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# Effect of Partially Covering Turkey Litter Surface on Ammonia Emission

H. Justin Chepete  
*Iowa State University*

Hongwei Xin  
*Iowa State University, [hxin@iastate.edu](mailto:hxin@iastate.edu)*

Hong Li  
*Iowa State University*

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## **Abstract**

Volatilization and ammonia (NH<sub>3</sub>) gas emission rate (ER) from poultry manure or litter is influenced by numerous factors including the nature and area of the emitting surface. In this study, the effect of the amount of exposed surface area of turkey litter on NH<sub>3</sub> emission was investigated. Samples of turkey litter were obtained from stockpiled litter for a turkey growout barn. The study was conducted in four environmentally-controlled emission chambers maintained at  $21 \pm 1$  °C and a concomitant relative humidity of  $50 \pm 5$ %. Four different treatments were investigated where 0% (Control), 25%, 50% and 75% of the litter surface area was covered with plywood boards. The boards were periodically shifted to different positions to simulate movement of the turkeys in the barn. The NH<sub>3</sub> concentration, litter temperature, air temperature and airflow rate through each chamber were measured continuously over a 6-d experimental period and replicated 3 times. NH<sub>3</sub> ER was calculated from the concentration and air-flow data. The results revealed that the initial placement of the covers on the litter suppressed NH<sub>3</sub> ERs to varying degrees. The covers served as physical barriers to NH<sub>3</sub> emission and tended to temporarily reduce and delay of the emission but did not affect the overall total NH<sub>3</sub> emission. Periodic shifting of the covers resulted in the escape of NH<sub>3</sub> trapped underneath the covers resulting in similar overall NH<sub>3</sub> ERs among the different treatments. The NH<sub>3</sub> ER was linearly related to litter temperature, moisture content, storage time and pH and these relationships have been developed.

## **Keywords**

Ammonia emission, turkey litter, litter cover, surface area

## **Disciplines**

Bioresource and Agricultural Engineering

## **Comments**

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2950 Niles Road, St. Joseph, MI 49085-9659, USA  
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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**Paper Number: 1009788**

## **Effect of Partially Covering Turkey Litter Surface on Ammonia Emission**

**Justin H. Chepete, Ph.D.**

Department of Agricultural Engineering and Land Planning, Botswana College of Agriculture, Private Bag 0027, Gaborone, Botswana (visiting professor at Iowa State University). Email: hchepete@yahoo.com

**Hongwei Xin, Ph.D.**

Department of Agricultural & Biosystems Engineering, 3204 NSRIC, Iowa State University, Ames, Iowa, 50011. Email: hxin@iastate.edu

**Hong Li, Ph.D.**

Department of Agricultural & Biosystems Engineering, 1242 NSRIC, Iowa State University, Ames, Iowa, 50011. Email: lwblue@iastate.edu

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## Introduction

In the United States, turkeys are reared under two main management systems: brooding (reared from day-old poults to nearly 5-6 weeks of age in a brooder house) and growout (period after brooding when turkeys are moved into growout house and reared until they reach market weight). During the growout period, the floor of the growout house is covered with bedding such as sawdust, rice hulls, or wheat straw. Over time, the bedding gets mixed with turkey manure producing litter. With addition of moisture from manure and drinking systems, ammonia ( $\text{NH}_3$ ) gas is volatilized. The litter is removed from the houses after the birds are removed for the market and is often stockpiled before being land applied.

The main manure or litter characteristics that determine  $\text{NH}_3$  volatilization are the total concentration of ammoniacal nitrogen ( $\text{TAN} = \text{NH}_4^+ + \text{NH}_3$ ), pH and dry matter content (Jarvis and Pain, 1990; Sommer and Husted, 1995), air velocity, the emitting surface, and concentration of urea in urine (Van der Peet-Schwering et al., 1999). The amount of emitting surface area greatly influences the  $\text{NH}_3$  emission rate. Several studies have been conducted that investigated the effect of covers on manure stores to reduce  $\text{NH}_3$  emission. Most of these studies involved fully covering pig slurry manure with different materials over 15 to 25 d (Portejoie et al., 2002; Hornig et al., 1999). Similar information for turkey litter has not been found in the literature. In the turkey barns, at night the birds tend to crowd in certain locations in the barn and sleep (thereby exhibiting some cover over the litter) while they spread out during the day as they feed and move about (thereby exhibiting some "shifting" of the cover). At the end of each growout, the caked litter (hardened surface layer especially along the feed and water lines) is removed from the barns and stockpiled on-farm without being covered. At the end of multiple growouts, a complete cleanout may be performed and the litter added to a stockpile or land applied.

Ammonia emissions for broiler and turkey barns have been observed to increase with time to certain age and then started to decrease with bird age (Burns et al., 2007; Li et al., 2008; Li et al., 2010). A speculation was that the decreased  $\text{NH}_3$  emission might stem from the increased coverage of the litter by the birds and the less movement of the birds as body weight increased. However, no quantitative data were available to validate or invalidate such speculation. A study is needed to document the patterns of  $\text{NH}_3$  emission rate as the turkeys sit and/or move about in the barn. Hence, the objective of this study was to determine (i) the effects of the amount of surface area coverage of poultry (turkey) litter on  $\text{NH}_3$  emission rate; (ii) the effect of periodic shifting of the covers on  $\text{NH}_3$  emission rate, if any; and (iii) the relationship between  $\text{NH}_3$  emission rate and litter temperature, moisture content (MC), pH and storage time.

## Materials and Methods

### *Measurement system*

The Livestock Environment and Animal Physiology (LEAP) Laboratory of Iowa State University was used to measure the  $\text{NH}_3$  emission of the turkey litter. The system (fig. 1) consisted of the following major components: four positive pressure individually-controlled environmental chambers (1.5 m W × 1.8 m L × 1.8 m H each); an air handler with capacity of 850 m<sup>3</sup>/hr (Model Climate-Lab-AA, Parameter Generation & Control or PGC, Black Mountain, NC); a dew point hygrometer (Model 2001, EG&G Moisture and Humidity Systems, Burlington, MA); an advanced photoacoustic multi-gas analyzer (Model 1314, INNOVA, Denmark); a barometric pressure sensor (Model CD105, Campbell Scientific Inc, Logan, UT); four thermoelectric air

mass flowmeters, one per chamber (Model LS-4F, Teledyn Hastings-Ravidist, Hampton, VA); a

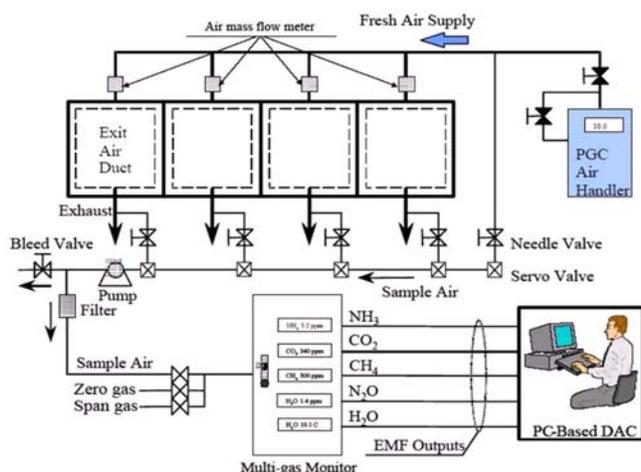


Figure 1. Schematic representation of environmentally-controlled emission measurement chamber system.

teflon diaphragm pump (Catalog L-79200-30, Cole-Parmer Instruments Co.); and a PC-based environmental control and data acquisition system (Model CR10, Campbell Scientific Inc., Logan, UT). More description and applications of the system can be found in previously reported studies (Xin and Harmon, 1996; Xin et al., 1996, 1998; Chepete et al., 2004; Green and Xin, 2009).

The fresh air was heated to the desired temperature of the chamber by two 1500 W electric heater/fan units (Model 3VU37, Grainger) located in the plenum space of the air inlet and the porous ceiling of the chamber. An air distribution duct was located along the perimeter of the chamber near the litter surface to enhance uniform mixing of the outgoing air. Electric heating cords (Cat No. H-03122-24, Cole Parmer Instruments Co.) in conjunction with a variable power controller (Model 2604-00, Cole Parmer Instrument Co.) were used to prevent moisture condensation inside the air sampling line (1/4 inch OD and 1/8 ID FEP tubing). Air samples from the four chambers and the fresh air were controlled by the control and data acquisition system-operated solenoid valves. Air sampling was performed at 6-min intervals, with the first 5 min used for purging and stabilization and the last 1 min used for data acquisition.

The data acquisition system took measurements every 2 s and stored the 1-min averages. The INNOVA 1314 analyzer was checked weekly with certified grade calibration gases (Matheson Gas Products, Inc., Chicago, IL). If the reading of the analyzer was out of  $\pm 2\%$  span gas range, the instrument would be recalibrated. CR10 program was used to run the control and data acquisition system and it performed: sequential and independent sampling and measurement of fresh air and exhaust air from individual chambers; continuous measurement of air-flow rate through each chamber; continuous measurement of fresh air and chamber air temperature, relative humidity (RH), dew-point temperature, barometric pressure, and turning the space heaters on and off as needed to maintain the desired chamber temperatures.

### **Litter handling**

Samples of turkey litter was obtained from a commercial turkey farm and used in the experiment. The litter comprised of about 67% oat hulls and 33% saw-dust and was from a growout barn that had both toms (80%) and hens (20%) reared together for fourteen (14) weeks. The litter had been removed and stockpiled in the open space next to the barn after the turkeys were marketed. Upon arrival at the LEAP Laboratory, the litter was placed on the concrete floor of the lab and thoroughly mixed before placement into the 4 environmentally-controlled calorimeter chambers. A rectangular wooden frame measuring 1.50 m L × 1.45 m W was put in each chamber where the litter was placed to a depth of 7 cm. The frame was wrapped with a thin plastic membrane to prevent absorption of the litter moisture by the wood material. Four 15.2 kg samples of litter were collected into separate buckets and each randomly placed in the chambers and spread evenly. This process was repeated 5 times, thus each chamber contained 76 kg of litter. Between each of the 5 placement sessions, the left-over litter was thoroughly mixed before filling up the buckets. A garden fork and rake was then used to further mix and level the litter in each chamber after placement was completed.

In each chamber, two temperature probes (Model TMC6-HA, Onset Computer Corporation, Bourne, Mass.) connected to a HOBO data logger (Model H08-006-04, Onset Computer Corporation) were inserted 5 cm into the litter at random positions to measure the litter temperature once every 30 min. One 105 CFM stirring axial fan (Model 4WT47, Dayton Electric Mfg. Co., Niles, IL) was placed in each chamber to enhance mixing of the air in the chamber.

### **Litter coverage treatments**

The treatments involved covering the litter surface with plywood boards such that 0 (Control), 25, 50 or 75% of the litter surface area was covered. The boards (54.7 cm L × 50.0 cm W × 0.64 cm H) were wrapped with a thin plastic film to avoid moisture absorption from the litter. A total of 2, 4, and 6 board covers were used in the 25, 50 and 75% cover treatments. The NH<sub>3</sub> concentration, litter temperature, air temperature and airflow rate through each chamber were measured continuously over a 6-d period. During the 1<sup>st</sup> day, the litter in all chambers was not covered to obtain the baseline emission data. In the following 3 days, the treatments were randomly allocated to the chambers. During this period, 3 times a day (0800h, 1300h and 1800h), the covers were randomly shifted to different positions to simulate turkey movement. On the 5<sup>th</sup> day, all the covers were removed until the end of the experiment.

At the end of the 6<sup>th</sup> day, all the litter in the chambers was removed and stockpiled on the floor awaiting the next trial the following day. In the next trial, nearly half of the litter was removed, disposed off and replaced with similar quantity of new litter. The new and old litter were then thoroughly mixed and placed back in the chambers following the same procedures as outlined above. This was done in all subsequent trials. A total of 4 trials were conducted with treatments randomly allocated to the chambers each time. The environmental conditions inside the chambers were maintained at 21±1°C and a concomitant RH of 50±5% in all trials.

Once each day of the experimental period, the litter in each chamber was sampled and used for pH and MC determination at the Iowa State University Waste Management Laboratory. Sampling was carried out by use of a hollow cylindrical metallic core inserted to the bottom of the litter to extract a sample. This was done at five different positions in each chamber or treatment. A composite sample for each treatment was made by thoroughly mixing all five samples and one subsample was removed, placed in a plastic ziplock bag, and carried to the laboratory for immediate analyses. This was done in each of the four trials conducted. The pH was determined using the pH meter (Model AB15 Plus Accumet® Basic, Fisher Scientific Inc., USA) by mixing 20 g of litter with 40 ml of distilled water and taking measurements after 45 min.

The MC was determined using the standard oven drying method at 105°C over a 24-hr period (AOAC, 1990 method number 934.01).

### **Calculation of ammonia emission rate**

The NH<sub>3</sub> emission rate (ER<sub>NH<sub>3</sub></sub>, g·hr<sup>-1</sup>·kg<sup>-1</sup> litter) was calculated as follows:

$$ER_{NH_3} = \{[NH_3]_e - [NH_3]_i\} \times 10^{-6} \times \frac{Q}{M} \times \frac{17.031 \text{ g/mol}}{0.0224 \text{ m}^3/\text{mol}} \quad (1)$$

where [NH<sub>3</sub>]<sub>e</sub>, [NH<sub>3</sub>]<sub>i</sub> is the NH<sub>3</sub> concentration at the exhaust and inlet air, respectively (ppm<sub>v</sub>), Q is the ventilation rate (m<sup>3</sup>·hr<sup>-1</sup>·chamber<sup>-1</sup>) at standard temperature (0°C) and pressure (1 ATM) (STP), and M is the initial mass of litter in the chamber (kg).

### **Experimental design and data analysis**

The experiment may be described in two parts: a Completely Randomized Block Design where the four experimental trials were blocks and the chambers within each trial (that were randomly assigned treatments) were the experimental units; and repeated measures were undertaken in each chamber over a 6-d period. Analysis of variance (ANOVA) was conducted on the data using Proc Mixed procedure of Statistical Analysis Systems (SAS) software (SAS 2008, SAS Institute Inc., Cary, NC) to determine treatment effects on NH<sub>3</sub> ER. A regression analysis was performed to determine the relationship between NH<sub>3</sub> ER and litter temperature, MC, pH and storage time.

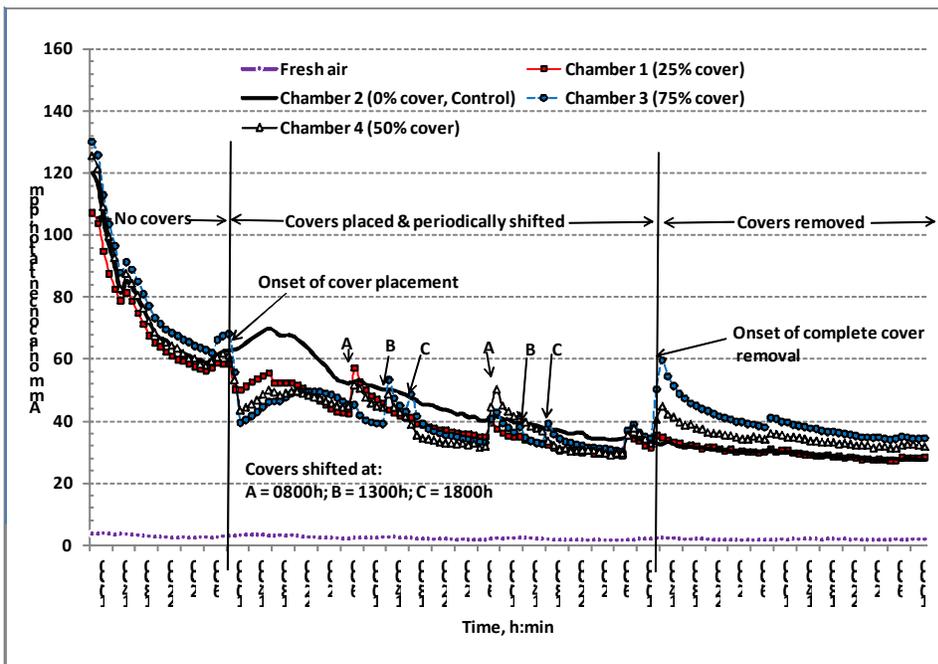
## **Results and Discussions**

### **Dynamic ammonia concentration and emission profiles**

Figures 2 and 3 show typical dynamic NH<sub>3</sub> concentration and emission profiles of the turkey litter over a 6-d monitoring period for each of the four treatments. In all the four trials conducted, there were instant suppressions in the NH<sub>3</sub> concentration (fig. 2) and emission (fig. 3) when the board covers were placed on the litter surfaces. This was probably caused by a reduction in the NH<sub>3</sub> emitting surface area of the litter due to placement of the covers. The covers acted as physical barriers and they stopped or reduced the air movement over the litter surface and increased the surface's resistance to ammonia volatilization (Portehoie et al., 2002). The suppressions, relative to the 0% surface coverage, ranged from 7 to 14%, 24 to 31% and 35 to 43% for the 25%, 50% and 75% surface coverage treatments, respectively. After sometime, the NH<sub>3</sub> concentration and emission rate gradually increased. Using a tent, floating foil, corrugated sheets and expanded polystyrene to cover pig slurry tanks, De Bode (1991) reported NH<sub>3</sub> emission reductions of 70-90%.

When the board covers were shifted, the NH<sub>3</sub> concentration and emission rate instantaneously rose in magnitude and subsequently declined, approaching the levels recorded before the boards were shifted. This trend occurred throughout all the moments when the board covers were shifted and the instantaneous NH<sub>3</sub> concentration and emission rate rises differed in magnitude from one shift moment to the other (figs. 2 and 3). The transfer of NH<sub>3</sub> from manure surface to free air is dependent on air velocity and temperature. As the air velocity increases, the boundary layer at the manure free air interface gets thinner resulting in lower resistance to the volatilization process thereby leading to higher mass transfer coefficient and mass transfer rate (Arogo et al., 1999). The NH<sub>3</sub> release flux is essentially a function of the convective mass transfer coefficient, the concentration of NH<sub>3</sub> in the gaseous phase at the manure surface and concentration of NH<sub>3</sub> gas in the free air stream (Ni, 1999). As such, shifting the covers exposed

surfaces to higher air velocity resulting in rapid ammonia volatilization. In this study the air velocity over the litter surface ranged from 0.032 to 0.036 m/s.



Comment [HX1]: Please fix the figure per our discussion

Figure 2. Typical dynamic ammonia concentration profile of the turkey litter as affected by dynamic, partial surface coverage over a 6-d period.

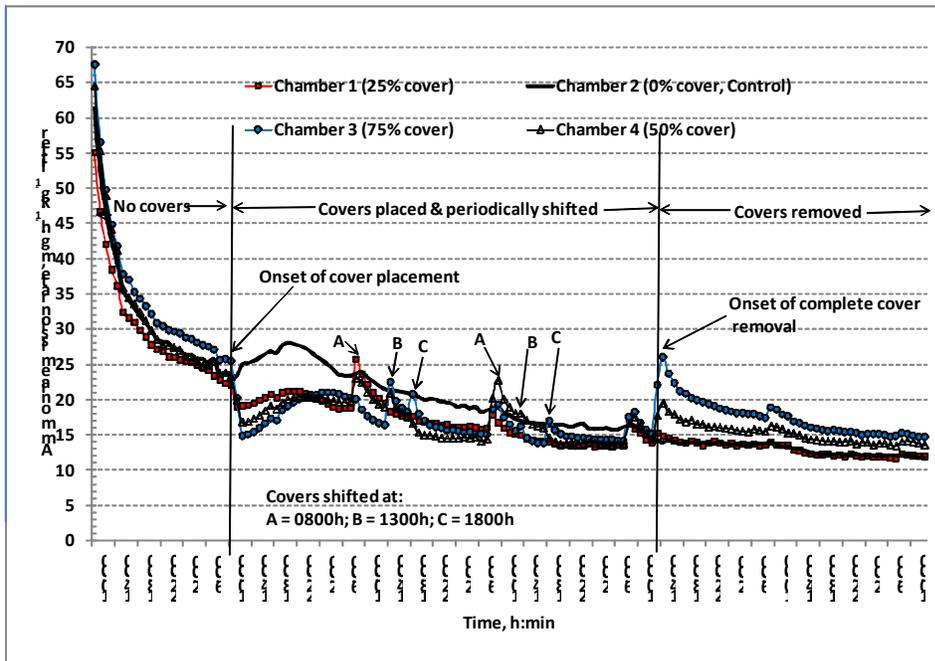


Figure 3. Typical dynamic ammonia emission rate profile of the turkey litter as affected by dynamic, partial coverage over a 6-d period.

It was observed when shifting the covers that the covered litter surface tended to get wet due to moisture condensation on the underside of the board covers. This moisture may have enhanced  $\text{NH}_3$  volatilization (Pratt et al., 2002) that became trapped underneath the covers and released once the covers were shifted. The  $\text{NH}_3$  ER instantaneously rose by 4 to 38%, 12 to 78% and 21 to 155% for the 25, 50 and 75% surface coverage, respectively, upon shifting of the covers. This is logical because the 75%-coverage covered the largest surface area and thus trapped more  $\text{NH}_3$  than the smaller counterparts. The highest instantaneous rises were experienced at the 0800h shift sessions while lower values were experienced either at 1300h or 1800h. The higher values in the mornings might have been caused by longer hours (1800h to 0800h or 14 hr) over which the litter was covered when compared the shorter coverage period for the other time periods (0800h to 1300h or 1300h to 1800h or 5 hr). The longer coverage period allowed for more  $\text{NH}_3$  trapping and volatilization beneath the covers.

The overall trend of  $\text{NH}_3$  concentrations and emissions over a 6-d period was a gradual decrease as more and more  $\text{NH}_3$  was being volatilized and depleted in the litter. This gradual decrease was expected because as time progressed, the nutrient loading and carbon:nitrogen (C:N) ratio of the litter became limiting as a source of energy for microbial growth (Kirchman and Witter, 1989). During the last 2 days when the covers were removed, the  $\text{NH}_3$  ER tended to approach that of the Control as expected.

### **Daily ammonia emission rates**

Figure 4 shows the overall daily  $\text{NH}_3$  ERs of the four treatments averaged over 3 trials. The 4<sup>th</sup> trial was not included due to problems encountered during the trial. There were no significant

differences ( $p=0.9773$ ) in  $\text{NH}_3$  ER between the treatments. However, the mean values of all the treatments are presented in figure 4 for appreciation of the ER magnitudes. Shifting the covers to different positions allowed the trapped  $\text{NH}_3$  to escape, which effectively resulted in similar total  $\text{NH}_3$  emission in each day. Thorough mixing of the litter prior to distribution into the chambers ensured higher uniformity of the litter characteristics which may have further contributed to similarity in the  $\text{NH}_3$  ER between the treatments. The covers did not seem to affect overall total  $\text{NH}_3$  ER.

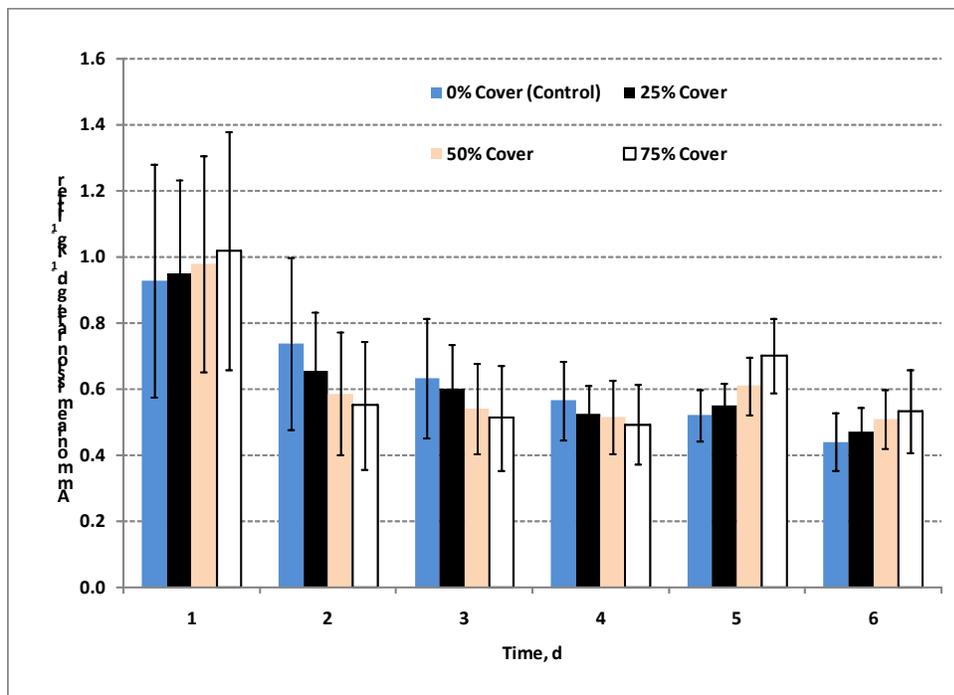


Figure 4. Overall daily ammonia emission rates of turkey litter as affected by dynamic, partial surface coverage (mean ± SE).

The covers tended to temporarily reduce and delay  $\text{NH}_3$  release into ambient air until when they were shifted.

Since the litter was porous, some volatilized  $\text{NH}_3$  under the covers may have diffused into the ambient air through the uncovered surface of the litter resulting in similar overall total  $\text{NH}_3$  emissions among the treatments. From the  $\text{NH}_3$  generation point in the litter,  $\text{NH}_3$  moves by molecular diffusion to the top surface where it constantly emits to the ambient air (Portejoie et al., 2002). The effect of day of monitoring largely depended on the treatment as indicated by the high significance level ( $p<0.0001$ ) of the interaction between the day and treatment. As the monitoring period progressed, more and more  $\text{NH}_3$  was volatilized and lost into the ambient air. This resulted in reduced  $\text{NH}_3$  ER especially in the first 2 days of the experiment. The ER appeared to stabilize from the 3<sup>rd</sup> to the 6<sup>th</sup> day (fig. 4) which may have caused similarity ( $P=0.0468$ ) in the overall  $\text{NH}_3$  emission over the experimental period. However, this trend was expected to gradually diminish if monitoring was done for a longer period due to depletion of nutrients by microbes responsible for  $\text{NH}_3$  production (Kirchman and Witter, 1989).

The results of the laboratory analyses showed that pH slightly increased with time. The pH was basic and averaged  $8.28 \pm 0.03$ ,  $8.32 \pm 0.04$ ,  $8.31 \pm 0.05$ ,  $8.33 \pm 0.04$  for the 0%-, 25%-, 50%- and 75%-cover, respectively. In solution, ammonium ( $\text{NH}_4^+$ ) exists in equilibrium with  $\text{NH}_3$  and this equilibrium is strongly pH dependent.  $\text{NH}_4^+$  is the predominant form of nitrogen under acidic and neutral conditions while  $\text{NH}_3$  is the predominant form at higher pH levels (Gay et al., 2006). The similarity in pH levels further explains why the treatments were similar in  $\text{NH}_3$  emissions. The high pH in the stored manure results in the majority of all nitrogen being lost as  $\text{NH}_3$  gas (Fowler et al., 1996) and the pH of 9 was found to be the optimum for the enzyme uricase, which is responsible for the initial aerobic breakdown of uric acid (Vogels and van der drift, 1976). Thus, the litter pH in this study was favorable for aerobic nitrogen decomposition.

The MC (as is) decreased as the monitoring period progressed and this result agrees with findings by Pratt et al. (2002). It averaged  $28 \pm 1\%$  in all the treatments. The moisture is important for microbial activity (Pratt et al., 2002) and ammonia loss from stored manure reduces when the MC falls below 30% (Carr et al., 1990). In this study, the MC was within limits that were suitable for high level of  $\text{NH}_3$  production in the first 3 days of monitoring and dropped to below 30% in the last 3 days and this may have reduced  $\text{NH}_3$  ER.

The litter temperatures decreased with time. Part of the heat in the litter was a result of microbial degradation of the dry matter of the litter that got depleted over time (Pratt et al., 2002) thereby resulting in reduced litter temperature and  $\text{NH}_3$  ER. The mean daily litter temperatures ranged from  $19.2$  to  $22.6^\circ\text{C}$ ,  $19.5$  to  $22.2$ ,  $19.6$  to  $23.7$ , and  $31.1$  to  $36.5$  for the 0%-, 25%-, 50%- and 75%-cover, respectively. The corresponding averages were  $20.9 \pm 0.6$ ,  $21.0 \pm 0.5$ ,  $21.4 \pm 0.6$  and  $33.7 \pm 0.8^\circ\text{C}$ , respectively. The highest litter temperature was recorded in the 75%-cover treatment. Due to the large surface area cover of this treatment, its litter may have had the lowest heat loss causing the litter to be warmer. In turn, this may have contributed to higher  $\text{NH}_3$  volatilization which got released upon shifting of the covers. Temperature has been reported to increase  $\text{NH}_3$  ER of pig slurry (Portejoie et al., 2002; Van der Peet-Schwering et al., 1999), dairy cow slurry (Van der Stelt et al., 2007), and laying-hen manure storage (Li and Xin, 2010). Pratt et al (2002) reported that the rate of volatile nitrogen loss increased curvi-linearly with storage temperature and the fastest rate occurred at temperatures greater than  $20^\circ\text{C}$ . Groot Koerkamp (1994) also observed an increased decomposition rate of uric acid at temperatures greater than  $20^\circ\text{C}$ . In this study, the ambient and litter temperature averaged higher than  $20^\circ\text{C}$ .

Figure 5 shows the overall mean cumulative  $\text{NH}_3$  ER of the 4 treatments. As with the daily ERs, there was no significant difference ( $p=0.8651$ ) in cumulative  $\text{NH}_3$  emission between the treatments due to reasons earlier advanced. By the 6<sup>th</sup> day, the cumulative  $\text{NH}_3$  emissions were  $3.83 \pm 1.07$ ,  $3.76 \pm 0.82$ ,  $3.74 \pm 0.93$ , and  $3.81 \pm 1.06 \text{ g}\cdot\text{day}^{-1}$  for the 0%-, 25%-, 50%- and 75%-cover, respectively. The treatments did not significantly ( $p=0.1003$ ) interact with the day of monitoring. However, there was significant difference ( $p<0.05$ ) in the emission between days of monitoring due to additive  $\text{NH}_3$  ER over time.

**Comment [HX3]:** This is a borderline p value that may be considered significant by some.

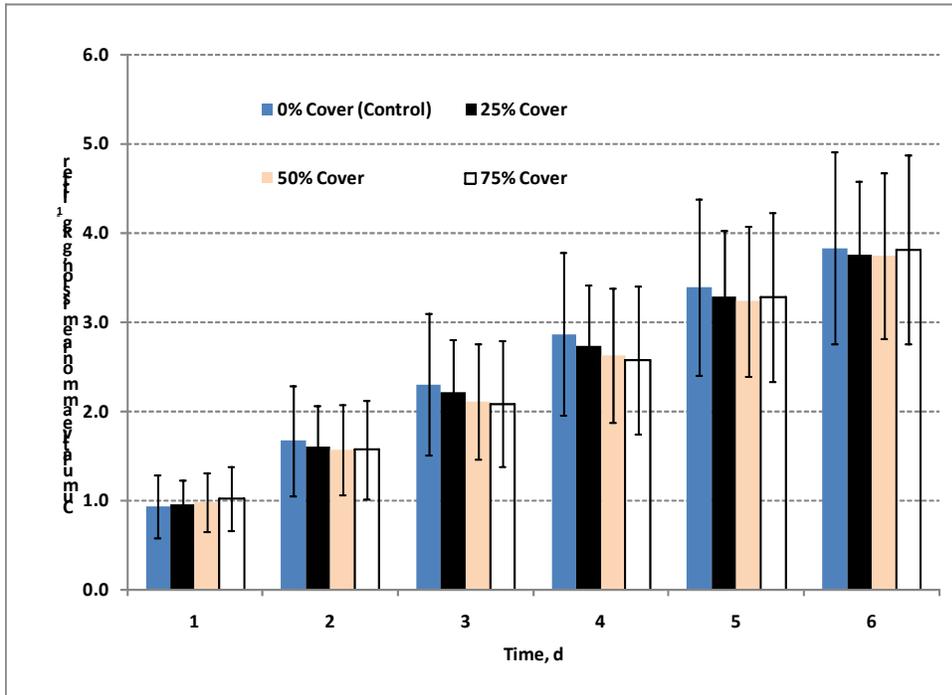


Figure 5. Overall cumulative ammonia emissions from turkey litter as affected by dynamic, partial surface coverage (mean  $\pm$  SE).

#### **Relationship between $NH_3$ ER and storage time, litter temperature, MC and pH**

Due to the strong correlation between storage time, litter temperature, MC and pH with  $NH_3$  ER, regressions were performed for each individual parameter to obtain the relationships.  $NH_3$  ER showed linear relationship with all the variables. Linearity was positive for both litter temperature and MC and was negative for both storage time and pH. The result for pH is contrary to the literature reports by Gay et al. (2006), Fowler et al. (1996) and Vogels and Van der Drift, (1976). This might have been caused by the fact that in this study, the monitoring started when the litter pH was already in the basic state and only a narrow change in pH was recorded which ranged from 8.23 to 8.40 across all the treatments. At these pH levels, the  $NH_3$  emission was in the diminishing phase, hence the inverse relationship. The relationship mentioned by the above authors were observed in studies where the pH ranged over a larger span from acidic to basic states (where the ER was increasing) and monitoring took a much longer time.

Since there were no significant differences between the treatments, the data from all the treatments were averaged and regression performed. Table 1 shows the regression equations developed. The equations are of the form,

$$ER_{NH_3}, g \cdot hr^{-1} \cdot kg^{-1} \text{ litter} = aX + b \quad (2)$$

where ,  $a$  is the slope,  $X$  is the variable investigated and  $b$  is the intercept.

Table 1. Regression equations developed for the turkey litter stored over six-day period

Variable “X” (unit)	Slope “a”	Intercept “b”	R <sup>2</sup>	Limits for “X”
Storage time (d)	-0.0011	0.0165	0.8486	1 - 6
Litter temperature (°C)	0.0011	-0.0139	0.4725	22.3 – 26.3
Moisture content (as-is, decimal)	0.1924	-0.0399	0.9177	0.26 – 0.29
pH	-0.0276	0.2420	0.7808	8.23 – 8.40

## Conclusions

The initial placement of partial covers on the turkey litter suppressed ammonia (NH<sub>3</sub>) emission rates (ER) to varying degrees. The covers served as physical barriers to NH<sub>3</sub> emission and tended to temporarily reduce and delay the emission but did not affect the overall total NH<sub>3</sub> emission. Periodic shifting of the covers resulted in the escape of NH<sub>3</sub> trapped underneath the covers resulting in similar overall NH<sub>3</sub> ERs across the different treatments. There was a direct linear relationship between NH<sub>3</sub> ER and litter temperature and moisture content. An inverse linear relationship was found between NH<sub>3</sub> ER and storage time and pH. These relationships have been developed through regression analysis.

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