Winter broiler litter gases and nitrogen compounds: Temporal and spatial trends

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Abstract

Understanding how animal activities, management, and barn structure affect litter gases and nutrients is fundamental to developing accurate emission models for meat-bird facilities. This research characterized the temporal and spatial variability of litter ammonia (NH\textsubscript{3}) and nitrous oxide (N\textsubscript{2}O) flux via a chamber method, as well as determined litter nitrogen (N) compounds by intensive sampling in two commercial broiler houses on aged litter. Thirty-six grid samples were taken during a winter flock in Mississippi on days 2, 22, and 45. On day 45, eight additional samples were taken near the feeders and waterers (F/W). Geostatistical contour plots indicate NH\textsubscript{3} flux on day 2 was elevated in the brood area of house one (H1) where litter and air temperatures were highest; a commercial litter treatment held the NH\textsubscript{3} flux near zero for approximately 45\% of the brood area in house two (H2). Day 45 NH\textsubscript{3} fluxes were similar, averaging 694 mg m\textsuperscript{-2} h\textsuperscript{-1} in H1 vs. 644 mg m\textsuperscript{-2} h\textsuperscript{-1} in H2; both houses exhibited greater NH\textsubscript{3} flux near the cooling pads. Ammonia flux, litter moisture and pH were diminished at the F/W locations. Heavy cake near the exhaust fans provided the lowest recorded litter pH, highest litter moisture and ammonium (NH\textsubscript{4}) with no NH\textsubscript{3} flux at the flock’s end. Trends in litter condition based on bird activity were evident, but individual differences persisted between the houses. The importance of cake formation over the litter surface and differences based on location, both related to bird activity and house structure, should be considered in NH\textsubscript{3} mitigation strategies.

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Keywords: Ammonia; Broiler; Cake; Litter

1. Introduction

In US commercial poultry production, meat-type birds or broilers are usually reared on an organic bedding material (i.e. wood shavings, rice hulls). The combination of deposited manure and urine, bedding material, feathers, spilled feed, and water is called “litter.” In high traffic areas, near the feeders and waterers or near the exhaust fans, a compacted layer, usually high in moisture, forms over the litter,
which is known as “cake.” Litter and cake removed from broiler houses are potential fertilizer sources for crops, but the conversion of N compounds in manure to NH$_3$ is a source of environmental concern. In response to this, the US Environmental Protection Agency (EPA) announced the Animal Feeding Operation Air Quality Compliance Agreement on January 21, 2005. Monitoring the project may begin early in 2007 to ensure compliance with applicable regulations and to evaluate animal feeding emissions.

Although the fundamental relationships among litter pH, moisture, and uric acid N are known (Gates et al., 1997), the lack of homogeneity of the litter creates difficulty in accurately estimating NH$_3$ volatilization from the litter surface. Nitrogen loss mechanisms in animal manure systems require additional characterization to be fully understood. Groot Koerkamp and Elzing (1996) maintain the need for understanding the influential parameters and reactions in litter degradation that lead to NH$_3$ volatilization.

Potential damaging effects of atmospheric NH$_3$ include eutrophication of waterways, increased soil acidity, and aerosol formation (EPA, 2004b; Mukhtar et al., 2003; Roadman et al., 2003). Elwinger and Svensson (1996) reported that animal manures can release 40% of the total N as NH$_3$. Sources of aerial NH$_3$ include industry, transportation, fertilizers, soils, humans, pets, wild animals, animal production, forest fires/slash burning, and waste disposal and recycling processes (Anderson et al., 2003). Although projections differ, animal production appears to be a significant source. The National Research Council (NRC, 2003) reports livestock’s contribution to aerial NH$_3$ as 50–70% in the US. Similar approximations for farm animals in Europe include 85% in The Netherlands (Groot Koerkamp et al., 1998) and 93% in Denmark (Rom, 1993). Of the total NH$_3$ emissions, the Danish report attributed animal housing to 35%, waste storage to 20%, and land spreading to 40% (Rom, 1993). Nicholson et al. (2004) arrived at similar divisions for bird housing, litter/cake storage, and land application in a broiler study with NH$_3$ losses at 28%, 15%, and 57%, respectively. Recent forecasts for poultry (turkeys and chickens) emissions in the US anticipated generating 664,238 tons of NH$_3$ in 2002 of which 31% evolved from housing (EPA, 2004a).

Process-based models to project emissions may require multiple years of data collection and exploration (NRC, 2003). There is a scarcity of scientifically derived emission factors characterizing US animal feeding facilities. Emissions should be correlated to specific animal species (source) activity with details of production like type of barn structure, air throughput, waste handling, animal maturity, stocking density, and body weight in conjunction with prevailing interior and exterior air temperature and humidity (EPA, 2004b). Many of these are interrelated factors that complicate ammonia emission rate assessments (Anderson et al., 2003; Worley et al., 2002), and the list is not exhaustive. Anderson et al. (2003) and Worley et al. (2002) report that litter characteristics such as dry matter content, pH, and NH$_4$ concentration must also be considered.

The research presented here represents an initial effort to assess trends within solid-side walled commercial broiler houses; this work may be dually applicable to the macro- (emission model development) and micro-scale (within house variability, time changes through the flock cycle) for determining litter gas evolution. In addition to developing a better understanding of the pathways between solid waste conversion to gas phase for N compounds in the litter, Confined Animal Feeding Operations are required by law and within their nutrient management plans to test litter sources at least annually for total manure N and P. The results of the spatial sampling presented within could provide a basis for determining a representative in house sample when needed.

Two previous studies investigating the spatial variability of litter composition or surface gas flux within commercial facilities were found in the literature. Tasistro et al. (2004) assessed the litter composition at the end of a growout in a 10.5 × 120 m house with cross-flow ventilation and where the sawdust/wood shavings bedding was removed after each flock (total cleanout). They associated the litter composition variation with the extent and conditions of the litter decomposition during the flock. Miles et al. (2006) reported litter pH, moisture, temperature, and gas (NH$_3$, CO$_2$, CH$_4$, and N$_2$O) flux on days 1 and 21 during the 29th flock on pine shavings litter in a 12.8 × 146.3 m curtain-sided house. The house was operated in tunnel ventilation mode in summer conditions. Both these works will be compared to the two commercial houses sampled for this report.
The objectives of this research were twofold: (1) to determine the magnitude of irregularity among litter parameters by intensive sampling and concurrent measurements at the beginning, middle, and end of a flock; and (2) to investigate the spatial variability of selected litter N species and litter gas flux within commercial broiler houses, hypothesizing that trends in variability could enhance understanding of litter changeability for future identification of housing/management strategies for reducing NH₃ emissions.

2. Materials and methods

Two commercial broiler houses, side-by-side and between the two other houses on a Mississippi farm, provided the site for determining litter gas flux and litter N species composition. Approximately 26,000 broilers were placed in each house. The research, representing the 13th consecutive flock, was conducted during a winter growout (January–February) where pine shavings were the original bedding material. Routine litter management between flocks included decaking and occasionally tilling the litter prior to decaking, where the latter is used more in summer conditions. Unlike decaking which removes the compacted layer at the litter surface, tilling the litter would mix the entire litter base releasing more moisture and NH₃ between flocks as well as into the next flock without sufficient drying time. Only decaking was performed prior to chick placement of the 13th flock.

The solid sidewall houses were approximately 2.5 years old, measuring 12.8 m by 146.3 m (42 ft by 480 ft) with evaporative cooling pads on each side of the west end. The half of the house, length-wise, from the center to the cooling pads represents the brood area of the house, the area that the chicks occupy from placement until they can maintain their own body temperature or until more floor/feeder space is required. Typically, the decision to utilize the full house is made by the grower and the brood period ends between 5 and 12 days after placement. The opposite end of the house, the fan or non-brood end, contained one 91 cm (36 in) fan and eight 122 cm (48 in) fans of which four were in the end wall and four nearby in the sidewalls. These fans were operated alone or in combination with each other and intermittently to maintain minimum ventilation early in the flock or a focal house temperature later in the growout. Vent boxes were located at regular intervals near the ceiling in the sidewalls of the house and were computer controlled to work in conjunction with the ventilation stage. The house contained no baffles or mixing fans. Gas fired brooders (heaters) were hung down the center of the house to provide heat as needed. The brooders were only used during the brood period (to approximately 10 days of age).

Twenty-four hours after chicks were placed (sampling day 2/the beginning of the flock), litter samples were taken along a grid, were chilled, and transported to the laboratory for further analyses. Gas flux was estimated, at the same locations as litter sampling, using inverted plastic chambers and a photoacoustic multigas analyzer (Innova 1312; California Analytical, Orange, CA). In H2, a litter amendment (PLT®; Jones-Hamilton Co., Walbridge, OH) had been added to the brood area. In the middle of the growout (day 22) and near the end (day 45), grid samples for litter and gas flux were repeated.

Litter samples ($n = 36$ on days 2 and 22; $n = 44$ on day 45) were collected along the grid depicted in Fig. 1. Three sampling points, 5 m apart, were placed across the house and 12 sites down the house, 12 m apart, to make up the grid. On day 45, eight additional samples were taken in a zigzag pattern down the house to investigate litter and gas flux properties in high traffic areas where greater manure deposition would be expected to influence litter composition and gas evolution. These additional samples are called feeder/waterer (F/W) samples because they were obtained equidistant between the water line and the feeder line. The F/W sample locations have been approximated in Figs. 2 and 3 using circles for the parameters having especially high or low values at these sites. Nipple waterer lines were 1 m on either side of the feeder lines. The location of the two feeder lines were approximately 1.3 m towards the center of the house from the outer grid samples. Litter samples were taken from the upper 5 cm at each sample location. Litter properties determined at the laboratory included moisture by loss in weight after drying for $48 \text{ h at } 65^\circ \text{C}$, and pH using a litter:deionized water ratio of 1:5. The litter was water extracted for determining NH₄ and NO₃ using flow injection analysis (QuikChem 8000; Lachat Instruments, Milwaukee, WI). Total Kjeldahl Nitrogen (TKN) was determined by block digestion and subsequent auto-distillation/titration (2300 Kjeltec Analyzer; FOSS in North America, Eden Prairie, MN). Relative humidity and air temperature,
approximately 1 m above the litter surface, were measured using a pocket weather meter (Kestrel 3000; Nielsen Kellerman, Chester, PA) at each sample location.

A static chamber method was used to determine litter gaseous flux (Miles et al., 2006). Similar flux methods have been used in nutrition trials and for evaluation of litter amendments (Ferguson et al., 1998a, b; Moore et al., 1997). Deriving NH₃ flux from a source can include theoretical relationships or measurements of N mass balance such as models or emission factors, micrometeorological techniques (usually outside the house) or chamber methods (Arogo et al., 2003). The accuracy of each type depends on many assumptions in addition to the accuracy of measurements and the care employed to meet desired objectives. At each sample site in the present study, a flux chamber (cylindrical with 35 cm height, 14.3 cm radius, containing a small electric fan) was inverted over the litter as the analyzer drew in the time zero gas sample. The chamber fan mixed the air within for 10 s prior to the second sample, captured at 70 s after time zero. The chamber area, elapsed time, concentration difference, and the ideal gas law were used to approximate litter gas flux at each location. Litter surface temperature was measured concurrently with gas sampling using an infrared thermometer (Raynger ST; Raytek Corporation, Santa Cruz, CA).

Variograms (contour plots) were developed using geostatistical software (Golden Surfer 8.0; Golden, CO) to visually survey the spatial variability among measured parameters and gas flux estimates for the beginning, middle, and end of the flock. The software uses kriging, a statistical method, to complete the surface feature estimates over the floor of the commercial houses. Kriging estimates the best value for a parameter by applying weighted linear combinations of nearby values while trying to lessen the error variance between samples. Color progression from dark blue (low values) to red (upper limit values) enables extremes in parameters across the floor area to be located quickly. Because the grid sampling imposes bias (samples are not random), traditional statistics were not applied to the assessed litter N compounds, the litter parameters, the air properties, or the gas flux estimates.

3. Results

3.1. Air and litter properties

The variograms for air relative humidity and temperature, litter temperature, litter moisture, and pH are given in Fig. 2. The air and litter temperatures are reported using the same scale so that they can be compared directly. Omitting pH on day 2, air and litter properties followed similar patterns in both houses. The heat supplied to warm the chicks in the brood half of the houses kept the relative humidity somewhat low (average 47%); whereas in the non-brood portions, the relative humidity was greater (average 64%). As expected, the air temperature was elevated in the brood areas, 31.1 °C vs. 22.4 °C in the non-brood. In the non-brood regions, the litter temperature was similar to the air temperature. The litter temperature profiles indicate the hottest litter lies down the center of the house in the brood areas, just over 40 °C.

At the mid-growout measurement (day 22), the relative humidity ranged from 62 to 85% in both
Fig. 2. Variograms of air and litter properties in two commercial broiler houses (H1 and H2) at the beginning, middle, and end of the 13th consecutive flock on pine shavings.
Fig. 3. Ammonia and nitrous oxide litter gas flux and litter N species as contour plots from two commercial broiler houses (H1 and H2) at the beginning, middle, and end of the 13th consecutive growout on pine shavings.
houses. No exceptional patterns were noted in the contour plots, but slightly higher bands of relative humidity appear near portions of the sidewalls. The air temperature at this date cooled to about 25 °C or less across most of the brood area of H1 and is approximately 25 °C down 75% of the center of H2. The air temperature was held at a nominal 26–27 °C in the remainder of the houses. The litter temperature appears greater than the air temperature on day 22; lacking notable trends on the variograms, the litter temperature averages 29.2 °C in each house.

Near the end of the growout (day 45), an unexplained and unusually high region of near 100% relative humidity was observed in front of the right cooling pad in H1, which did not correlate to an extreme in any other measurement for that place and time. This house had a greater overall relative humidity down the length of the center of the house (60–75%) than neighboring H2 which was at 45–55%. Time of day might explain the gross difference in relative humidity between the houses, because H1 was sampled earlier in the morning than H2. Corresponding to the time of the measurements, local climatic data indicate that relative humidity decreased from 100% at 7 a.m. to 54% at noon. Air temperatures in both houses decreased further, as expected with flock age, to range 19–23 °C. Alternatively, the day 45 litter temperatures lingered close to those of the mid-flock at 27.7 °C, where the variograms show an increased number of smaller, cooler regions over the floor area of both houses.

Litter moisture, pH, temperature, TKN, NH4, NO3, and N2O and NH3 flux for the two broiler houses at the beginning, middle, and end of the growout are given as means in Table 1. Because the chicks were in half house brood during the day 2 sampling, it is recognized that the report for average temperature is misleading. The range of litter temperature was similar for both houses in the winter conditions on day 2 at approximately 18–42 °C. On day 45, the average litter temperatures for both houses were greater than on day 2, 27.7 vs. 27.1 °C.

The average litter moistures in Table 1 show an increase from the beginning to the end of the flock. In Fig. 2, the contour plots indicate that individual areas ranged from very dry during brood (~13%) to very moist in the high cake areas at the end of the flock (~57%). The brooder heat effectively dried the litter in the brood areas on day 2, ranging from 12% to 26% moisture with an average of 18.6% in H1 and 20.9% in H2. At the mid-flock measurement, low moisture is still prevalent in portions of the brood area in both houses. The non-brood ends appear to have some drier regions than on day 2, but have nominal increases near the fans across the house width. By the end of the growout, moisture increased in both houses, more so near the sidewalls. The additional samples taken at the F/W sites, which are approximated with circles on day 45 in Fig. 2, are especially interesting; these high traffic areas were predominantly caked but had lower moisture (~24%) than surrounding litter samples (>30%). In H2, an extreme caked area (“U” shaped) was present near the fans and exhibited the highest litter moisture, averaging 50.7% for eight grid samples in that area. This high moisture/

<table>
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<th>Litter properties</th>
<th>Bird age (day)</th>
<th>House 1</th>
<th>House 2</th>
<th>House 1</th>
<th>House 2</th>
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<tr>
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<td>2</td>
<td>22</td>
<td>45</td>
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<td>6184</td>
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<tr>
<td></td>
<td>NO3</td>
<td>1145</td>
<td>456</td>
<td>110</td>
<td>2350</td>
</tr>
</tbody>
</table>
caked area is denoted with a rectangle in Figs. 2 and 3 to point out the high moisture, low pH, low NH₃ flux, and high NH₄ specific to that area of H2.

Litter pH appeared to decline over the flock on average. In H1, average litter pH dropped from 8.61 to 8.43 from the beginning to the end of the growout. However, day 22 pH averaged 8.24. In H2, average litter pH was initially 8.3 vs. 8.0 at the end of the growout, with a mid-flock pH of 8.5. The freshness of the feces in the sample can reduce pH, but this would not fully explain the decline, especially considering the number of samples contributing to the average. New sawdust bedding has a pH between 5 and 6.5 (Elliott and Collins, 1982). Although litter pH is generally projected to increase with bird age and the number of flocks (Nahm, 2003), documentation of within flock changes on built up litter are sparse.

The pH down the center of the brood area in H1 on day 2 was slightly lower than the surrounding litter (8 vs. 8.2). The litter amendment applied to the brood area of H2 produced consistently lower pH (~7) in much of that area on day 2. Reece et al. (1979) reported that modest NH₃ volatilization occurs at pH 7 and below. On day 22, both brood areas indicate lower pH than the remainder of the houses, but H1 was lower than H2. By day 45, much of H1 litter had a pH >8 with a lesser magnitude of pH at the F/W locations. The pH in H2 at the end of the growout appeared to decrease from day 22 in much of the house, masking the appearance of low pH in the F/W samples. The area of extreme cake that formed near the exhaust fans in H2 on day 45 resulted in the lowest recorded pH of the experiment, 5.44.

3.2. Litter gas flux and N compounds

Litter NH₃ flux followed a trend similar to litter moisture, increasing with bird age (Table 1). On day 2, the litter treatment in H2 seemed responsible for a lesser overall flux estimate; 307 mg m⁻² h⁻¹ vs. 400 mg m⁻² h⁻¹ in H1. The overall middle flock NH₃ fluxes appeared to remain near those of day 2 for each house: in H1, 412 vs. in H2, 294 mg m⁻² h⁻¹. Similar and higher values for overall flux were evident by the end of the growout, 694 mg m⁻² h⁻¹ in H1 and 649 mg m⁻² h⁻¹ in H2.

Variograms for NH₃ flux over the floor area of the two houses are presented in Fig. 3. With the beginning of the flock, the brood area of H2 litter treatment applied) had NH₃ flux that was essentially zero over approximately 45% of the area. In the brood area of H1, NH₃ flux was elevated down the center of the house, which corresponded to the location and operation of hanging brooders. By day 22 the profile for NH₃ flux was primarily linear along the length of both houses, with greater flux evident near the sidewalls in H1. A comparable trend was sustained at the end of the flock. In addition, during the final measurement, two significantly elevated regions of NH₃ flux were apparent in the brood area in the center of H2. Also on day 45, the NH₃ flux was greatest near the cooling pads of both houses. The extreme caked area in H2 at the fan end had virtually no NH₃ evolution. The circles on the day 45 variograms approximate the location of F/W samples where NH₃ flux was generally less than surrounding samples.

Nitrous oxide flux from the litter was low in magnitude throughout the growout, 0–5 mg m⁻² h⁻¹ over most of the floor area in both houses (Fig. 3). However, there was a slight increasing trend with bird age. Including a consistently elevated region near the right cooling pad in H2, the average N₂O flux for the flock was 18 mg m⁻² h⁻¹. The sidewalls in H2 on day 45 contributed to the increase to some extent and N₂O flux was greater in H2 than in H1.

Total Kjeldahl N from the grid litter samples was higher in the brood areas compared to the non-brood ends of the houses at the beginning of the flock (Fig. 3). In H1 the brood area averaged 23,600 mg kg⁻¹ whereas the fan end was 19,900 mg kg⁻¹. For H2, the brood area average was 21,700 and 18,700 mg kg⁻¹ in the opposite end of the house. The trend of greater TKN, approximately 23,000 mg kg⁻¹, in the brood regions was obvious into the middle of the flock. At the end of the flock, the higher TKN regions still remained near the same magnitude of 23,000 mg kg⁻¹, but stretched over the entire floor region with a few lower regions near the sidewalls. The F/W samples revealed the highest TKN concentrations for the flock, approximately 31,000 mg kg⁻¹. Table 1 presents the whole house averages for each sample date, indicating an increase with flock age.

Ammonium in the litter tended to increase over the flock cycle. The H1 average NH₄ concentrations for the beginning, middle, and end of the flock were 3600, 4200, and 6200 mg kg⁻¹ as compared to H2 values of 5100, 5800, and 7700 mg kg⁻¹, respectively. Trends within the houses are difficult to
detect in Fig. 3 due to the relatively small differences compared to the particularly high NH$_4$ concentrations (near 24,000 mg kg$^{-1}$) found in the extreme caked region of H2 on day 45. For H2, litter NH$_4$ in the center of the brood region (approximately 10,000 mg kg$^{-1}$) appeared greater than surrounding litter (near 5000 mg kg$^{-1}$) on days 2 and 22.

Nitrate concentrations were more variable between the houses than the other N species measured in the litter. As seen in Fig. 3, H2 exhibited the highest litter NO$_3$ on day 2 with one small area near the left sidewall brood area and nearly half the fan area from the left sidewall to the center of the house. Also, compared to litter TKN and NH$_4$, the trend with bird age was reversed so that NO$_3$ levels dropped during the flock. In H1, days 2, 22, and 45 NO$_3$ sample concentrations averaged 1150, 460, and 110 mg kg$^{-1}$ (Table 1). For H2, these values were 2350 mg kg$^{-1}$, 1300 mg kg$^{-1}$, and 90 mg NO$_3$ kg$^{-1}$. The NO$_3$ concentrations were lowest in both houses on day 45 with the exception of one elevated area near the right side of the fan end in H1. Although difficult to detect on the variograms, the day 45 F/W litter NO$_3$ levels were elevated somewhat compared to the remainder of the floor area.

4. Discussion

4.1. Air and litter properties

Half house brood conditions on day 2 were obvious in the temperature and relative humidity profiles in the brood area for both houses. The highest overall measured temperatures for the flock were observed on day 2 for the litter down the center of the brood area which corresponds to the supplied heat from the brooders. The results for elevated litter temperature, in addition to low litter moisture, during brooding have been previously shown to correspond spatially to this management scheme in a curtain-sided commercial broiler house (Miles et al., 2006). In a southern US study on particulate matter and NH$_3$ emission factors for tunnel-ventilated broiler houses, Lacey et al. (2003) conducted measurements primarily in summer conditions, but reported one mean relative humidity value for the middle of a winter flock, approximately 46% ± 4. Compared to the spatial report given here, that level of relative humidity was present at the beginning of the flock in only the brood regions of the houses. However, it was also encountered in H2 down the center of the house at the end of the growout. Although climatic factors like air temperature and relative humidity are thought to impact NH$_3$ generation within broiler facilities, the spatial trends for these parameters presented here do not appear to have any significant correlation to gas flux or N compounds in the litter. In the work by Lacey et al. (2003), neither house ambient temperature nor relative humidity was found to be significant influences on emissions. Still, the role relative humidity plays in the fate of NH$_3$ outside an animal facility may be important. For example, the formation of ammonium nitrate depends on relative humidity, and the phase of the compound as a particulate or a gas is related to ambient temperature and relative humidity (Baek et al., 2004; EPA, 2004b).

Seasonal changes in temperature necessitate complementary ventilation management to keep the birds at an appropriate temperature. Seasonal variability in temperature has been thought to contribute to sizeable emission fluctuations (EPA, 2004b). Elliott and Collins (1982) reported 1–2°C increases in temperature can greatly increase NH$_3$ volatilization. The variograms showed that litter temperatures were maintained higher than air temperatures. External temperatures are not provided and some herding of the birds existed while accomplishing the measurements. However, it was obvious that the larger birds insulated the litter surface towards the middle and end of the flock which may be more influential on litter gas flux than seasonal conditions.

Ventilation controls litter moisture (Gates et al., 1997) and winter fan operation rates are generally less than warmer seasons to reduce heating costs. The objective of ventilation is to provide an optimal thermal environment for bird growth (Lacey et al., 2002). Controlling litter moisture (drying the surface) and house NH$_3$ concentrations (diluting with incoming air) are subordinate effects. Increased ventilation rates are required to reasonably reduce NH$_3$ levels within houses, which are higher than rates needed for moisture control (Xin et al., 1996). The greater moisture near the sidewalls at the end of the growout could be an artifact of ventilation where a more fully developed air flow profile is present down the middle of the houses and able to strip away litter moisture. Although emissions may decrease at moisture extremes, appropriate relationships for intermediary levels have not been developed (Elliott and Collins, 1982). Large increases in aerial NH$_3$ may occur at >30% moisture
(Carr et al., 1990). Carey et al. (2004) suggest litter moisture ranging from 25% to 35% as favorable for reduced odor/dust, but individual house features should be known to arrive at a precise level.

The presence of caked surfaces over the bedding has been primarily characterized by high moisture, but physical effects of the cake condition have scarcely been defined. Sistani et al. (2003) found the average cake moisture for three farms in MS was 44–47.7%, whereas litter moisture ranged from 25.6% to 29.7%. In the spatial litter study by Tasistro et al. (2004), average water content in the litter bedding was 29.7% in the center of the house, 17.4% at the feeders, and 54.6% below the waterers. The results of the current study are comparable when discussing average litter moisture within the houses. In addition, the results presented here seem to differentiate cake based on location and moisture. The additional samples taken on day 45 between the feeders and waterers were predominantly cake. However, these samples had lower moisture (expected to result from the addition of dry matter from spilled feed) and lower pH than the surrounding friable litter. The extreme caked area in H2, near the fans on day 45, was a high moisture cake. The caked samples are discussed further below with respect to NH3 flux.

The trend in litter pH on average was not consistent between the houses; the dynamic nature of the pH changes may be due to the litter amendment application in only H2 prior to chick placement. Early in the growout litter amendments are the primary means for altering litter pH, but their control does not endure through the entire flock. Although litter pH is frequently expected to increase with the litter age, and corresponding flock age, a similar phenomenon has been reported previously where litter pH decreased between days 1 and 21 (Miles et al., 2006). Greater deposition and, thus inclusion of fresher excreta, later in the growout could explain the overall decrease in pH from the beginning to the end of the flock. As most of the samples maintained pH 8 or greater on the built up litter, one would not expect NH3 volatilization to be diminished due to pH. The intensive sampling demonstrates how litter characteristics can vary within the flock cycle.

4.2. Litter gas flux and N compounds

Much of the recent emphasis on gas measurement surrounding animal facilities centers around developing process-based emission factors (the product of house concentration and ventilation rate) to determine potential for regulatory action. The focus of this study was to look at trends in the litter surface to create baseline data for identifying collinear management and climatic factors during the flock that shapes those trends. The litter gas flux values for NH3 appear reasonable compared to other chamber measurements, although many comparisons among house specific/interrelated factors (i.e. bedding type, diet, and management) and distinction in methodology were not feasible. Brewer and Costello (1999) reported a mean NH3 flux of 208 mg m⁻² h⁻¹ after six flocks were raised on rice hulls. Baracho et al. (2001) found day 39 NH3 flux (wood chip bedding) averaged 2568 mg m⁻² h⁻¹.

Brood conditions on day 2 (heat supply) caused an increase in NH3 flux in H1, whereas, the litter amendment reduced the NH3 flux in H2 for a portion of the brood area. It is unknown why the reduction in NH3 flux was skewed toward the left side of H2, whether the product was applied unevenly or some other factors caused the product to be exhausted more rapidly near the opposite side. The magnitude of flux in both houses was essentially unchanged from the beginning to the middle of the growout, but the pattern of the flux migrated from brood vs. non-brood to flow down the length of the house. This is in contrast to a previous study (Miles et al., 2006) of one, curtain-sided broiler house in summer where the litter flux (1) decreased between days 1 and 21 and (2) maintained a brood vs. non-brood nature of comparison from the beginning to the mid-growout measurement. The increase in ventilation under summer conditions likely diluted the house and litter surface NH3 concentrations during the second measurement (Miles et al., 2006).

The caked areas at the F/W samples and near the fans in H2 showed reduced NH3 flux. While the TKN at the F/W samples was elevated, the fan area TKN was not as pronounced. The H2 fan area cake had low litter pH and high litter NH4. High moisture can cause the cake to become anaerobic, diminishing NH3 production (Carr et al., 1990).

Additionally, the compaction of the cake from bird traffic suggests a physical barrier impeding NH3 volatilization. It is apparent that cake formation during the flock can affect the accuracy of predicting NH3 emissions from the litter surface. The formation of cake within houses is currently unavoidable. Although the diminished NH3 flux
from caked surfaces may be desirable, the cake can “slick over” with increased deposition or moisture in the house (i.e. from improperly operated misters) creating a platform for increased contact with the litter surface, thus excreta, for the birds.

The ambient levels of N\textsubscript{2}O within the houses (observed before, after, and between flux measurements) were below 2 ppm which is similar to winter mean N\textsubscript{2}O concentrations (~2.2 ppm) observed in UK houses (Wathes et al., 1997). Flux estimates were low because the differential concentrations measured (the increase in gas buildup within the chamber for a sample time and location) were low. Nitrous oxide fluxes from the houses were comparable to a previous study over litter (Miles et al., 2006) showing generally low flux levels with slight elevations at the ends of the house and near the sidewalls. An opposing trend in this study indicated an increase (near double) in N\textsubscript{2}O flux from day 2 to day 22, whereas the previous study indicated no change for the same time period. Further, the day 45 overall results indicated a slight decrease in N\textsubscript{2}O flux in H1, while in H2, there was a sufficient increase.

Total Kjeldahl N concentrations were influenced by half house brood management through the middle of the flock, indicating greater concentrations in the brood area of the houses (~23,000 mg kg\textsuperscript{-1}). The levels, ranging from 10,500 to 36,500 mg kg\textsuperscript{-1} in this report, appear somewhat lower than the three-producer, one year survey grand averages reported by Sistani et al. (2003). Litter and cake TKN analyzed by Sistani et al. (2003) using the same method as the current study were 32,800 and 37,600 mg kg\textsuperscript{-1}, respectively. The spatial work by Tasistro et al. (2004) for a cross-flow commercial house found total N concentrations from 30,000 to 50,000 mg kg\textsuperscript{-1} (dry litter) using combustion analysis at the end of a single growout and that decreased total N was correlated to increased pH. In the variorgrams for TKN and litter pH, the same association is evident except for the application of the litter treatment in H2 on day 2.

Organic N is converted to NH\textsubscript{4} via N mineralization. Ammonia volatilization and mineralization, commencing upon defecation (EPA, 2004a), are the N transformations in the ammonification portion of the N cycle (Tiquia and Tam, 2000). Conversions of N compounds provide the pathways for emissions to air and water. When water is present, NH\textsubscript{3} solubilizes in it to form NH\textsubscript{4}\textsuperscript{+}. Ammonium in litter provides beneficial nutrients for plants when litter is land applied. However, maintaining it in the litter and reducing NH\textsubscript{3} losses are challenging. Litter amendments work by reducing litter pH so that the equilibrium between NH\textsubscript{3} and NH\textsubscript{4} favors the later, as indicated by the increased NH\textsubscript{4} in the H2 brood area on day 2. Ammonium concentrations in cake and litter were reported by Sistani et al. (2003) as 12.5% and 11.5% of the total N. The comparable fractions for the current study are greater. In H1, on days 2, 22, and 45 the % NH\textsubscript{4} of total N were 16.7%, 18.8%, and 26.6%. In H2, the respective portions were 25.3%, 27.2%, and 31.7% NH\textsubscript{4} of total N. Thus, in both houses the relative amount of NH\textsubscript{4} increased with bird age, but H2 had higher concentrations than H1.

In poultry housing adsorbent litter bedding materials retain some N, permitting microbes the opportunity to start N immobilization, the conversion of NH\textsubscript{4} to NO\textsubscript{2} then NO\textsubscript{3} (Nahm, 2003). Though immobilization provides a mechanism to reduce air emissions from manure, without proper care in storage and land application, water contact may cause NO\textsubscript{3} leaching. Nitrate levels ranged between 0 and 4200 mg kg\textsuperscript{-1} and decreased as the flock aged, unlike NH\textsubscript{4} and TKN. Days 22–45 samples were similar to the Sistani et al. (2003) reports of 290 mg kg\textsuperscript{-1} in litter and 590 mg kg\textsuperscript{-1} in cake. The slightly elevated NO\textsubscript{3} concentrations at the F/W samples (caked) were consistent with those of Sistani et al. (2003) indicating greater NO\textsubscript{3} in cake. However, the elevated NO\textsubscript{3} levels did not carry over to the extreme caked fan area in H2 at the end of the flock.

5. Conclusions

During a winter flock, NH\textsubscript{3} and N\textsubscript{2}O flux were estimated to learn more about the surface chemistry of the litter and, with concurrent measurements of air and litter parameters and litter sampling, how litter and gas parameters change over the floor area of commercial broiler houses. House management, feeder and waterer placement, and bird activity influence litter gas flux and N compounds in the litter. Data trends agree with established relationships for the influence of pH, moisture, and temperature on gas emissions. Bird age/size affected litter temperature; the larger birds appeared to insulate the litter base which could potentially negate seasonal effects on emissions. Also, aberrations in the physical condition of the litter, whether
friable or caked, should be considered regarding the litter surface chemistry and NH3 generation.

The two most prominent litter characteristics that emerged in this study were the presence of cake with respect to NH3 potential and the origination of the cake (near F/W or tunnel fans). The effect of the compaction of the cake to create a deterrent seal and, thus, a decline in NH3 generation has not been explored in the current literature. Caked areas in the house produced lower NH3 flux, but differed in moisture content based on location. Cake moisture was lower between feeders and waterers but higher near the exhaust fans. Also, cake from the F/W samples differed in moisture, pH, TKN, and NH3 flux from the surrounding litter. The F/W cake had lower moisture, pH, and NH3 flux, but higher litter TKN. Other researchers have characterized cake by water content and nutrients or have characterized litter under waterers, feeders, and in the middle of the house, but have not made the distinction based on location within commercial houses while reporting litter condition, litter moisture, and potential NH3 flux.

Comparing the tabular averages of data to the variograms reveals that single point measurements must be obtained with caution so that an upper or lower threshold value is not reported as a representative condition for the broiler flock. The trends noted in the litter parameters, gas flux, and litter composition for this study should be compared to replicate studies to establish trends related to house structure, management, and bird activity. Further studies of the spatial variability are expected to lead to new best management practices. Input from broiler managers will be required to evaluate potential management practices to prevent detrimental effects on the birds. Zone litter treatment during the flock is one example. Sampling recommendations for litter nutrient analyses as part of comprehensive nutrient management plans should consider the potential variability and areas represented within commercial houses by friable litter, F/W cake, and cake from areas in other high traffic zones.

References


