Nitrogen losses and enrichment of soil and sawdust coverings during composting of poultry manure

ABSTRACT

Aims: Composting poultry manure is an effective way of enhancing its nutrient content and reduce nutrient losses. There is the need to reduce gaseous nutrient losses during composting through the use of covering materials. Assess the level of chemical enrichment of soil and sawdust used as covering materials; and identify the most suitable medium that can best perform as a covering material during composting of poultry manure.
Materials and methods: Experiments were set up to examine the changes in the chemical properties of soil and sawdust used as covering material for composted poultry manure. Five treatments – no covering, layers of 2.8 kg soil, 5.6 kg soil, 0.9 kg sawdust, and black polythene sheet on 5.28 kg broiler and layer manure heaps with four replications were arranged in a completely randomized design. Samples were taken from the manure piles and the soil and sawdust covering materials for chemical analysis at 3, 6 and 9 weeks after composting.
Results: The pH, N, P, K, Na and Ca, in both soil covers increased as time elapsed, whereas the Mg and C/N ratios of the soil coverings decreased with time. With regards to the broiler manure, however, the pH and the nutrient content of the two levels of soils used as cover increased at all the stages of composting. Composting of both poultry manures resulted in the improvement of the chemical properties of both sawdust and soil coverings. The enrichment ratio of N was greater in the 5.6 kg soil than the 2.8 kg soil covering. Additionally, the 5.6 kg soil covering was highly efficient (*P* = .05) in reducing N losses by 57 and 83.85% from the broiler and layer piles, respectively. In general, the 5.6 kg soil was the most effective covering material.

Keywords: Compost, Organic matter, Poultry manure, Soil nutrients

1. INTRODUCTION

Composting may be defined as a spontaneous, biological decomposition process of organic materials in a predominantly aerobic environment. During the process of composting, bacteria, fungi and other microorganisms break down organic materials to stable, usable organic substances called compost. It is a useful way of transforming organic waste into valuable organic matter for use as an organic amendment for soils [1]. It is, therefore, regarded as an environmentally acceptable method of waste treatment which uses naturally occurring microorganisms to convert biodegradable organic matter into humus-like product. The quality of the manure as a fertilizer increases when composted, because the nitrogen becomes more stable and nutrients are released more slowly than they are from raw manure [2]. Composting also stabilizes organic wastes [3], and destroys most parasites, and pathogens contained in the wastes. A well composted material is environmentally safe and a valuable soil amendment for growing certain crops. In view of this, composting has received increasing interest as an effective method for handling manure. Hence, composting could serve as an inexpensive alternative for disposal of poultry-based wastes and other biological residues. [4].

Farmers usually cover the manure during composting with sawdust and polythene sheets. According to Subair et al. [5], slow decomposing materials that are high in lignin, such as sawdust exhibit lower rate of N immobilization, with immobilized N remaining in organic form for a long time. They went further to conclude that materials with moderate lignin contents are more effective in reducing volatile N losses from amended manure. Additionally, in order to reduce N losses, most peasant farmers add or cover manure with soil [6]. Accordingly, Kirchmann and Lundvall [7] noted that the amount of N lost from covered manure heaps was lower than uncovered ones. The covered manures also had higher moisture contents, which may have accounted for the lower N losses. Accordingly, Nommik and Vahtras [8] reported that soils with fine texture, high cation exchange capacity, low base saturation and low pH can be effective absorbents of NH_4^+/NH_3^-N from manure.

Most farmers usually cover manure heaps with polythene sheets, soil and sawdust because they are inexpensive, and also protect the manure from direct raindrop impact. Since the purpose of composting manure is to contribute more to the organic matter content of the soil, and enhance nutrient stability and availability, the best performing covering material should be able to reduce gaseous losses during the composting process. The objectives of the present study were, therefore, to:

1. Assess the level of chemical enrichment of soil and sawdust used as covering materials during composting of poultry manure.
2. Identify a suitable medium that can best perform as a covering material for composting of poultry manure.

2. MATERIAL AND METHODS

2.1 Experimental design, set up and analyses

The study was conducted in a screen house at the Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. Three-month old broiler and layer manures were used for the study. Soil samples collected from 0-15 cm depth were uniformly mixed to obtain a composite sample. Manure composts were prepared with 3.5 kg poultry manure in plastic buckets of 12 L volume, and compressed uniformly to the 8 L mark to give a bulk density of 0.44 g/cm^3. A 0.2 mm plastic mesh was placed on top of the manure followed by the imposition of cover. Each complete set up was moistened with 250 mL of water and composted for a period of 9 weeks with a turning every three weeks.

The experiment was set up in a Complete Randomized Design with four treatments and four replications giving sixteen experimental units. The Treatments comprised no covering, 2.8 kg ≈ 2 L volume topsoil covering, 5.6 kg ≈ 4 L volume topsoil covering, 0.9 kg ≈ 2 L volume sawdust covering, and black polythene sheet. At each turning of the compost (21 day intervals), the soil and sawdust coverings were analyzed for pH using H1 9017 Microprocessor pH meter in a 1:2.5 suspension of soil and water, total nitrogen by the Kjeldahl's Method [9], available phosphorous by the Bray P-1 method [10], organic carbon (OC) by the Walkey and Black wet oxidation method [11], and exchangeable bases were by the 1.0 N ammonium acetate extraction method buffered at pH of 7.0. Soil particle size was analyzed by the hydrometer method [12]. Temperatures of the composted manure piles at the 10 days' interval were taken between 16 and 17:30 h GMT when the ambient temperature was fairly stable. The data obtained from the study was subjected to analysis of variance (ANOVA) using GenStat (12th edition). Mean comparison was done using the standard error of difference (SED) at P = .05. Mean pairs with significant differences were identified using the Duncan's Multiple Range Test.

3. RESULTS AND DISCUSSION

3.1 Initial physico-chemical properties of manure and covering materials

Tables 1 and 2 present the initial physico-chemical composition of the different poultry manure, and sawdust and soil. The pH of both manures was high (basic). This may be attributed to the moderately high exchangeable bases especially calcium in the litter used. In addition, the chemical analysis revealed that both manures were chemically rich in the major nutrients [13]. The high organic carbon content observed could be due to the high bedding materials present in the manure.

Table 1. Chemical properties of the broiler and layer manures used for composting

Parameters	Layer	Broiler
Total Nitrogen (%)	2.62	2.35
Available Phosphorus (mg/kg)	0.67	0.70
Potassium (cmol/kg)	3.33	3.09
Organic Carbon (%)	37.36	31.92
Calcium (cmol/kg)	1.41	1.56
Magnesium (cmol/kg)	2.01	1.31
Sodium (cmol/kg)	0.31	0.26
C/N ratio	14.26	13.61
pH (1:1 H_2O)	8.50	8.81

The physico-chemical properties of the sawdust and soil used as covering materials are presented in Table 2. The pH of the soil was moderately acid, while that of the sawdust was neutral. The amount of soil N, P, and OC were 0.13, 11.78 and 1.98, whereas those of the sawdust were 0.41, 0.86 and 44.49, respectively (Table 2). The exchangeable cations, Ca, Mg, Na, and K were 2.32, 1.16, 0.10, and 0.18%, while those of the sawdust were 0.36, 0.37, 0.30, and 0.09%, respectively (Table 2). The C/N ratio of the soil was < 1/20 whilst that of the sawdust was > 1/20. This is a clear indication that the sawdust was not desirable for composting.

Table 2. Physico-chemical properties of soil and sawdust coverings

Parameters	Soil	Sawdust
Total N (%)	0.13	0.41
Available P (mg/kg)	11.78	0.86
Exch. K (cmol/kg)	0.18	0.09
OC (%)	1.98	44.49
Ca (cmol/kg)	2.32	0.36
Mg (cmol/kg)	1.16	0.37
Na (cmol/kg)	0.10	0.30
C/N ratio	15.32	108.51
pH (1:1 H_2O)	5.77	7.42
Bulk density (g/cm^3)	1.40	0.45
Sand (%)	68.28	-
Clay (%)	18.72	-
Silt (%)	13.00	-
Texture	Sandy loam	-

3.2 Temperature in the composts

The temperature profiles obtained with the average values registered in the various piles covered with 2.8 and 5.6 kg soil, and 0.9 kg sawdust throughout the composting period are presented in Figures 1 and 2. Composting of the poultry manures was characterized by an initial increase in temperature to *ca*. 40°C (Figs. 1 and 2).

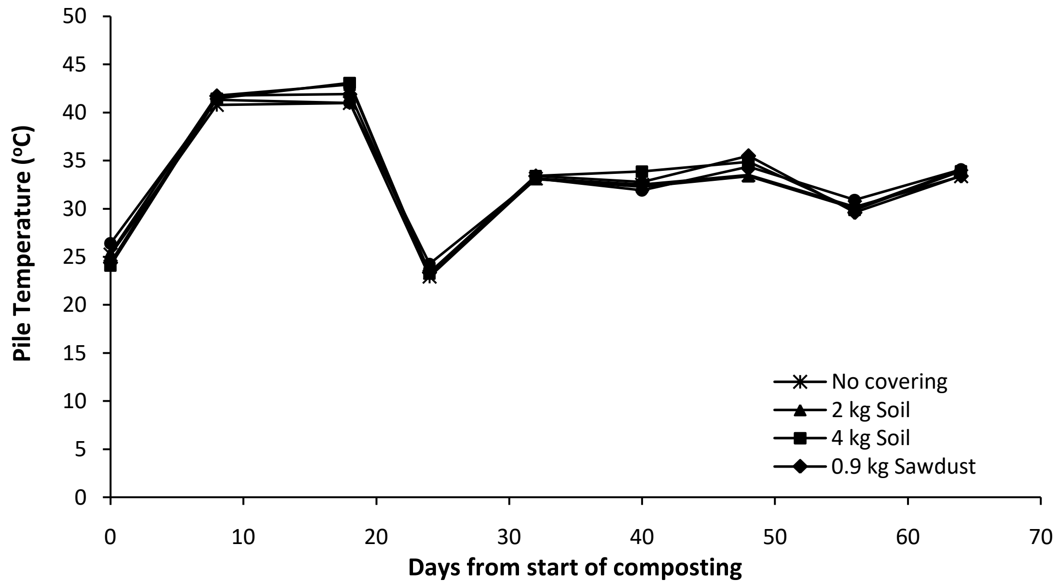

Figure 1. Temperature profile of the composting process of broiler manure with different covering materials (*P* = .05)

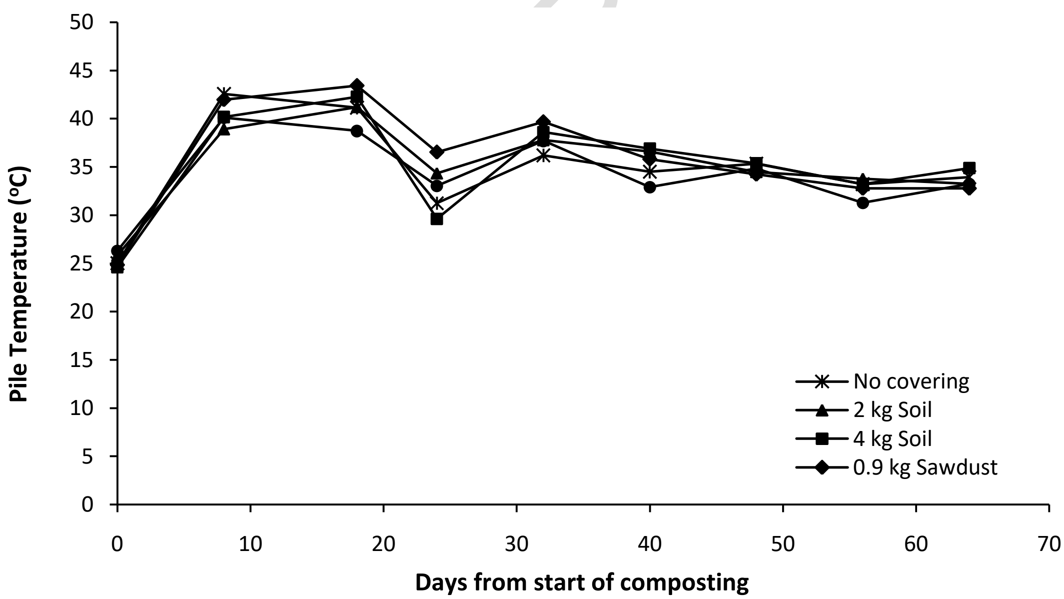

Figure 2. Temperature profile of the composting process of layer manure with different covering materials (*P* = .05)

The profiles describe a typical trend of temperature-time curve of compost for the different treatments. The temperatures declined from the peak level (*ca*. 40°C) at 16 days after composting (DAC). At *ca*. 30 DAC and beyond, the temperatures increased by *ca*. 5 – 10°C in the piles. These increases could be as a result of the growth of fungi, which was rendered inoperative at the initial high temperatures during the composting processes [14, 15]. For both manures, the peak temperatures under all treatments were above 40°C, although they were below the thermophilic conditions (> 45°C). These trends can be taken as a proximate indicator of more persistence availability of biodegradable organic matter, hence slower degradation rates in the composts [16, 17]. At 24 DAC, however, there was a fall in temperature from the peak in all the treatments (Figs. 1 and 2) to ambient levels (< 30^{o}C); the temperatures increased and remained steadily above 30^{o}C from the 32 DAC, and remained relatively constant from 40 DAC until the end of the experiment (64 DAC). This could have resulted from the depletion of the readily decomposable organic matter with time, which subsequently caused the temperatures to drop and the considerable retardation in the process.

The periodic declines in temperature as evident in Figs. 1 and 2 were the due to the cooling effect resulting from turning the piles and breakdown of organic materials by microorganisms during the composting process. The subsequent fall in temperature observed in the composts as time elapsed could be the result of the unavailability of energy/substrate for microbial decomposition. Accordingly, Barrington et al. [18] reported that this observed phenomenon, where the thermophilic temperature is maintained after a few days or weeks is fundamental in composting. Similarly, Khater et al. [19] observed peak temperatures of compost piles after 14 days of composting, and a progressive decrease to constant levels after 40 DAC.

3.3 Chemical enrichment of soil covering

The results of the chemical properties of the soil coverings on both broiler and layer manure piles at various sampling periods during the composting process are presented in Tables 3 and 4.

Table 3. ‡Chemical properties of soil coverings on broiler manure pile

Parameters	2.8 kg soil			5.6 kg soil		
	3 WAC	6 WAC	9 WAC	3 WAC	6 WAC	9 WAC
Total N (%)	0.18^{b}	0.17^{b}	0.21^{a}	0.16^{b}	0.18^{b}	0.43^{a}
Available P (mg/kg)	47.90^{b}	50.70^{a}	40.00^{c}	50.80^{a}	43.20^{b}	26.40^{c}
K (cmol/kg)	1.08^{c}	1.49^{b}	1.63^{a}	1.58^{a}	1.11^{b}	1.02^{c}
Na (cmol/kg)	0.67^{c}	1.11^{a}	0.91^{b}	0.38^{b}	0.59^{a}	0.67^{a}
Ca (cmol/kg)	3.02^{b}	4.41^{a}	3.07^{b}	3.29^{b}	3.46^{a}	2.69^{c}
Mg (cmol/kg)	0.62^{a}	0.67^{a}	0.38^{b}	0.64^{b}	0.60^{b}	0.75^{a}
OC (%)	1.97^{b}	2.70^{a}	1.92^{b}	1.84^{b}	2.14^{a}	1.96^{ab}
C/N Ratio	10.94^{b}	15.88^{a}	9.14^{c}	11.50^{a}	11.89^{a}	4.56^{b}
pH (1:1 H_2O)	7.39^{b}	7.24^{c}	7.42^{a}	7.42^{b}	7.19^{c}	7.88^{a}

‡Data are means of four composite samples; WAC = Weeks after composting; Means within a row with different superscripts differ significantly (*P* = .05)

Table 4. ‡Chemical properties of soil coverings on layer manure pile

Parameters	2.8 kg soil			5.6 kg soil		
	3 WAC	6 WAC	9 WAC	3 WAC	6 WAC	9 WAC
Total N (%)	0.18^{a}	0.18^{a}	0.19^{a}	0.15^{a}	0.16^{a}	0.16^{a}
Available P (mg/kg)	47.90^{b}	50.71^{a}	40.00^{c}	50.80^{a}	43.20^{b}	26.40^{c}
K (cmol/kg)	1.08^{c}	1.49^{b}	1.63^{a}	0.58^{c}	1.11^{a}	1.02^{b}
Na (cmol/kg)	0.67^{c}	1.11^{a}	0.91^{b}	0.39^{b}	0.59^{a}	0.67^{a}
Ca (cmol/kg)	3.02^{b}	4.41^{a}	3.07^{b}	3.29^{a}	3.46^{a}	2.69^{b}
Mg (cmol/kg)	0.62^{a}	0.67^{a}	0.38^{b}	0.64^{b}	0.62^{b}	0.75^{a}
OC (%)	1.97^{b}	2.70^{a}	1.92^{b}	1.84^{c}	2.04^{a}	1.96^{b}
C/N Ratio	10.94^{b}	15.00^{a}	10.11^{b}	12.27^{b}	12.75^{a}	12.25^{b}
pH (1:1 H_2O)	7.53^{b}	6.85^{c}	8.34^{a}	7.08^{b}	6.81^{c}	7.29^{a}

‡Data are means of four composite samples; WAC = Weeks after composting; Means within a row with different superscripts differ significantly (*P* = .05)

The results showed that the time of composting affected the nutrient composition of the soil coverings of the manure piles. The results showed that the chemical properties of the soil coverings on both manure piles, with the exception of Mg in both, and C/N in the layer manure pile covering increased throughout the composting period (Tables 3 and 4). On the other hand, Mg and C/N ratios of the soil decreased with time in the case of the layer manure pile soil coverings. Organic carbon was highest (*P* = .05) at 6 weeks after composting (WAC) in the soil coverings on both manure piles. The increase in pH observed in the soil coverings resulted from the entrapment of volatilized N from the manure piles. This could also explain the observed increase in total nitrogen content of the soil coverings, since under high pH conditions, bacteria activity is reduced with a consequential increase in the nitrification of organic matter [20]. The 5.6 kg soil was the most efficient in tapping gaseous N from both manure piles.

Enrichment ratio (ER) defined as the ratio of the concentration of nutrient in the soil after composting to the concentration of the nutrients in the soil before composting, was used to evaluate N and OC enrichments in the soil covering. An ER greater than 1.0 indicated enrichment. In respect of the broiler manure, the enrichment ratios of C and N at 3, 6 and 9 WAC were 0.99, 1.36, and 0.97 kg, and 1.38, 1.31 and, 1.6, respectively for the 2.8 kg soil covering, and 0.92, 1.08, 0.99 and 1.23, 1.38, 3.3, respectively for 5.6 kg soil cover. For the layer manure, the enrichment ratios of the for the 2.8 kg soil cover at 3, 6 and 9 WAC were 0.98, 1.35 and 0.96, and 1.38, 1.38, and 1.46 for OC and N, respectively. Conversely, the ER of OC and N were 0.92, 1.02, and 0.98, and 1.15, 1.23, and 1.23, respectively for the 5.6 kg soil. Thus, covering the poultry manure with soil was beneficial with respect to nitrogen over the entire composting period for both manures. The ER of N was generally higher in the 5.6 kg soil covering on the broiler manure pile, and the 2.8 kg soil on the layer manure pile. This could have resulted from the entrapment of N and CO_2 released from the manure piles during the composting process. It also appeared that the evolution and entrapment of CO_2 from both manure piles peaked at 6 WAC, thus increasing the C content of the soil coverings. However, before 3 WAC and after 6 WAC, the C contents of the soil coverings remained fairly stable and were lower than the initial levels.

The reduction in the C/N ratio of the soil coverings during composting indicates an enhanced quality due to N enrichment. There was a fluctuation in the C/N ratio (rise and fall) during the period of composting for both 2.8 kg soil and 5.6 kg soil covers. At 9 WAC, both levels of soil covering had reduced C/N ratios, with the broiler manure pile showing a drastic reduction. This was an indication of the extent of decomposition of the initial C-rich material. This could be attributable to the mineralisation of organic matter resulting in the evolution of CO_2 and heat [21]. In addition, apart from the total N and C, the 2.8 kg soil, and 5.6 kg soil coverings were also significantly enriched in available P and other nutrients; available P was higher before 9 WAC in the soil coverings for both broiler and layer manure piles.

3.4 Chemical enrichment sawdust used as covering material

The nutrients content of the sawdust as affected by composting are presented in Table 5. The results show that composting of both broiler and layer manure resulted in increased N, Ca, Mg and K contents of the sawdust, whereas, Na and C/N ratio reduced as time elapsed. On the other hand, contrasting results were observed for available P, OC and pH, wherein, broiler manure was observed to increase OC, but reduced P and pH in the sawdust, and vice versa, in the case of the layer manure.

Table 5. ‡Chemical properties of the sawdust covering on both broiler and layer manure piles

Parameters	Broiler manure			Layer manure		
	3 WAC	6 WAC	9 WAC	3 WAC	6 WAC	9 WAC
Total N (%)	1.40^{a}	0.58^{b}	0.60^{b}	2.46^{a}	2.37^{b}	2.35^{b}
Available P (mg/kg)	0.40^{a}	0.10^{b}	0.10^{b}	1.44^{b}	1.57^{a}	1.46^{b}
K (cmol/kg)	0.38^{a}	0.33^{b}	0.34^{b}	2.96^{a}	2.97^{a}	3.00^{a}
Na (cmol/kg)	0.25^{a}	0.18^{b}	0.20^{ab}	0.26^{a}	0.28^{a}	0.26^{a}
Ca (cmol/kg)	0.59^{a}	0.56^{a}	0.54^{a}	1.27^{c}	1.43^{b}	2.39^{a}
Mg (cmol/kg)	0.54^{a}	0.60^{a}	0.53^{a}	1.26^{c}	2.88^{b}	3.46^{a}
OC (%)	48.81^{a}	47.11^{a}	45.08^{b}	33.70^{a}	32.30^{a}	30.60^{b}
C/N Ratio	34.86^{c}	81.22^{a}	75.13^{b}	13.69^{a}	13.62^{a}	13.02^{b}
pH (1:1 H_2O)	7.13^{a}	7.05^{a}	7.09^{a}	8.55^{b}	8.73^{b}	9.56^{a}

‡Data are means of four composite samples; WAC = Weeks after composting; Means within a row with different superscripts differ significantly (*P* = .05)

The trend of the results, however, showed that the C content trapped in the sawdust from the manure piles were highest (*P* = .05) at 3 and 6 WAC. In a similar manner, N trapped from both manures piles were higher at 3 WAC. The decrease in N content after 3 WAC may be attributed to immobilisation of NH_4^+ by the microorganisms with time. This could have resulted from low the N relative to C, resulting in the immobilization of N in the microbial biomass during decomposition of C-rich materials [22], and the utilization of microbial N by other microorganisms when they die. This is a clear indication that the entrapment by the sawdust of volatilized N from both manures piles resulted in increased amount of N in the sawdust compared to the soil coverings. These observations suggest that sawdust covering could be an effective approach to minimizing C and N losses from manure heaps.

3.5 Nitrogen losses during composting

Gaseous losses of N during composting of were quantified in this study. The results were obtained by subtracting N content of the compost from the initial amount of N in the manure before composting. The total amount of N lost under the various treatments are presented in Figure 3.

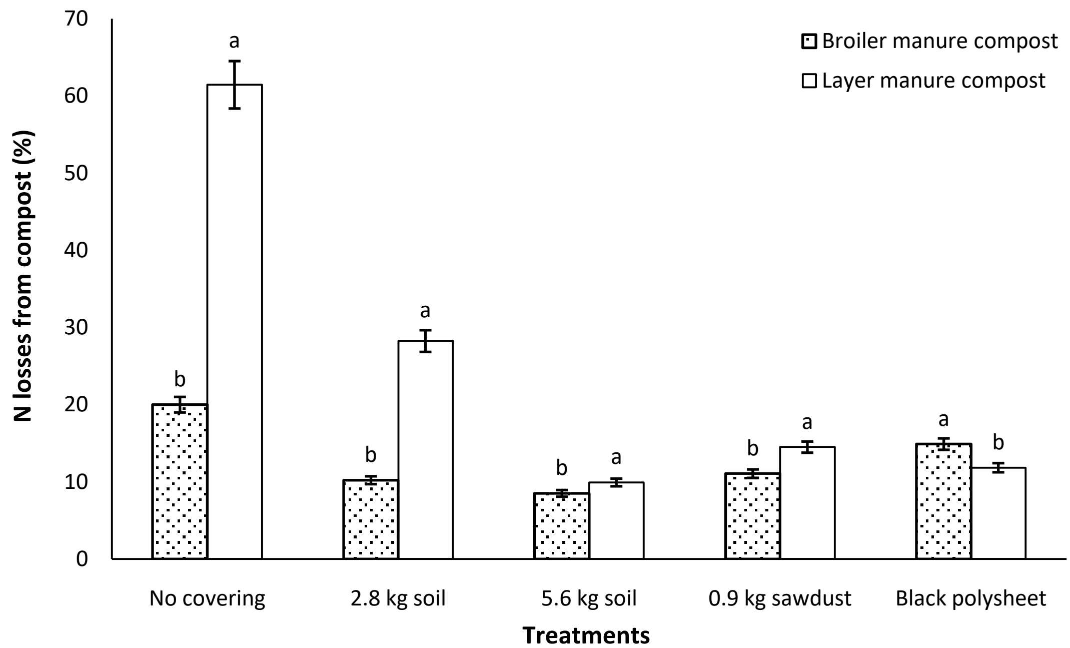

Figure 3. Nitrogen losses from broiler and layer manure compost piles by different covering materials at 9 WAC (*P* = .05)

Evidently, N losses from both manure piles were highest (*P* = .05) under the no covering treatment and lowest under the 5.6 kg soil covering. The N losses from the broiler manure ranged between *ca*. 9 to 20%, and from the layer manure, *ca*. 10 to 62%. Obviously, N losses from the layer pile were significantly higher than from the broiler manure pile under the various treatments. These variations in the volatilization losses of N from the manure piles under the different treatments greatly depended on the balance with available carbon [23, 24] and oxygenation level [25].

The higher (*P* = .05) losses of N from the layer manure pile could be attributed to its relatively lower C/N ratio in relative to the broiler pile since high C/N ratio significantly reduces N losses during storage and composting of livestock solid manure [26]. The losses from the manure piles agree well with reports by several studies. For instance, Hansen et al. [27, 28] reported N losses of 33% and 31% during the composting of layer manure and straw. Bonazzi et al. [29] also reported N losses between 50 to 63%. Mahimairaja et al. [30] measured a 17% loss of N during composting of fresh chicken manure. Thus, the results from the current study corroborates the reports by Martins and Dewes [19], Rao Bhamidimarri and Pandey [31], and Tiquia and Tam [32], who concluded that *ca*. 20 to 77% of the initial N of the manure could be lost during composting

The relative abilities of the different covering materials to reduce N losses (i.e., trap N gases) from both broiler and layer manure piles are presented in Figure 4.

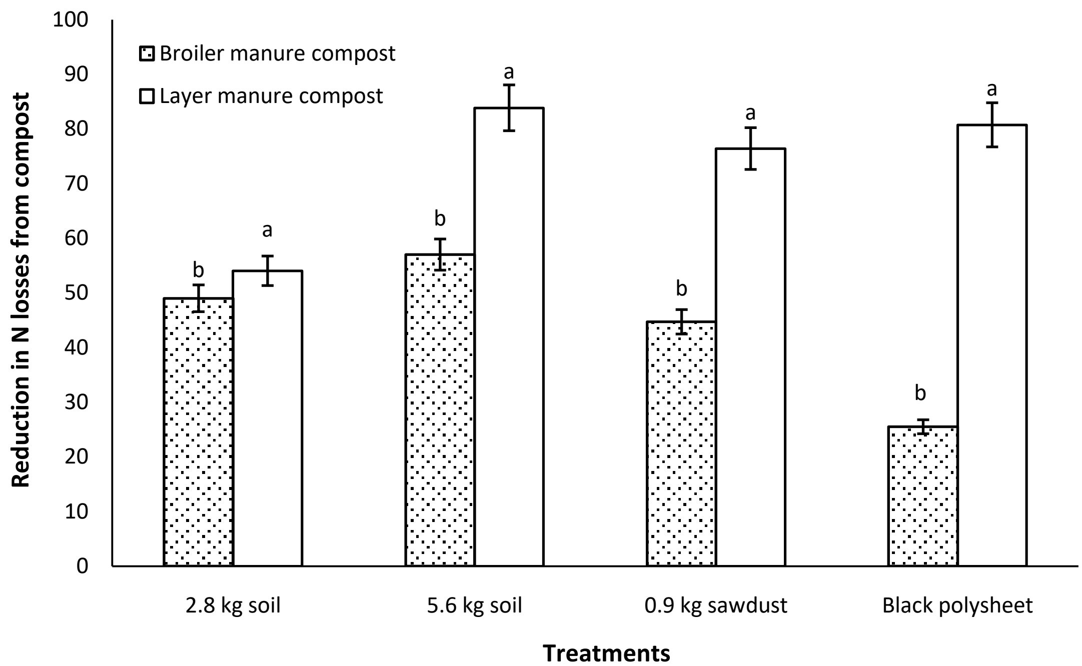

Figure 4. Reduction in Nitrogen losses from broiler and layer manure piles by different covering materials at 9 WAC (*P* = .05)

With regard to the broiler manure pile, reduction in N losses was observed to be in the order of 5.6 kg soil (57%) > 2.8 kg soil (49%) > 0.9 kg sawdust (44.7%) > black polythene sheet (25.5%). For the layer manure compost, reduction in N losses was in the order of 5.6 kg soil (83.85%) > black polythene sheet > (80.74%) > 0.9 kg sawdust > (76.40%) > 2.8 kg soil (54.03%). Overall, composting with 5.6 kg soil as covering material significantly reduced ($p < 0.05$) the loss of nitrogen from both piles; reductions from the layer manure was, however, relatively higher ($P = .05$). This result is similar to what was observed by Gotaas [6] that N loss can also be reduced by adding soil to manure or covering the heap with soil. Interestingly, the reduction in N losses (i.e., level of trapped N) from the layer manure by the covering materials was higher compared to the broiler manure. This could be due to the relatively higher initial amount of N in the layer manure pile, and also the high C/N ratio of the sawdust and soil coverings on the layer manure pile.

4. CONCLUSION

Following the composting of layer and broiler poultry manures, the chemical properties of both sawdust and soil covering were highly enhanced. With the exception of Mg (for both) and C/N ratio (for layer manure) of the two levels of soil used as covering were enhanced. The ER of N was generally greater in the 5.6 kg soil cover than the 2.8 kg soil. During composting the 5.6 kg soil covering greatly reduced N losses by 57 and 83.85% from the broiler and layer piles, respectively. Although the sawdust had highest nitrogen content, compared to the soil, 5.6 kg soil is recommended due to its high ER, and the high C/N ratio of sawdust (> 30) throughout the composting period.

REFERENCES

1. Gajdos R. The use of organic waste materials as organic fertilizers-recycling of plant nutrients. Acta Hort. 1992; 302: 325-331.
2. Zhao Z, Knowlton KF, Love NG. Hormones in waste from concentrated animal feeding operations. 291-329pp. In: D.S. Aga editor. Fate and transport of pharmaceuticals in the environment and water treatment systems. 1st ed. CRC Press, 2008; Boca Raton, FL.

3. Tiquia SM, Richard TL, Honeyman MS. Effects of windrow turning and seasonal temperatures on composting of hog manure from hoop structures. Environ. Techn. 2000; 21: 1037-1046.
4. Anonymous. Natural rendering: Composting livestock mortality and butcher waste. Cornell Waste Management Institute. 2002.
5. Subair S, Fyles JW, O'Halloran IP. Ammonia volatilization from liquid hog manure amended with paper products in the laboratory. J. Environ. Qual. 1999; 28: 202-207.
6. Gotaas HB. Composting Sanitary Disposal and Reclamation of organic waste. World Health Organisation, Monograph 31. Geneva, Switzerland. 1956.
7. Kirchmann H, Lundvall A. Treatment of solid animal manures; identification of low NH_3 emission practices. Nut. Cyc. Agro. Ecosys. 1998; 51: 65-71.
8. Nommik H, Vahtras K. Retention and fixation of ammonium and ammonia in soil, Nitrogen in Agricultural soil. In: Stevenson FJ editor. Agronomy Monograph Nozz, American Society of Agronomy, Madison, Wisconsin. 1982; Pl 23-252.
9. Soils Laboratory Staff. Royal Tropical Institute. Analytical methods of the service laboratory for soil, plant and water analysis. Part 1: Methods for soil analysis. Royal Tropical Institute. Amsterdam, 1984.
10. Bray RH, Kurtz LT. Determination of total, organic and available forms of phosphorus in soil. Soil Sci. 1945; 599: 39-45.
11. Nelson DW, Sommers LW. Total carbon, organic carbon, and organic matter. *In*: Page, A.L., R.H. Miller, and D.R. Keeney (eds.). Methods of soil Analysis. 2. Chemical and Microbiological properties. Agron. 1982; 9: 301-312.
12. Boyoucos GJ. Hydrometer methods improved for making particle size analysis of soils. Proc Soil Sci. Soc. Am. 1962; 26: 464-465.
13. van Faassen HG, van Dijk H. Manure as a source of nitrogen and phosphorous in soils. In: Meer van der HG, Unwin RJ, Dijk van TA and Ennik GC editors. Animal Manure on Grassland and Fodder Crops: Fertilizer or Wastes? Martinus Nijhoff Publishers, Dordrecht. 1987; 27-45pp.
14. Hellmann B, Zelles L, Palojärvi, A, Bai Q. Emission of climate-relevant trace gases and succession of microbial communities during open-windrow composting. Appl. Environ. Microbiol. 1997; 63: 1011-1018.
15. Sommer SG. Effect of composting on nutrient loss and nitrogen availability of cattle deep litter. European J. Agron. 2001; 14: 123-133.
16. Adhikari BK, Barrington SF, Martinez J, King S. Effectiveness of three bulking agents for food waste composting. Waste Man. 2013; 29: 197-203.
17. Oviedo-Ocaña R, Marmolejo-Rebellón LF, Torres-Lozada F, Daza M, Andrade M, Torres-López WA and Abonia-Gonzalez R. Effect of adding bulking materials over the composting process of municipal solid biowastes. Chilean J. Agric. Res. 2015; 75 (4): 472-480.
18. Barrington S, Choinière D, Trigui M, Knight W. Compost convective airflow under passive aeration. Biores. Technol. 2003; 86: 259-266.
19. Khater EG, Bahnasawy AH, Ali SA. Mathematical model of compost pile temperature prediction. J. Environ. Anal. Toxicol. 2014; 4(6): 1-7.
20. Landon JR. Booker Tropical Soil Manual a Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics, Longman Scientific and Technical Co-published in the United State with John Wiley and Sons Inc., 605 third avenue, New York, NY 10158. 1991; 109-117pp.
21. Said-Pullicino D, Erriquens FG, Gigliotti G. Changes in the chemical characteristics of water-extractable organic matter during composting and their influence on compost stability and maturity. Biores. Techn. 2007; 98(9): 1822-1831.
22. Witter E, Lopez-Real JM. The potential of sewage sludge and composting in a nitrogen recycling strategy for agriculture. Biol. Agric. Hort. 1987; 5(1): 1-23.
23. Martins O, Dewes T. Loss of nitrogenous compounds during composting animal wastes. Biores. Technol. 1992; 42: 103-111.
24. Rynk R, van de Kamp M, Willson GB, Singley ME, Richard TL, Kolega JJ, Gouin FR, Laliberty Jr L, Day K, Murphy DW, Hoitink HAJ and Brinton WF. On-Farm Composting Handbook. NRAES, Cornell University, Ithaca, New York, USA, 1992; 186 pp.

25. Michel Jr FC, Reddy CA. Effect of oxygenation level on yard trimmings composting rate, odor production, and compost quality in bench-scale reactors. Compost Sci. Util. 1998; 6: 6-14.
26. Kirchmann H. Losses, plant uptake and utilisation of manure nitrogen during a production cycle, Acta Agric. Scand. Suppl. 1985; 24.
27. Hansen RC, Keener HM, Hoitink, HAJ. Poultry manure composting – an explanatory study. Trans. ASAE. 1989; 36: 2151-2157.
28. Hansen RC, Keener HM, Dick WA, Marugg C, Hoitink, HAJ. Poultry manure composting: ammonia capture and aeration control. Paper No. 90-4062, ASAE, St. Joseph, MI. 1990.
29. Bonazzi G, Vialli L, Piccinini S. Controlling ammonia emission at composting plants. BioCycle. 1990; 31: 68-71.
30. Mahimairaja S, Bolan, NS, Hedley, MJ, Macgregor, AN. Losses and transformation of nitrogen during composting of poultry manure with different amendments: an incubation experiment. Biores. Technol. 1994; 47: 265-273.
31. Rao Bhamidimarri SM, Pandey SP. Aerobic thermophilic composting of piggery solid wastes. Water Sci. Technol. 1996; 33(8): 89-94.
32. Tiquia SM and Tam NFY. Fate of nitrogen during composting of chicken litter. Environ. Pollut. 2000; 110: 535-541.