; Ogunwande and Osunade, 2011). Seepage losses were considered insignificant as there was no free flow of water from the piles.

3.1 Pile Temperature

The results of the ANOVA showed that PC, PS and the interaction of PC and PS (PC*PS) had significant ($p \leq 0.05$) effect on pile temperature (Table 2). The LSD test (Table 3) showed that piles with IT pipe had higher temperature than piles with Vs pipe. The low temperatures recorded in piles with PS of 15 and 35 mm diameters may have been due to inadequate and excessive air, respectively supplied to the piles. Diaz et al. (1993) had reported that inadequate air supply reduces microbial activities and consequently heat produced while excessive air supply reduces pile temperatures. Perforation size of 25 mm diameter appeared to have resulted in a balanced temperature for the piles. The daily temperature profiles obtained with the average of the temperature values recorded at the two levels within the piles during composting process are shown in Fig. 2a,b. The temperature evolution followed similar pattern. Thermophilic temperatures within the range of 46.0 ºC and 56.8 ºC registered within 24 h of composting was an indication of high microbial activities (Bernal et al., 2008) and that the initial C:N ratio of 32:1, MC of 60% and the pile configuration were ideal for composting chicken litter. The peak temperatures between 54.3 ºC and 69.0 ºC observed within 2-4 days was close to results obtained by Mathur et al. (1990) and Zhan et al. (1992). The temperatures dropped from peak values to 32.7-34.5 ºC and 31.9-34.7 ºC by week 6, and rose slightly to 33.8-36.8 ºC and 35.8-36.7 ºC by week 10 in piles with IT and Vs pipes, respectively and decreased to stable values (30.8-31.8 ºC) by the end of composting. The slight increments noticed in the pile temperatures after moisture replenishments in the early days of composting suggest that periodic moisture replenishment may have had significant effect on the re-activation of microbial activities. The thermophilc phase ranged between 20-23 days while pile IT15 failed to attain temperatures >55 ºC (for at least three days) required for weed abatement and hygienic compost. This could be attributed to the airflow resistance in the IT pipe, coupled with the inadequate air supplied by the 15 mm diameter perforations. It was observed that the thermophilic temperatures increased as airflow resistance coefficient (K) decreased, suggesting that PC may have influenced airflow in the pipe and consequently, the pile temperatures. The K values computed, according to Steidel, Jr. et al. (1987), were 3.0 and 2.5 for IT and Vs pipes, respectively. As a result, pipe IT15 was adjudged not suitable for PAC.

The effectiveness of each AP for producing uniform composting rate within the pile was evaluated by comparing the upper and lower level thermophilic temperatures. The results of the *t*-test analysis showed that the two temperatures were the same ($p > 0.05$) in all the piles (Table 4). This implied that all the APs were effective for uniform composting rate; hence the quality of the compost within each pile would not differ significantly ($p > 0.05$). However, pipe Vs35 which had the highest p-value appeared to be the most effective.

Table 2. The results of the ANOVA showing the effects of PC and PS on compost properties

Parameter	Source	Df	SS	MS	*F*-value	Pr>F
Temperature	PC	1	0.56	0.56	16.30	0.002
	PS	2	6.08	3.04	88.54	<.0001
	PC*PS	2	1.11	0.56	16.21	<.0001
	Error	12	0.41	0.03		
Pre-r MC (%)	PC	1	12.54	12.54	19.67	0.001
	PS	2	23.65	11.83	18.55	<.0001
	PC*PS	2	29.07	14.53	22.79	<.0001
	Error	12	7.65	0.64		
pH	PC	1	0.01	0.01	1.83	0.201
	PS	2	0.08	0.04	14.80	0.001
	PC*PS	2	0.01	0.01	1.69	0.226
	Error	12	0.03	0.01		
EC	PC	1	0.68	0.68	25.39	<.0001
	PS	2	0.71	0.35	13.08	0.001
	PC*PS	2	0.33	0.16	6.05	0.015
	Error	12	0.32	0.03		
Total C	PC	1	345.14	345.14	20.89	0.001
	PS	2	96.12	48.06	2.91	0.093
	PC*PS	2	112.99	56.49	3.42	0.067
	Error	12	198.28	16.52		
Total N	PC	1	498.70	498.70	3.47	0.087
	PS	2	312.52	156.26	1.09	0.368
	PC*PS	2	86.85	43.43	0.30	0.745
	Error	12	1726.34	143.86		
Total P	PC	1	386.82	386.82	4.48	0.056
	PS	2	1015.03	507.52	5.87	0.017
	PC*PS	2	83.65	41.82	0.48	0.628
	Error	12	1036.85	86.40		
C:N ratio	PC	1	4.29	4.29	0.66	0.433
	PS	2	8.85	4.42	0.68	0.526
	PC*PS	2	16.96	8.48	1.30	0.309
	Error	12	78.32	6.53		

Pre-r: pre-replenishment.

Table 3. Least Significant Difference (LSD) test of PC and PS on compost properties

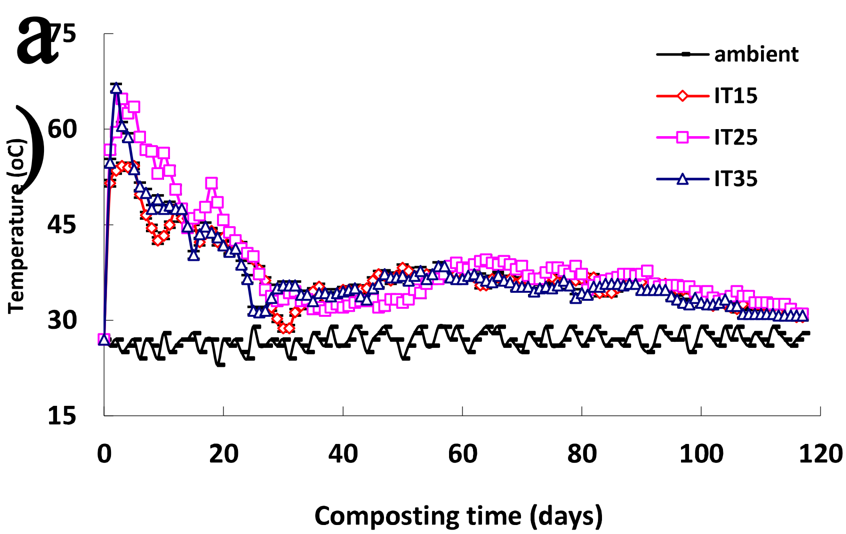
Parameter	Pipe configuration			Perforation size (mm diameter)			
	IT	Vs	LSD	15	25	35	LSD
Temperature (°C)	37.5[b]	37.2[a]	0.19	37.4[a]	38.0[b]	36.5[c]	0.23
Pre-r MC (%)	48.1[a]	49.7[b]	0.82	47.7[a]	48.6[a]	50.4[b]	1.00
pH	8.08[a]	8.11[a]	0.05	8.03[a]	8.19[b]	8.05[a]	0.07
EC (mS cm^{-1})	2.74[b]	3.13[a]	0.17	3.07[b]	2.65[a]	3.07[b]	0.21

Total C (%)	47.2[a]	56.0[b]	4.07	53.4[a]	53.1[a]	48.3[a]	4.98
Total N (%)	9.22[a]	19.7[a]	10.6	15.0[a]	19.3[a]	9.13[a]	13.0
Total P	13.5[a]	4.22[a]	14.1	-1.77[b]	14.2[a]	14.1[a]	17.3
C:N ratio	19.4[a]	18.4[a]	0.77	18.1[a]	19.8[a]	18.7[a]	0.94

Superscripts with the same letter are not statistically different at $p \leq 0.05$; Pre-r: pre-replenishment.

3.2 Pre-replenishment Moisture Level

It was observed that PC, PS and PC*PS had significant ($p \leq 0.05$) effect on pre-replenishment MC (Table 2). More moisture was lost from piles with IT pipe (Table 3), probably as a result of the low C_T loss and consequently high porosity of the piles. Although, same ($p > 0.05$) but lower level of pre-replenishment moisture was observed using 15 and 25 mm diameter perforations, the trend of moisture loss was contrary to expectation that loss would increase as PS increases. The initial MC (60%) of the chicken litter dropped to the lowest pre-replenishment values of 41.5-44.2% and 39.8-43.5% within 2 weeks of composting in piles with IT and Vs pipes, respectively. This was as a result of high microbial activities in the chicken litter due to intense OM degradation during this period. The pre-replenishment moisture levels picked up thereafter as the level of microbial activities were decreasing in the piles.



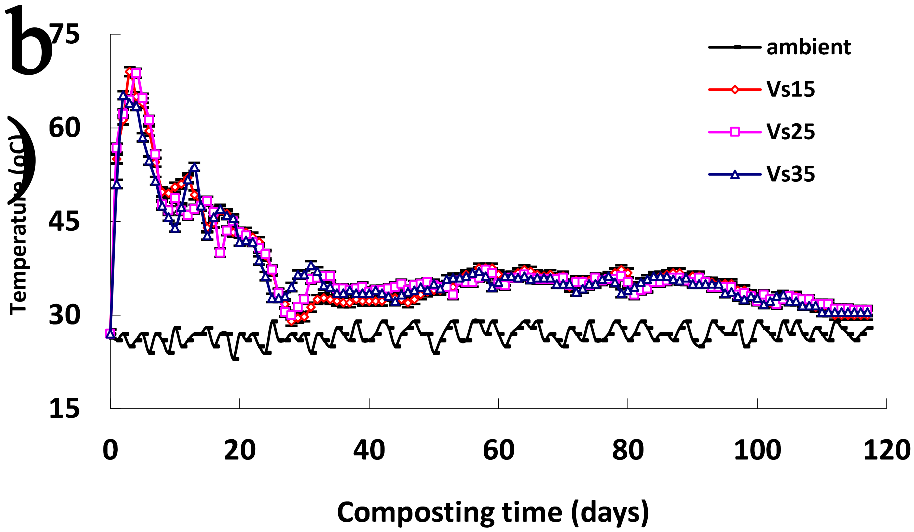


Fig. 2. Daily temperature profiles of composting piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

Table 4. Thermophilic characteristics of the piles

Pile	Duration (days)		Temperature (ºC)			*p*-value
	> 42 ºC	> 55 ºC	Peak	Upper	Lower	
IT15	23	0	54.3	46.7[a]	45.7[a]	0.486
IT25	22	10	64.8	52.0[a]	53.1[a]	0.605
IT35	20	4	66.5	49.9[a]	48.5[a]	0.550
Vs15	23	5	69.0	50.4[a]	51.6[a]	0.610
Vs25	22	5	68.8	52.2[a]	49.6[a]	0.327
Vs35	22	5	65.3	49.5[a]	49.9[a]	0.843

Superscripts with the same letter are not statistically different at $p \leq 0.05$.

3.3 pH and Electrical Conductivity

The chicken litter had an alkaline pH throughout the composting process. The initial value was within the range of 6.0-9.0 recommended for rapid composting (Rynk et al., 1992; Metcalf and Eddy Inc., 2003). Perforation size influenced ($p \leq 0.05$) the pH during composting (Table 2). The mean values showed that piles with 15 and 35 mm diameter perforations had same ($p > 0.05$) but lower values. This may be related to the inadequate and excessive air, respectively supplied to those piles. The pH of pile IT25 was consistently the highest during composting, in piles with IT pipe (Fig. 3a). The pH of pile IT15 maintained a low profile while that of pile IT35 decreased and increased remarkably. The pH of piles with Vs pipe followed nearly similar patterns (Fig. 3b). The initial pH increased to high values between weeks 4 and 12 and decreased thereafter. Generally, increase in pH could be linked to the biodegradation of the organic acids, mineralization of organic compounds and the consequent release of volatile NH_3 (Huang et al., 2004; Said-Pullicino et al., 2007). The drops in pH noticed in some piles in the early days of composting (IT35- weeks 4 and 6, and Vs35- week 6) may have been due to the production of organic acids during decomposition of OM contained in the chicken litter (Charest and Beauchamp, 2002). The decrease in pH towards the end of composting could be attributed to increased nitrification process by nitrifying bacteria in the chicken litter (Caceres et al., 2006) or an indication of maturity process. The final pH values (7.87-8.15) were within the range of 6.0-8.5 compatible with most plants (Lasaridi et al., 2006).

Electrical conductivity was significantly ($p \leq 0.05$) affected by PC, PS and PC*PS (Table 2). Piles with Vs pipe had higher EC (Table 3). Electrical conductivity of piles with 15 and 35 mm diameter perforations had higher but same value of EC. The effect of PS on EC was similar but oppositely related to that of pH. The evolution of EC followed the same pattern in all the piles (Fig. 4a,b). It increased from the initial value of 2.24 mS/cm to between 3.13 mS/cm and 4.03 mS/cm, and 3.74 mS/cm and 4.24 mS/cm in piles with IT and Vs pipes, respectively within 4 weeks. Thereafter, the EC decreased to low values (2.02-2.78 mS/cm) between weeks 8 and 10 and increased to final values between 2.44 mS/cm and 4.37 mS/cm. The increase in EC observed in the piles may 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).

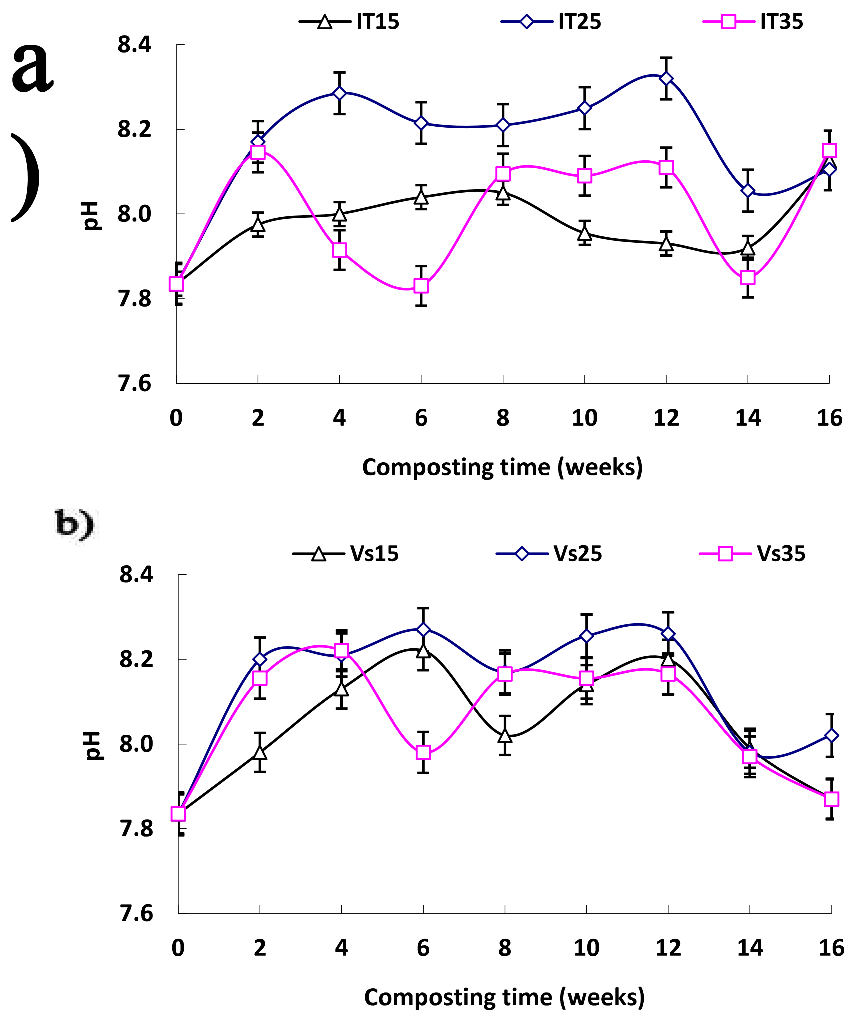


Fig. 3. Changes in pH with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means (n = 3)

The decrease in EC noticed in the middle of the composting process could be due to volatilization of NH_3 and precipitation of mineral salts (Wong et al., 2005). By the end of composting, piles Vs15 and Vs35 had their EC above the upper limit of 4.0 mS/cm considered tolerable by plants of medium sensitivity (Lasaridi et al., 2006). Therefore, composts from these piles must be mixed well with soil or other materials with low EC before it can be used for growing crops.

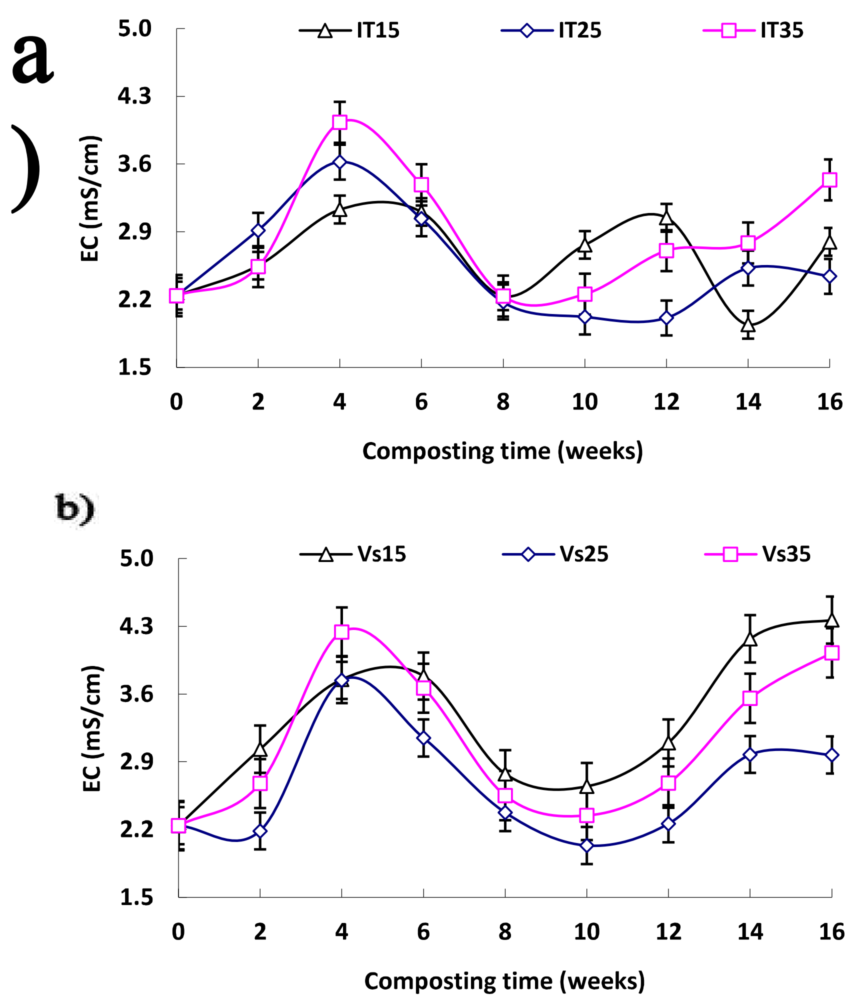


Fig. 4. Changes in EC with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means (n = 3)

3.4 Total Carbon

As the OM degradation occurred in the piles, the ash content increased and C_T decreased with composting time. The results of the ANOVA revealed that only PC had significant ($p \leq 0.05$) effect on C_T loss (Table 2). The effect was higher in piles with Vs pipe (Table 3), probably as a result of the losses during the thermophilic phase which was higher in piles with Vs pipe (24.7-53.7%) than in piles with IT pipes (14.5-51.2%). The C_T losses, which increased gradually to final values between 53.4% and 76.1% (Fig. 5a,b) could be attributed to bio-oxidation of OM resulting in the evolution of CO_2 and heat (Said-Pullicino et al., 2007). The high losses in the early days of composting indicated a high level of OM biodegradation in the piles (Fang et al., 1999). Some noticeable drops in losses in some piles (IT15 and IT35 during week 4 and IT15, Vs15, Vs25 and Vs35 during week 10) may have been due to increased carbon concentration in those piles. Pile IT15 recorded the least loss by the end of composting (Table 5). Although, the loss was correlated with N_T loss (R^2 = 0.60), it could also have been as a result of the relatively low thermophilic temperatures in the pile.

3.5 Total Nitrogen

The N_T concentration increased gradually with time during the composting process; a phenomenon reported in previous composting studies (Charest and Beauchamp, 2002; Huang et al., 2004; Liang et al., 2006; Said-Pullicino et al., 2007) as due to the concentration effect caused by the weight loss as OM is biodegraded and mainly librated as CO_2. The mass balance analysis indicated losses (except in pile IT15) in final N_T contents (Table 5). The results of the ANOVA showed that neither PC, PS nor the interaction had significant ($p > 0.05$) on the loss observed in the piles (Table 2). Although not significantly different, the mean values showed that the losses were greater in piles with Vs pipe and piles with 25 mm diameter perforations (Table 3). The final losses (0.30-25.2%) recorded in this study were lower than 45-92% (Tiquia and Tam, 2002; Ogunwande et al., 2008; Silva et al., 2009), probably as a result of the passive aeration method used. Pile Vs35 recorded gain in N_T content in the first two weeks of composting while pile IT35 recorded it in the first four weeks of composting (Fig. 6a,b). The gain could be attributed to increased nitrification (formation of NO_3-N) process by nitrifying bacteria which can easily develop at moderate temperature in chicken litter (Caceres et al., 2006) and also, to the significant ($p \leq 0.05$) positive relationship between pile temperature and N_T ($R^2 = 0.61$ and 0.33 for piles Vs35 and IT35, respectively) during the thermophilic phase.

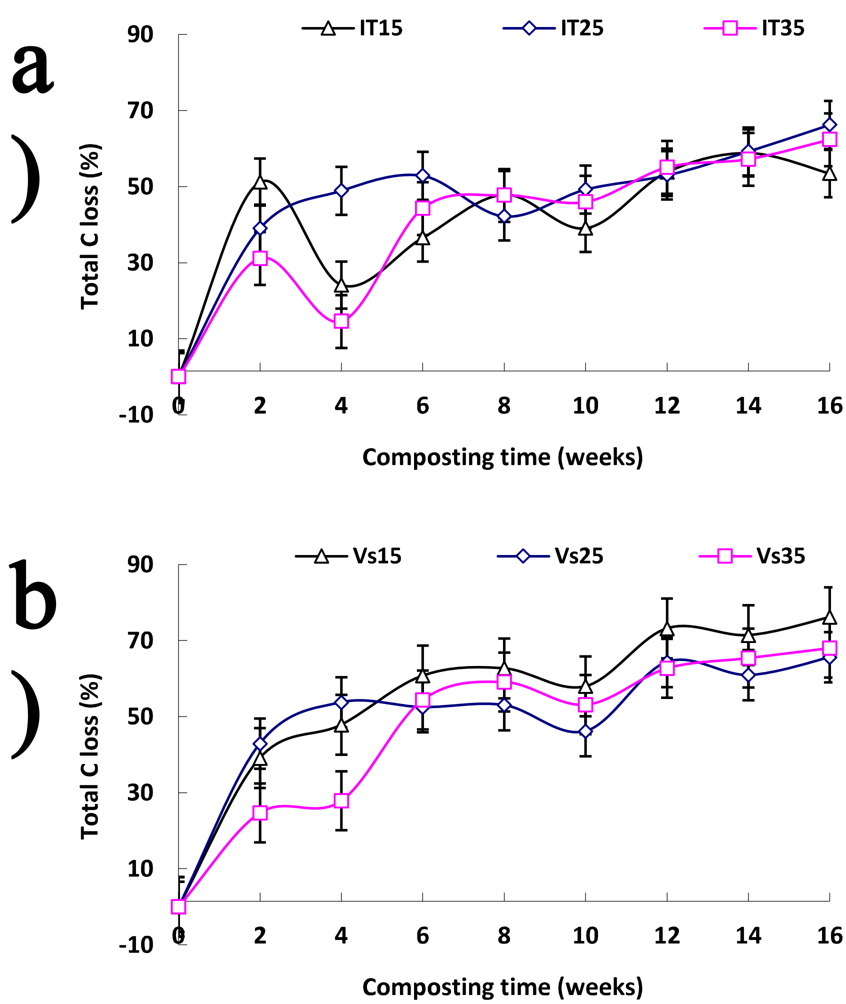


Fig. 5. Variation of total C losses with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

Table 5. Final characteristics of compost piles

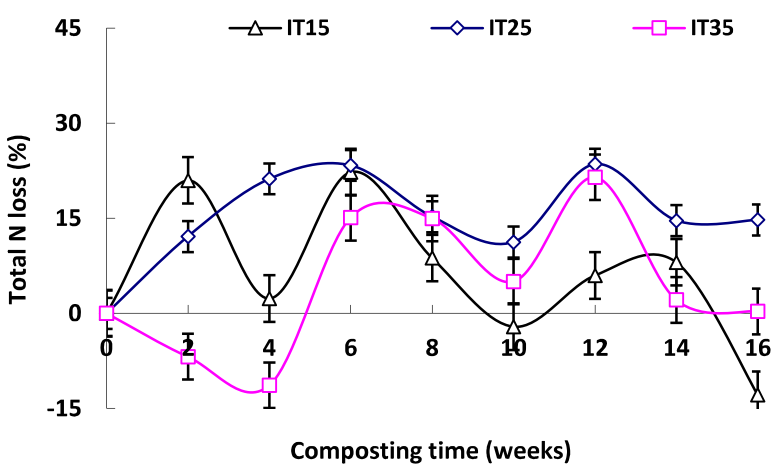
Pile	Ash (%)	Total C (%)		Total N (%)		Total P (%)		C:N ratio
		Conc	Loss	Conc	Loss	Conc	Gain	
IT15	51.2[a]	27.1[c]	53.4[a]	2.04[a]	12.8*[a]	1.24[a]	50.3[b]	13.3:1[b]
	(1.90)	(1.05)	(3.55)	(1.13)	(3.21)	(0.08)	(8.61)	(1.40)
IT25	59.3[b]	22.6[b]	66.3[b]	1.77[a]	14.7[b,c]	1.14[a]	19.8[a]	12.8:1[b]
	(3.15)	(1.74)	(4.38)	(0.17)	(5.52)	(0.17)	(6.37)	(0.22)
IT35	56.6[b]	24.1[b]	62.3[b]	1.97[a]	0.30[a,b]	1.10[a]	19.6[a]	12.3:1[b]
	(2.97)	(1.65)	(4.54)	(0.22)	(1.24)	(0.10)	(5.10)	(0.53)
Vs15	67.3[c]	18.2[a]	76.1[c]	1.77[a]	25.2[c]	1.12[a]	3.84[c]	10.3:1[a]
	(2.56)	(1.43)	(2.77)	(0.07)	(5.94)	(0.12)	(2.20)	(0.38)
Vs25	58.6[b]	23.0[b]	65.6[b]	1.70[a]	17.8[b,c]	1.36[a]	43.3[b]	13.5:1[b]
	(0.69)	(0.38)	(0.98)	(0.09)	(3.20)	(0.04)	(5.49)	(0.91)
Vs35	60.7[b]	21.8[b]	68.0[b]	1.70[a]	19.7[b,c]	1.11[a]	14.9[c]	12.9:1[b]
	(4.33)	(2.40)	(5.75)	(0.15)	(4.91)	(0.18)	(6.10)	(0.26)
p-value	0.001	0.001	<0.001	0.060	0.006	0.153	0.018	0.002

Mean and standard deviation (in parenthesis) are shown ($n = 3$).
[*] Percent gain.

Superscripts with the same letter in one column are not statistically different at $p \leq 0.05$; Conc: concentration.

The other piles recorded high losses within six weeks of composting (Fig. 6a,b). The losses were largely attributed to NH_3 volatilization (Tiquia and Tam, 2002; Huang et al., 2004; Zhu et al., 2004; 2006; Liang et al., 2006; Silva et al., 2009), which was favoured by the high pile temperatures (>33 ºC) and pH (>8.04) during the period. The peak losses observed during the mesophilic phase in piles IT25, IT35, Vs15 and Vs35 suggest that N_T may have been lost by denitrification due to the aerobic nature of certain denitrifying bacteria (Mahimairaja et al., 1995; Liang et al., 2006). Analysis of the final losses showed that pipe IT35 was equally as effective ($p > 0.05$) as pipe IT15 in minimizing N_T loss (Table 5).

a)



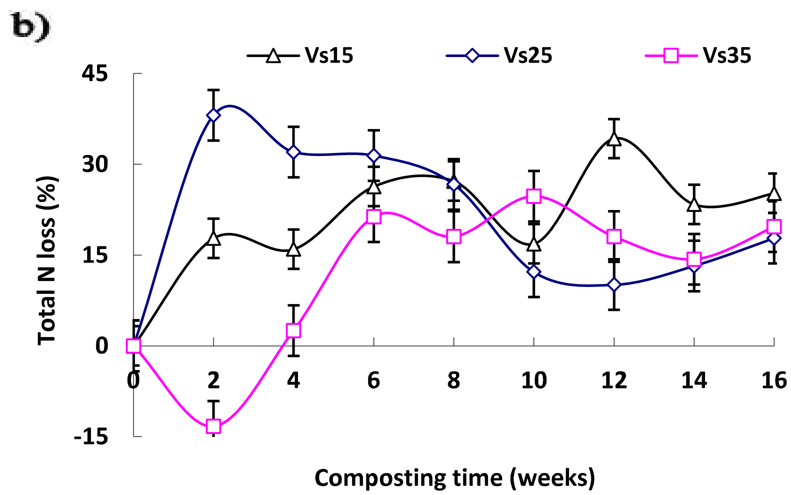
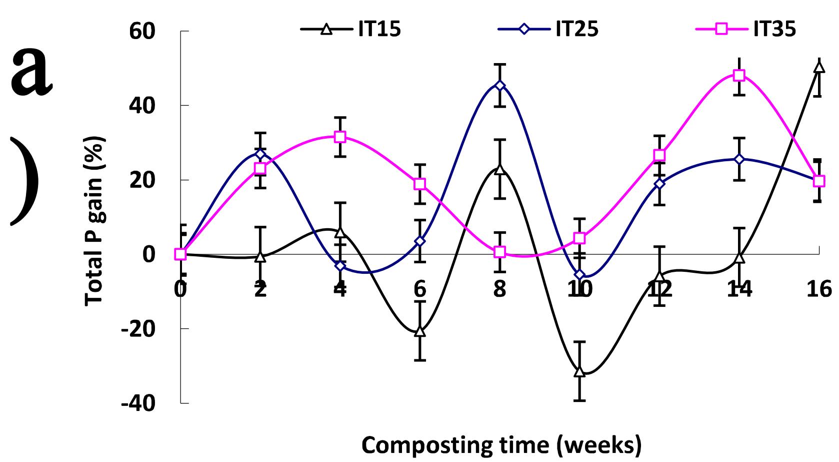


Fig. 6. Variation of total N losses with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means (n = 3)

3.6 Total Phosphorus

The P_T concentration increased significantly during composting; a situation that was attributed to net loss of dry mass as a result of decrease in the OM content (Charest and Beauchamp, 2002; Tiquia and Tam, 2002; Huang et al., 2004), and to conservation of inorganic ions in the chicken litter (Sartaj et al., 1997). The results of the ANOVA showed that PS affected ($p \leq 0.05$) P_T during composting (Table 2). The P_T variation in each pile followed a sinusoidal pattern and was characterised by gain and loss in P_T content (Fig. 7a,b). The final values showed that all the piles had gain in P_T content (Table 5). Although, the evolutions of P_T during composting of livestock manure have been scarcely reported in the literature, however, in this study, significant ($p \leq 0.05$) correlations were found between P_T and pile temperature (R^2 = 0.76 and 0.58; pile IT35 and Vs35, respectively), pH (R^2 = 0.51; pile Vs15) and N_T (R^2 = 0.62; pile Vs35). The final gains revealed that pipe Vs25 was equally as effective ($p > 0.05$) as pipe IT15 in minimizing P_T loss (Table 5).



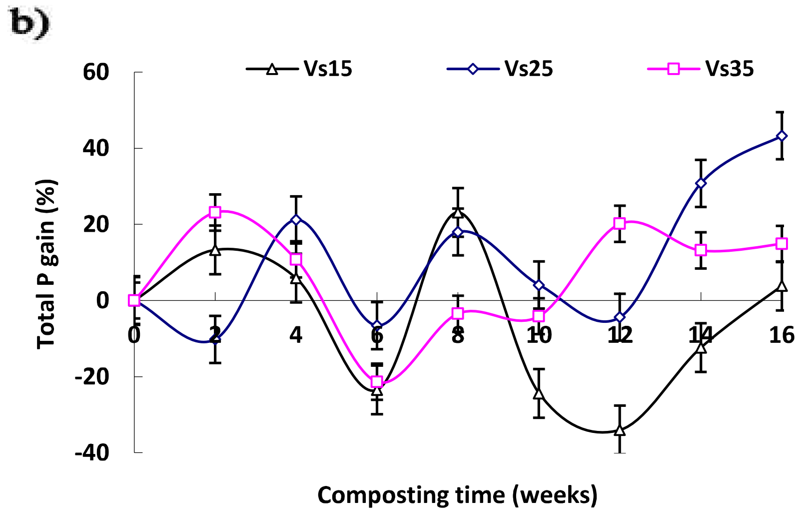
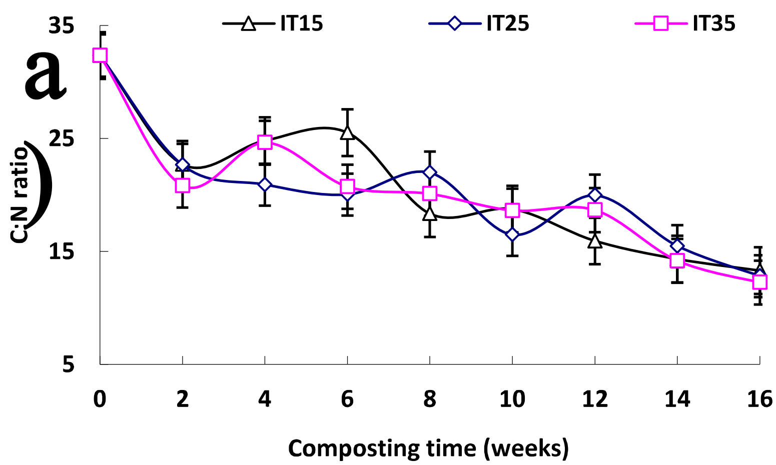


Fig. 7. Variation of total P gains with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

3.7 C:N ratio

The initial C:N ratio (32:1) of the chicken litter was within the range of 20:1-35:1 recommended by Rynk et al. (1992) and Metcalf and Eddy Inc. (2003) for rapid composting. It was observed that neither PC nor PS had significant ($p > 0.05$) effect on the C:N ratio of composting piles (Table 2). A gradual decrease was noticed in all the piles (Fig. 8a,b) due to either the mineralization of OM present in the chicken litter or increase in total N concentration resulting from a concentration effect as C is biodegraded. Decrease in C:N ratio with time have also been reported in previous composting studies (Solano et al., 2001; Charest and Beauchamp, 2002; Zhu et al., 2004; Sylla et al., 2006). The final C:N ratios ranged between 10.3:1 and 13.5:1 (Table 5). These values were within the range of 10:1 and 15:1 for final composts (Misra et al., 2003), and an indication of compost stability (Hoornweg et al., 2000) and compost maturity (Bernal et al., 1998; CCQC, 2001).



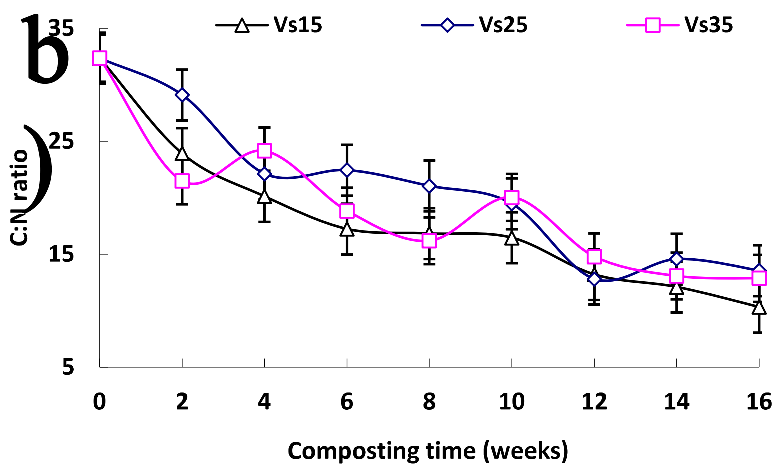


Fig. 8. Variation of C:N ratio with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

4. CONCLUSIONS

The results of the study showed that all the piles attained thermophilic temperatures for effective biodegradation, and that pipe IT15 was not promising for composting as the pile equipped with it failed to meet the sanitation requirements for hygienic compost. Pipe configuration had significant effect on pile temperature, pre-replenishment MC, EC and C_T while perforation size had significant effect on pile temperature, pre-replenishment MC, pH, EC and P_T. Neither PC nor PS affected N_T and C:N ratio. Although both PCs were effective for uniform composting rate, Vs pipe appeared to be more effective. Pipes IT35 and Vs25 were equally as effective as pipe IT15 in minimizing N_T and P_T losses, respectively.

NOMENCLATURE

IT15 inverted T pipe with 15 mm diameter perforations
IT25 inverted T pipe with 25 mm diameter perforations
IT35 inverted T pipe with 35 mm diameter perforations
Vs15 V-shaped pipe with 15 mm diameter perforations
Vs25 V-shaped pipe with 25 mm diameter perforations
Vs35 V-shaped pipe with 35 mm diameter perforations

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