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Fate of nitrogen during composting of chicken litter

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"Capsule": *Composting reduced the value of chicken litter as a N fertilizer.*

Abstract

Chicken litter (a mixture of chicken manure, wood shavings, waste feed, and feathers) was composted in forced-aeration piles to understand the changes and losses of nitrogen (N) during composting. During the composting process, the chemical [different N fractions, organic matter (OM), organic carbon (C), and C:N ratio], physical, and microbial properties of the chicken litter were examined. Cumulative losses and mass balances of N and organic matter were also quantified to determine actual losses during composting. The changes in total N concentration of the chicken litter piles were essentially equal to those of the organic N. The inorganic N concentrations were low, and that organic N was the major nitrogenous constituent. The ammonium (NH_4^+)-N concentration decreased dramatically during first 35 days of composting. However, the rapid decrease in NH_4^+-N during composting did not coincide with a rapid increase in ($NO_3^- + NO_2^-$)-N concentration. The concentration of ($NO_3^- + NO_2^-$)-N was very low (<0.5 g kg^{-1}) at day 0, and this level remained unchanged during the first 35 days of composting suggesting that N was lost during composting. Losses of N in this composting process were governed mainly by volatilization of ammonia (NH_3) as the pile temperatures were high and the pH values were above 7. The narrow C:N ratio ($<20:1$) have also contributed to losses of N in the chicken litter. The OM and total organic C mass decreased with composting time. About 42 kg of the organic C was converted to CO_2. On the other hand, 18 kg was lost during composting. This loss was more than half (59%) of the initial N mass of the piles. Such a finding demonstrates that composting reduced the value of the chicken litter as N fertilizer. However, the composted chicken contained a more humified (stabilized) OM compared with the uncomposted chicken litter, which would enhance its value as a soil conditioner. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Composting; Nitrogen; Nitrification; Denitrification; Organic matter loss

1. Introduction

Chicken litter is a mixture of excreta, wood shavings, wastes feed, and feathers which is removed from poultry houses, and can be applied to soil as an amendment. Composting of this litter prior to application as a fertilizer is recommended to control the spread of pathogens, minimize the production of phytotoxic substances, improve storage and handling, and reduce unpleasant odors (Edwards and Daniel, 1992; Hansen et al., 1993; Tiquia and Tam, 1998a). Composting is also an effective and inexpensive means of stabilizing organic matter (OM; Golueke, 1977). However, the composting changes the nature of the waste and can affect its usefulness as a soil amendment. For instance, composting may affect nitrogen (N) transformations such as N mineralization, ammonia (NH_3) volatilization, nitrification, and denitrification. N mineralization is of extreme importance because it converts organic N into ammonium (NH_4^+). NH_3 volatilization and denitrification may lead to significant losses of N (Martins and Dewes, 1992; Bernal et al., 1996). Such a loss will affect the agronomic quality of the composted product. These losses during composting of animal manure range from 21% upward to 77% (Martins and Dewes, 1992; Rao Bhamidimarri and Pandey, 1996). N losses vary depending on several environmental factors such as aeration, moisture content, and temperature (Bishop

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and Godfrey, 1983). The carbon (C):N ratio of the initial composting material has also been reported to affect losses of N during composting (de Bertoldi et al., 1980, 1985; Bishop and Godfrey, 1983; Witter and Lopez-Real, 1988). A very narrow C:N ratio can lead to loss of N through NH_3 volatilization (de Bertoldi et al., 1985; Tam and Tiquia, 1999), especially if the compost piles are aerated mechanically or turned manually. de Bertoldi et al. (1983) reported that the N loss was greater with turning (18% N loss) than with forced aeration (5% N loss). Such a loss in N would decrease the nutrient value of the mature compost material.

A considerable body of literature exists concerning the composting facilities (Elwell et al., 1998; Tiquia and Tam, 1998b), physical operation of chicken litter (Raviv et al., 1999; Wan et al., 1999), and mineralization of nutrients in soil (Weinzaepflen et al., 1999). Little has been written, however, concerning the fate of N during the composting of chicken litter. The nutrient that has received the most attention in composting systems is N since it is the most needed element for plant nutrition, and it has certainly the highest concentration of any plant nutrient in manures (Bishop and Godfrey, 1983; Martin and Dewes, 1992; Cooperband and Middleton, 1996; Rao Bhamidimarri and Pandey, 1996). Apart from N, C is an element that is also most likely to be lost during the composting process. The present study therefore aims to: (1) investigate the changes in N transformation during composting of chicken litter in forced-aeration piles; (2) determine losses in N and C during composting; and (3) assess the effects of composting at different locations of the forced-aeration piles.

2. Materials and methods

Chicken litter was collected at the Castle Peak Chicken Farm, New Territories of Hong Kong, and stacked in windrows. The water content of the litter was adjusted to 65% (w/v) at the beginning of composting, and no further adjustment in water was made throughout the composting process. The chemical properties of the initial chicken litter material are summarized in Table 1. Twenty-millimeter diameter polyvinyl chloride (PVC) pipes were laid at the base of the pile, with perforations (25 mm diameter) facing upward. Three piles were built on perforated pipes connected to an air pump. Each pile was triangular in shape, about 2 m in width at the base and 1.5 m in height. The total weight of each pile was approximately 2000 kg (fresh wt.). The distance between each perforation was 20 cm. The pipes were covered by wood chips to prevent blockage of the holes, and air was blown to the piles (from bottom to top of the pile) using air pump (Regenair R1102, Gast Manufacturing Corporation, USA). The air was pumped continuously at a rate of 634 l min^{-1} during the entire period of composting. The chicken litter piles were then topped off with a 5-cm thick layer of mature compost to insulate the piles, and to act as a biofilter to minimize odors. Chicken litter samples were taken at four different locations in the pile: top (130 cm from the base of the pile), middle (75 cm from the base of the pile), bottom (30 cm from the base of the pile), and surface (5 cm from the surface of the pile) at day 0, and then weekly until the end of the composting process (day 168). A total of five subsamples were taken from each location. These samples were merged together to give one composite sample. Approximately 1 kg sample was collected from each of the four locations of each pile.

Table 1
Chemical properties of the initial chicken litter material

Chemical parameters	Concentration (dry wt. basis)[a]
Total N (g kg^{-1})	33.9 ± 1.2
Organic N (g kg^{-1})	22.7 ± 1.2
NH_4^+-N (g kg^{-1})	10.9 ± 0.1
$(NO_3^- + NO_2^-)$-N (g kg^{-1})	0.26 ± 0.1
Total P (g kg^{-1})	16.9 ± 0.4
Total K (g kg^{-1})	20.3 ± 2.4
Total C (g kg^{-1})	491.4 ± 2.0
Ash content (g kg^{-1})	141 ± 3.4
Total Cu (mg kg^{-1})	85 ± 5.7
Water-extractable Cu (mg kg^{-1})	16 ± 0.4
Total Zn (mg kg^{-1})	197 ± 43
Water-extractable Zn (mg kg^{-1})	47 ± 1.3
C:N ratio	14.5 ± 0.2
pH	8.3 ± 0.1
Electrical conductivity (dS m^{-1})	5.1 ± 0.2

[a] Mean and standard deviation of three replicates are shown. Data are based on 105°C dry weight basis.

The chicken litter was analyzed for the following parameters: water content (105°C for 24 h); pH (1:10 w/v litter:water extract) using a pH electrode; electrical conductivity (1:5 w/v litter:water extract) using a conductivity electrode; OM and ash content (550°C for 5 h) (loss on ignition) (Allison, 1965); total P (acid digest) using the ascorbic acid method (APHA, 1995); total K (acid digest) (atomic absorption spectrophotometry) (APHA, 1995); total (acid digest), and water-extractable (1:10 w/v litter:water extract) Cu and Zn (atomic absorption spectrophotometry) (APHA, 1995); Kjeldahl N (Bremner, 1996); NH_4^+-N and $(NO_3^- + NO_2^-)$-N using the KCL extraction method (Mulvaney, 1996); and denitrifying bacterial population by inoculation of tubed liquid media using the Most Probable Number (MPN) method (Alexander, 1982).

The OM concentration of the chicken litter was computed from the ash content [1−ash content×(1000)]. On the other hand, the total organic C was estimated from the OM value using the conventional "Van Bemmelem Factor" of 1.724. This factor is based on the assumption that soil OM contains 58% C (Allison, 1965). The theoretical total N concentration of the chicken litter was calculated by adding the Kjeldahl N with the ($NO_3^- + NO_2^-$)-N, whereas the organic N concentration was derived by subtracting the NH_4^+-N from the Kjeldahl N. The C:N ratio was then computed based on the concentration of total organic C and N.

Quantitative estimation of NH_4 and nitrite oxidizing bacteria were assayed using the plate frequency technique (Tiquia and Tam, 1998a, b; Tiquia et al., 1998). This technique involves inoculating 0.1 ml of the serially diluted spent litter suspension on the eight sections of the agar plate. Observation of bacterial colonies in any of the eight sections was considered positive growth. The total number of positive growths was counted, and the population size of microorganisms in the sample was estimated using an MPN computing package (Tam, 1982).

The mean and standard deviation of the three replicates were reported for all parameters measured. To compare the variations in composting at different locations of the forced-aeration piles, one way analysis of variance (ANOVA) statistical testing was performed. Subsequently, the means of the physical, microbial and chemical parameters at four locations (top, middle bottom and surface) of the chicken litter piles were compared using the Bonferroni test. All statistical analyses were based on the procedures described by Zar (1996).

3. Results and discussion

3.1. Effects of composting at different locations of the forced-aeration piles

The forced-aeration composting method has been developed in the present study to reduce the labor cost and space requirement for windrow composting (turning method). Under the forced-aeration composting system, the efficiency of composting at different locations may be different due to variations in aeration levels. This result might affect the efficiency of composting, and the changes in N during the composting process. Results of the ANOVA test revealed that composting at different locations of the forced-aeration piles was similar in terms of the water content (Fig. 1a), chemical (Figs. 1b, 2, and 3), and microbial (Fig. 4) properties, with the exception of temperature (Fig. 5). The peak temperatures occurred in the middle (63°C) and bottom (58°C) part were significantly higher than those recorded in the top (54°C) and surface (48°C) location of the forced-aeration piles. The low top and surface temperature could be attributed to the excess loss of heat since this location was closer to the ambient air than the other two locations (middle, and bottom). Differences in temperature suggest that aeration varied at different locations of the forced-aeration piles. The air diffusion, oxygen availability, and redox potential should be measured in the future studies for a better understanding of composting at different locations of the chicken litter piles. Despite these differences, the time required for the temperature to return to that of ambient air was similar for all four locations (126 days) (Fig. 5).

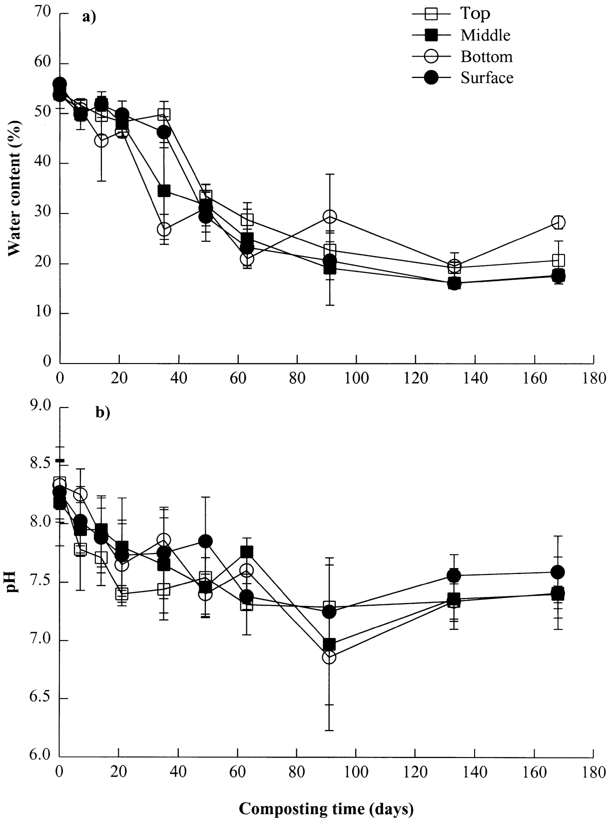

Fig. 1. Changes in (a) water content, and (b) pH of the chicken litter piles during a 168-day composting process. Mean and standard deviation are shown. Moisture content (P=0.97, ns); pH, (P=0.77 ns); ns, not significant.

3.2. Nitrogen dynamics

The changes in total N concentration of the chicken litter piles were essentially equal to those of the organic N (Fig. 2a, b). This result relates to the facts that the inorganic N concentrations (Fig. 2c, d) were low, and that organic N was the major nitrogenous constituent. At day 49, the organic N increased in all four locations of the forced-aeration piles (Fig. 2b). This increase in organic N can be attributed to a concentration effect as a consequence of strong degradation of organic C compounds (Fig. 3a), which reduced the weight of the dry mass (Table 2). At day 49, the organic N decreased in

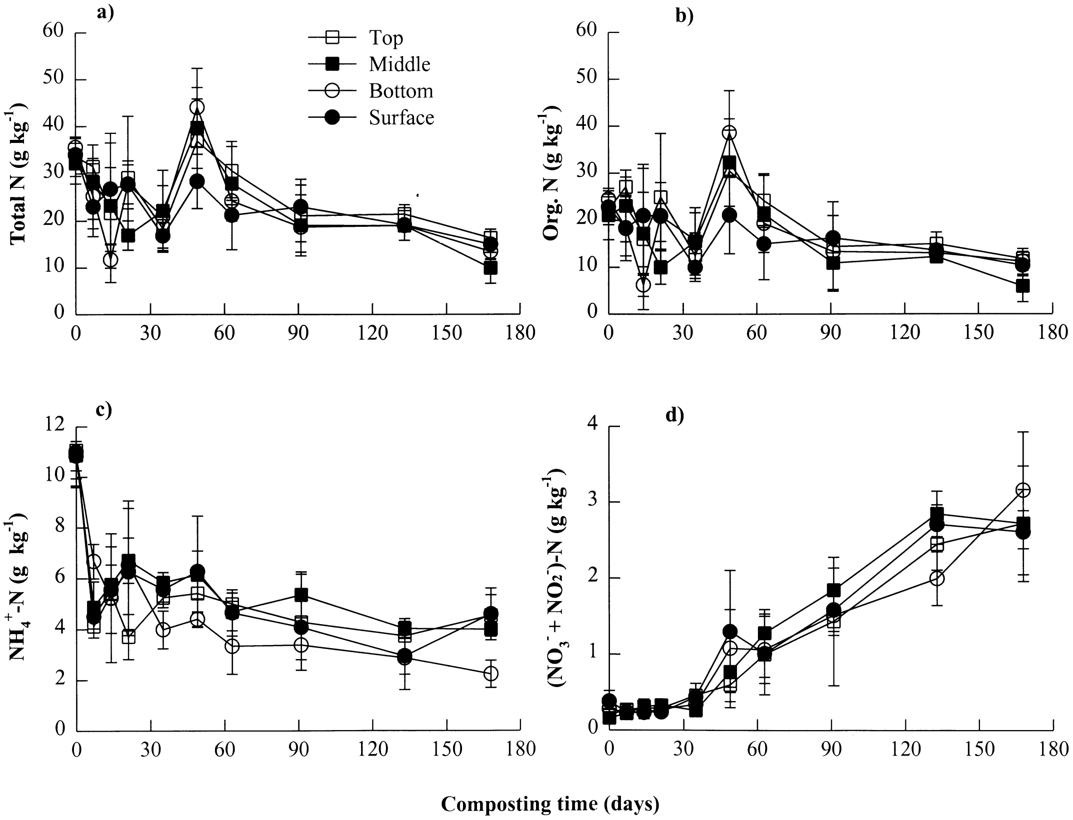

Fig. 2. Changes in concentrations of different forms of N of the chicken litter piles during a 168-day composting process. Mean and standard deviation are shown. Data are expressed on a 105°C dry weight basis. (a) Total N ($P=0.88$, ns); (b) organic N ($P=0.77$, ns); (c) NH_4^+-N ($P=0.83$, ns); (d) $(NO_3^- + NO_2^-)$-N ($P=0.99$, ns); ns, not significant.

Table 2
Losses and mass balances of nitrogen (N), carbon (C), organic matter (OM), and ash during composting of chicken litter in forced-aeration piles[a]

Composting time (days)	Cumulative losses (%)			Mass and balance (kg)			
	Mass	OM	N	N	OM	Organic C	Ash
0	0	0	0	31	779	452	141
7	0.9	0.9	21	25	772	448	148
14	1	1	38	19	768	446	152
21	3	3	26	23	753	436	167
35	4	4	41	18	750	435	170
49	5	5	9	34	737	428	183
63	7	7	24	24	727	421	193
91	5	5	38	19	739	429	181
133	7	7	41	18	721	419	199
168	9	9	59	13	707	409	213
Balance	–	–	–	−18	−73	−42	+73

[a] The balances of N, C, OM, and ash were calculated by subtracting the final with the initial mass. Mean of the top middle, bottom, and surface locations are shown. Data are based on 105°C dry weight basis.

the chicken litter piles, due to ammonification of organic N to NH_3.

The NH_4^+-N concentration decreased dramatically (from around 11.5 to 5.5 g kg^{-1}) by day 7, increased slightly between days 21 and 35, then stabilized at around 204 g kg^{-1} by the end of composting (Fig. 4c). The slight increase in NH_4^+-N concentration between days 21 and 35 could be due to conversion of organic N to NH_4^+-N *via* the ammonification process. This decrease was also followed by a slight increase in population of NH_4 oxidizers (Fig. 4b), and a decrease in organic N concentration (Fig. 2b) at this stage of composting. However, the rapid decrease in NH_4^+-N during composting did not coincide with a rapid

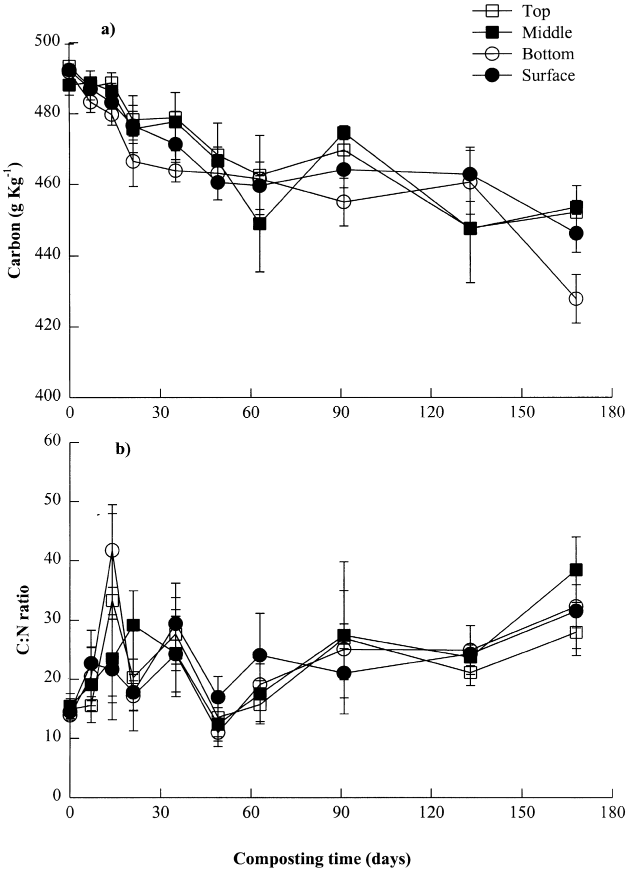

Fig. 3. Changes in concentration of (a) total C, and (b) C:N ratio of the chicken litter piles during a 168-day composting process. Mean and standard deviation are shown. Data are expressed on a 105°C dry weight basis. Total C ($P=0.76$, ns); C:N ratio ($P=0.76$, ns); ns, not significant.

increase in (NO$_3^-$ + NO$_2^-$)-N concentration. The concentration of (NO$_3^-$ + NO$_2^-$)-N was very low (<0.5 g kg^{-1}) at day 0, and this level remained unchanged during the first 35 days of composting (Fig. 4d) due to inhibition by excessive amount of NH$_3$, and high temperature (Morisaki et al., 1989; Fang et al., 1999). This result suggests that N was lost during composting. Some of the NH$_4$ was lost through NH$_3$ volatilization as the pile temperatures were high (Fig. 5) and the pH values were above 7.0 (Fig. 1b), giving conditions that favored NH$_3$ volatilization. Bishop and Godfrey (1983) and Witter and Lopez-Real (1988) also reported that losses of N by NH$_3$ volatilization were significant at a pH above 7.0 and high temperatures (>40°C). Some of the (NO$_3^-$ + NO$_2^-$)-N was lost through microbial denitrification as the population of denitrifying bacteria was high during the early stage of composting (Fig. 4d).

The population of denitrifying bacteria was highest at day 0 (Fig. 4d), indicating the presence of anaerobic pockets in the chicken litter piles. However, as composting progressed, their numbers decreased to around 5.0–5.5 log$_{10}$ MPN g^{-1} by day 21 and were maintained at this level until the end of composting. This result demonstrates that active denitrification only occurred during the early stages of composting. Once the air was forced into the chicken litter piles, denitrification decreased significantly. Results of this study show that the loss of N through denitrification was significant only during the first 14 days of composting.

3.3. OM and N losses

To reveal the actual loss in the chicken litter piles, mass and balances as well as cumulative dry mass, OM, and N losses were calculated during the composting period (Table 2). The OM loss in the chicken litter piles was only 9% of the initial OM. This OM loss was similar to that found by Fang et al. (1999) during composting of sewage sludge. The mass of OM and total organic C also decreased with composting time (Table 2). The decrease synchronized with an increase in mass ash of the chicken litter piles. About 42 kg of the organic C was converted to CO$_2$ (Table 2). This loss is about 9% of the initial total OM, which is relatively low compared to the results in the literature (Benedict et al., 1988; Fang et al. 1999). It could be that the chicken litter contained little degradable OM.

The total N in the compost mass (concentration× mass of the pile) dropped from 31 to 13 kg during the entire period of composting (Table 2). This loss was about 59% of the initial N mass of the piles and is comparable to losses reported on composting of animal manure (21–77%) (Martins and Dewes, 1992; Rao Bhamidimarri and Pandey, 1996). In this composting experiment, losses of N can be attributed largely to NH$_3$ volatilization. It has been noted that the properties of the initial material, in particular, the C:N ratio, and the composting conditions such as aeration, moisture content, and temperature are affected by the degree of N loss (Bishop and Godfrey, 1983). The initial C:N ratio was very narrow ($<20{:}1$) at the beginning of composting (Fig. 3b). This narrow C:N ratio could have also contributed to losses of N in the chicken litter via NH$_3$ volatilization. As composting proceeded, the C:N ratio of the chicken litter increased. Increases in C:N ratio had been reported also during composting of sewage sludge (Morisaki et al., 1989) in which increasing C:N values occurred during composting due to vigorous NH$_3$ volatilization. However, the addition of a bulking agent (rice husks) in their study reduced the loss of NH$_3$. The addition of bulking agent (i.e. yard trimmings, woodchips, rice husks) to the chicken litter might help reduce the loss of N. Wan et al. (1999) co-composted the chicken litter with yard trimmings in forced-aeration piles. Their research demonstrated that N loss was reduced significantly when yard trimmings was added to the chicken manure. In their study, the N loss was $>15\%$

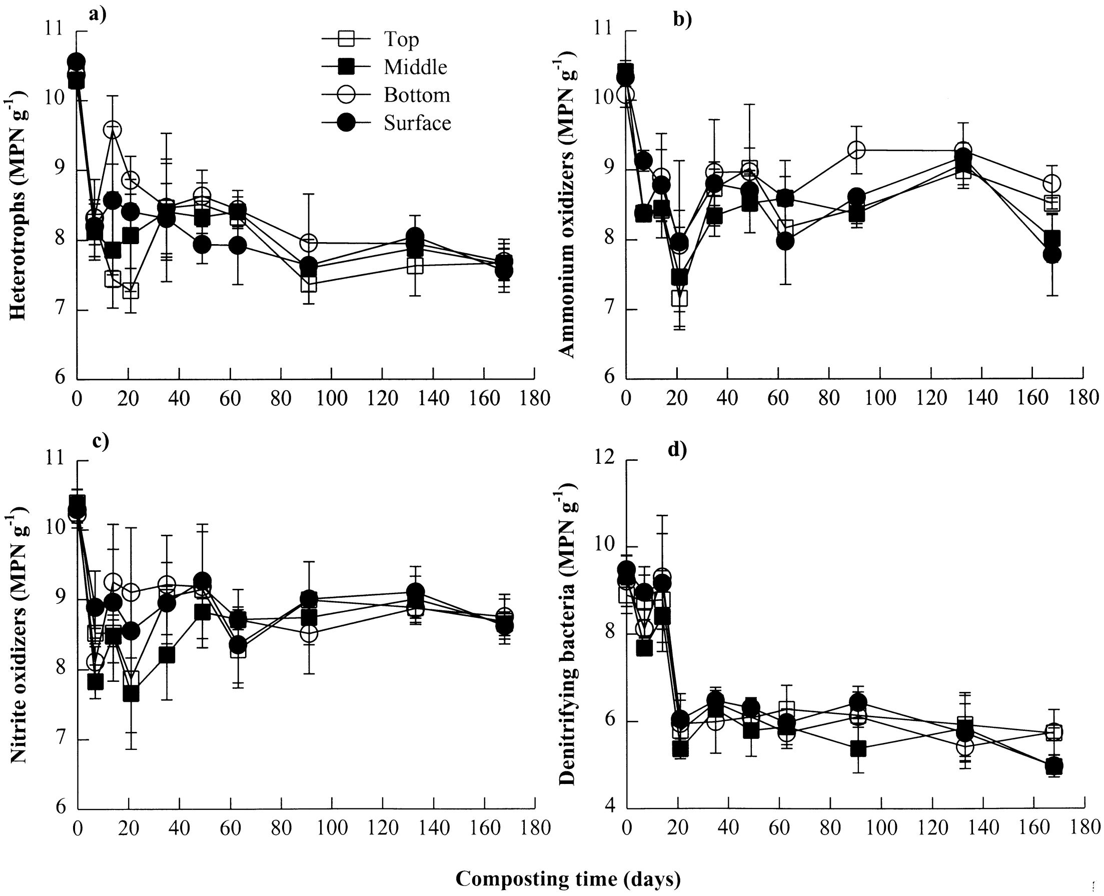

Fig. 4. Changes in the microbial population sizes of the chicken litter during a 168-day composting process. Mean and standard deviation are shown. (a) Total aerobic heterotrophs ($P=0.61$, ns); (b) ammonium oxidizers ($P=0.72$, ns); (c) nitrite oxidizers ($P=0.56$, ns); (d) denitrifying bacteria ($P=0.90$, ns); ns, not significant. MPN, most probable number.

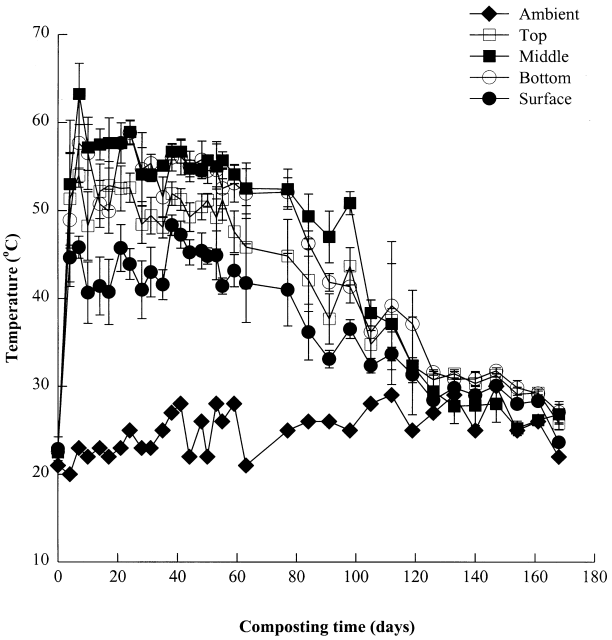

Fig. 5. Changes in air and pile temperatures of the chicken litter piles during a 168-day composing process. Mean and standard deviation are shown. $P=0.004$, significant (Top < Middle = Bottom > Surface).

in all piles. A recent study by Raviv et al. (1999) showed that addition of 5% (on a dry wt. basis) of squeezed grapefruit peels lowered the pH (around 5.8–6.6), and consequently increased the amount of conserved N in chicken manure by 80%.

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