INTRODUCTION

Broiler chicken production in the United States in 2011 totaled more than 8.6 billion chickens. Approximately 58% of broilers were produced in Georgia, Arkansas, Alabama, North Carolina, and Mississippi (National Agricultural Statistics Service, 2012). Optimal delivery of water and feed to broiler chickens and a myriad of other factors interrelate and contribute to grower and industry profitability. One such factor is the litter covering broiler house floors; its quality and management are prime contributors to bird well-being. Because growers are challenged by natural processes that generate ammonia (NH₃) from accumulated fecal matter as litter ages, a better understanding of NH₃ volatilization relative to specific locations (i.e., around feeders and sidewalls) within houses can provide useful insights for more effective management.

Key words: ammonia, broiler, litter, rice hull, waterer

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ABSTRACT Ammonia (NH₃) volatilized from broiler litter diminishes indoor air quality, which can potentially decrease bird productivity. Emissions of NH₃ exhausted from broiler houses pose environmental concerns for ecosystem biodiversity, aquatic nutrient enrichment, and particulate formation in the atmosphere. Research was conducted sampling litter (rice hull base) in 3 tunnel-ventilated commercial broiler houses during wk 3 (mid-growout) of 6 flocks. The purpose was to assess NH₃ generated near the sidewalls, waterers, and feeders. Litter samples (100 g) were placed in chambers receiving constant air flow. Boric acid (H₃BO₃) titration each 24 h for 4 d was used to determine NH₃ volatilized from the samples. Litter located near waterers emitted the most cumulative NH₃ (approximately 12.3 mg of N·kg of litter⁻¹·h⁻¹) with less NH₃ associated with feeders and sidewalls (2.9 to 7.6 mg of N·kg of litter⁻¹·h⁻¹). Moisture content of litter samples was greatest at waterers (45%) followed by sidewalls (26%) and feeders (20%). In addition, litter pH at the sidewalls and feeders could be predicted by linear equations associated with the number of flocks on the litter. At the waterers, litter pH was differentiated based on the half of house where higher litter pH existed in the nonbrood half (8.55 vs. 8.13). The results indicate that controlling NH₃ near watering lines to a level consistent with feeding lines and near the house wall could reduce NH₃ generated by 38 to 77%. These findings support efforts for NH₃ control at mid-growout, especially considering zone litter treatments near waterers and appropriate attention to waterer management.
duce excess N excretion and thereby reduce NH3 emissions (Council for Agricultural Science and Technology, 2002) as another mitigation strategy. In addition, NH3 scrubbers are emerging in the United States to treat exhaust air from broiler houses (Lahav et al., 2008). Use of scrubbers would satisfy environmental concerns, but would not address the house interior atmosphere. As with most new technologies, widespread implementation will not be immediate, and most of the industry will need to hone existing technology and house management for the best NH3 control.

Factors pertinent to litter and NH3 generation include physical and chemical litter properties (temperature, moisture, pH, and N content), type of original bedding material, between flock management such as windrowing and decaking, effects and frequency of top dressing, and spatial characteristics of gas evolution within houses. Elliott and Collins (1982) indicated an increase in NH3 with temperature, moisture, and pH. Coufal et al. (2006b) cited moisture and pH as more readily manipulated in houses than temperature, which is controlled for bird comfort. Separately, for reducing N volatilization when reusing litter (rice hull base and top dressing), Coufal et al. (2006a) recommended that top dressing not be used. A comparative laboratory study of organic vs. inorganic bedding materials reported that wood shavings and rice hulls produced less NH3 than sand and vermiculite and increases in litter moisture increased NH3 produced for all materials (Miles et al., 2011b). Spatial characterization of litter relative to NH3 volatilization has shown higher litter moisture content near waterers (Tasistro et al., 2004), increased NH3 volatilization just outside water lines (Brewer and Costello, 1999), and that litter between feeders and waterers can be consistently differentiated from surrounding samples from mid to late growout, but the magnitude of moisture is not reliably higher or lower between winter and summer (Miles et al., 2011a). The present study is more similar to Tasistro et al. (2004) in that NH3 measurements were conducted on litter samples removed from the houses rather than performed in houses on undisturbed litter such as Brewer and Costello (1999) and Miles et al. (2011a). The current research is explicitly differentiated from Tasistro et al. (2004) by having tunnel ventilation from 11 (1.3 m) fans vs. cross-flow ventilation from 4 (91 cm) fans; being conducted in 3 larger commercial houses with footprint 15.2 × 152.4 m (50 × 500 ft), solid-side-wall house had the following components: 3 automated feeder lines with nipple waterer lines on both sides of the feeders, an insulated drop ceiling, box inlets near the ceiling, brood heaters down the center of the entire house, evaporative cooling pads on each side at the front of the house (brood half, west end), two 0.91-m (36 in) fans in the west end for minimum ventilation, eleven 1.3-m (52 in) fans on the east end (nonbrood half), capacity for up to 30,000 chicks at placement, rice hull bedding, and migration fencing (division of the house into quarters, lengthwise). The houses were operated in all-in/all-out mode, and each growout was approximately 53 d. For each house and after each flock, decaking followed by top dressing with rice hulls was performed during a 2- to 3-wk layout. At the beginning of each flock, chicks were placed in the west end or brood half of the house for variable time periods determined by the grower’s preference.

Litter sampling and analyses

Access to a new commercial farm in Mississippi afforded a unique opportunity to investigate the progression of NH3 volatilization at selected locations within new houses where birds had never been grown. Construction on the 6-house broiler farm was completed in 2009. Each 15.2 × 152.4 m (50 × 500 ft), solid-side-wall house had the following components: 3 automated feeder lines with nipple waterer lines on both sides of the feeders, an insulated drop ceiling, box inlets near the ceiling, brood heaters down the center of the entire house, evaporative cooling pads on each side at the front of the house (brood half, west end), two 0.91-m (36 in) fans in the west end for minimum ventilation, eleven 1.3-m (52 in) fans on the east end (nonbrood half), capacity for up to 30,000 chicks at placement, rice hull bedding, and migration fencing (division of the house into quarters, lengthwise). The houses were operated in all-in/all-out mode, and each growout was approximately 53 d. For each house and after each flock, decaking followed by top dressing with rice hulls was performed during a 2- to 3-wk layout. At the beginning of each flock, chicks were placed in the west end or brood half of the house for variable time periods determined by the grower’s preference.

Litter samples were collected at the northern sidewall, waterer line, and feeder line in 3 of the 6 broiler houses (Figure 1). Five samples for each treatment were obtained at equally spaced intervals along a 45.7-m (150 ft) lengthwise section of both the brood and nonbrood halves of each house. At each interval, samples were picked up by a gloved hand from approxi-
mately the upper 5 cm (2 in) from a 930 cm² (1 ft²) area. Gloves were changed between treatments. These 5 samples were combined to create the brood-sidewall, brood-waterer, brood-feeder, nonbrood-sidewall, nonbrood-waterer, and nonbrood-feeder treatments. Each treatment from each house was placed in a 1-gallon (3.79 L) plastic bag. The bags were sealed, transported back to the laboratory via cooler, and then refrigerated at 4.4°C (40°F) for 3 d. Just before NH₃ measurement, the contents within each bag were mixed by gloved hand. Friable samples were mixed by stirring the entire contents of the bag. Where the bags contained small pieces of cake (1–98 cm³) as well as friable litter, the contents were turned carefully so that the cake was not unnecessarily broken down. Samples taken from the bag for NH₃ characterization (described below) were selected in portions of friable litter and pieces of cake (if present) to visually represent the entire treatment at the time of collection.

Samples were collected at the end of flocks 1, 2, and 3 (data not shown) and at 3 wk into the growout for flocks 2, 3, 4, 5, 7, and 9. Those flocks corresponded to sampling dates in June, August, and December of 2009 and February, June, and November of 2010. The mid-flock (3 wk) time was chosen to ascertain the potential of NH₃ release during this phase of the growout as well as to avoid the greater degree of cake expected near feeders and waterers later in the flock. Qualitative descriptions of litter condition were made before NH₃ measurements. Litter moisture content was determined by loss in weight after oven drying for 48 h at 65°C and pH was measured using a deionized water to litter ratio of 5:1 (wt:wt). Litter ammonium (NH₄⁺) was determined by extracting 2 g of litter with 20 mL of 2 M potassium chloride (KCl), followed by shaking for 1 h (Keeney and Nelson, 1982), then filtering through a funnel containing Whatman No. 1 paper. Extract was analyzed by flow injection analysis (QuikChem 8000, Lachat Instruments, Milwaukee, WI).

**NH₃ Measurement**

Litter samples (2 duplicates from each treatment bag) were placed in 1-L chambers receiving humidified air that was exhausted into boric acid solution (H₃BO₃). The laboratory system was designated the chamber acid trap (CAT) system, and was described in greater detail in a previous publication (Miles et al., 2008a). Briefly, compressed, humidified air passed through the 1-L containers, which housed 100-g litter samples. For each chamber, the air containing volatilized NH₃ exhausted into a series of 2 flasks each containing 30 mL of H₂BO₃ (Miles et al., 2008a). Each 24 h for 4 d, the series trap solutions for a treatment were combined and titrated with hydrochloric acid (HCl) to determine the NH₃ captured (mg of N). The system has the capacity

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**Figure 1.** Schematic for sidewall, waterer, and feeder sampling in commercial broiler houses (not to scale). Color version available in the online PDF.
to use 48 chambers during a trial. During this study, 36 chambers were used for litter samples (3 houses × 6 locations × 2 duplicate samples) and 3 chambers served as blanks (negative controls) to ensure no contamination of incoming supply air. During the 6 trials, the average flow rate to each chamber in the system was 112 mL/min (SD of 10 mL/min). House pad (soil) samples and fresh rice hull bedding were evaluated in the CAT system before the litter trials.

### Statistical Analyses

The data were checked for normality followed by ANOVA using procedures of SAS (SAS Institute, Inc., 2003). PROC UNIVARIATE was used to determine if the responses for NH3 generation were normally distributed. No abnormalities were associated with the distributions; thus, no transformations of the responses were needed for further evaluation of the data. Least significant difference (PROC GLIMMIX) means separation procedures were used to determine significance of NH3 response, as well as to determine changes in litter NH4+, moisture and pH relative to flock, half of house (brood or nonbrood), and location (sidewalls, waterers, or feeders). House was treated as a random variable. The significance level declaration was \( P = 0.05 \). Both daily NH3 volatilization and cumulative NH3 (total volatilized during the 4 d experiment in the CAT system) were analyzed. Although simplified by analyzing by location, initially, 9 significant effects were present in the daily NH3 volatilization. Because of the complexity and lack of utility of the quadratic responses to predict daily NH3 for the sidewalls, waterers, or feeder locations, these equations are not reported.

### RESULTS AND DISCUSSION

Mid-flock litter characteristics of 1) cumulative NH3, reported as a flux of mass N per kg of litter per h (mg of N·kg of litter\(^{-1}\)·h\(^{-1}\)); 2) litter NH4+ (mg/kg of litter); 3) moisture content (%); and 4) pH are given in Table 1. Because the farm construction was recently completed and the broiler houses were new, a unique opportunity arose to test background levels of NH3 in the house pad (soil) samples and unused rice hulls. House pad samples (13.3% moisture with pH = 7.67) emitted no NH3 in the CAT system. Total generation of NH3 from the unused rice hulls was 0.18 mg of N·kg of rice hulls\(^{-1}\)·h\(^{-1}\), or between 1 and 6% of the mean overall litter-generated NH3. Fresh rice hulls had a moisture content of 11% and a pH = 6.46. Mid-growth litter samples during 6 flocks gave the following overall results for litter moisture content and pH, respectively, of the reused rice hull litter: sidewalls, 25.8 ± 2.9% and 8.7 ± 0.4; waterers, 45.2 ± 8.8% and 8.3 ± 0.5; and feeders, 20 ± 3% and 8.4 ± 0.4.

During the mid-flock assessment, litter moisture content was significantly affected by location \( (P < 0.0001) \). Moisture contents during mid-flock at the sidewalls, waterers, or feeder locations are given in Table 1, where litter at waterers had the greatest moisture content, followed by sidewalls, then feeders. Analysis of litter pH indicated significant interaction of flock × location \( (P = 0.0107) \) as well as significant effects of sampling location \( (P = 0.0002) \), half of house \( (P = 0.0169) \), and flock \( (P = 0.0008) \). Separating by location and confining the analysis to significant components resulted in linear equations to predict pH based on the number of flocks for feeder and sidewall litter pH (Table 1). However, for the waterers, only half of the house was significant \( (P = 0.0105) \), which indicated mean pH was 8.13 in the brood half and was significantly lower than the nonbrood half of the house (8.55). Litter NH4+ mean separation was similar to moisture content, straightforward as significantly affected by location \( (P < 0.0001) \). Waterer litter NH4+ was greatest followed by the feeders and sidewalls that did not appear different (Table 1).

Mean cumulative NH3 released from litter at sidewalls, waterers, or feeders during mid-flock for 6 flocks on reused rice hull bedding is presented in Table 1. Two significant effects on total NH3 from the litter samples included location \( (P < 0.0001) \) and a half house × location interaction \( (P = 0.0497) \). Responses were separated based on brood and nonbrood half of house. In the brood half, sidewall and feeder litter NH3 appeared similar at 5.68 and 4.52 mg of N·kg of litter\(^{-1}\)·h\(^{-1}\). At 12.3 mg of N·kg of litter\(^{-1}\)·h\(^{-1}\), the NH3 associated with the waterers in the brood half of the house was

### Table 1. Mean cumulative NH3, litter NH4+, moisture content, and pH from reused rice hull litter samples (2 to 9 flocks) at the sidewall, waterer, and feeder in tunnel ventilated commercial broiler houses

<table>
<thead>
<tr>
<th>Item</th>
<th>Sample location</th>
<th>Sidewall</th>
<th>Waterer</th>
<th>Feeder</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative NH3 [mg of N/(kg of litter-h)]</td>
<td>Brood</td>
<td>5.68b</td>
<td>12.3a</td>
<td>4.52b</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>Nonbrood</td>
<td>7.57b</td>
<td>12.2a</td>
<td>2.85c</td>
<td>0.65</td>
</tr>
<tr>
<td>NH4+ (mg/kg of litter)</td>
<td>2.399b</td>
<td>3.119b</td>
<td>2.632b</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>25.8b</td>
<td>45.2a</td>
<td>20.0f</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>Brood</td>
<td>8.13b</td>
<td></td>
<td></td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Nonbrood</td>
<td>8.55a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole house</td>
<td>8.9715 – 0.0574 × (flock)</td>
<td>9.8 – 0.1055 × (flock)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a,b Means within a parameter lacking a common letter differ significantly \( (P \leq 0.05) \).
greater than the brood-sidewalls and brood-feeders, but did not appear different than the nonbrood-waterers (12.2 mg of N-kg of litter$^{-1}\cdot$h$^{-1}$). The NH$_3$ volatilized from the nonbrood-sidewalls (7.57 mg of N-kg of litter$^{-1}\cdot$h$^{-1}$) was less than the nonbrood-waterers and statistically analogous to the brood-sidewall and brood-feeder NH$_3$ generation. The least amount of NH$_3$ was generated by the nonbrood-feeder litter (2.85 mg of N-kg of litter$^{-1}\cdot$h$^{-1}$). These results compare with rice hull litter-generated NH$_3$ at 14.3 mg of N-kg of litter$^{-1}\cdot$h$^{-1}$ in a similar laboratory CAT system after 4 brood-feeder NH$_3$ generation. The least amount of NH$_3$ of litter$^{-1}\cdot$h$^{-1}$ was less than the nonbrood-waterers, brood-sidewalls and brood-feeders, with nonbrood half NH$_3$ flux indicated lower brood NH$_3$ flux (136 vs. 310 mg-m$^{-2}\cdot$h$^{-1}$) with somewhat lower pH (7.6 vs. 7.9) and litter moisture content (23.4 vs. 25.5%) during the 29th flock on reused litter. The most recent study (Miles et al., 2011a) reported similar values for whole-house litter pH, moisture content, and NH$_3$ flux as the 2 aforementioned studies. Although the data were presented as pooled for the entirety of the houses, color variograms indicated an effect of half-of-house management for some parameters (e.g., brood half litter temperature at the beginning of the flocks), but the effect was limited to NH$_3$ flux at the mid-growout. Miles et al. (2011a) measured a greater summer flux (522 vs. 278 mg-m$^{-2}\cdot$h$^{-1}$) and an increased nonbrood flux (482 vs. 316 mg-m$^{-2}\cdot$h$^{-1}$). The latter study sampled litter and NH$_3$ flux at an equidistance between the feeders and waterers to capture gross trends in this area due to traffic and cake formation. At the mid-growout, the combined feeder/waterer samples were inconsistent with respect to high or low moisture content and did not appear different than surrounding samples for NH$_3$ flux. Like Tasistro et al. (2004) at the end of the growouts, the combined feeder/waterer samples exhibited lower NH$_3$ flux than surrounding samples, likely due to heavy cake forming a seal over the litter in those areas (Miles et al., 2011a).

The complexity and impact of cake formation has scarcely been discussed in the literature relative to gaseous emissions. Sistani et al. (2003) characterized the rate of cake production during 1 yr on 3 commercial farms and reported 57% of litter remained in the house after decaking between flocks. In pen trials, Coufal et al. (2006a) found that top dressing litter reduced cake production, but did not affect total litter production. With qualitative notes of litter condition at grid sampling sites, Miles et al. (2008b, 2011a) noted low NH$_3$ flux in caked areas near fans and feeder/waterer lines. In the current research, there was some cake formation; however, choosing the mid-flock measurement precluded...
ed the sealing effect that was noted in earlier spatial flux measurements.

Significant variability was found when comparing results of the present study with earlier reports of litter NH$_3$ moisture content, and pH. This is not surprising when considering the dynamic confluence of factors affecting these parameters. Still, it is logical to make inferences based on housing characteristics and management practices. The present study is the first of its kind to specifically assess NH$_3$ generation at sidewalls, feeders, and waterers in modern commercial broiler houses during 6 flocks on reused litter. By sampling at mid-flock, intermittently during 2 yr (6 flocks total), the present study consistently demonstrated the effect of litter location at sidewalls, feeders, and waterers relative to potential for NH$_3$ generation and differences in moisture content, pH, and litter NH$_4^+$. The effect of half of house was less pronounced, indicating lower NH$_3$ at feeders in the nonbrood area and higher pH of half of house was less pronounced, indicating lower to 33% of the total NH$_3$ and litter near feeders contributes 54–55%, whereas litter near sidewalls contributes 25%, but 13 to 20% of the total NH$_3$ generated by the litter, partitioning the data attributed to each location indicates just more moisture content, pH, and litter NH$_4^+$. The effect of half of house was less pronounced, indicating lower NH$_3$ at feeders in the nonbrood area and higher pH at waterers there. With the greatest NH$_3$ volatilization and moisture content at waterers, the results suggest reducing litter moisture by approximately 20 to 25% under waterers can reduce NH$_3$ by 38 to 77%. Relative to the total NH$_3$ generated by the litter, partitioning the data attributed to each location indicates just more than half of the NH$_3$ can be expected near waterers (54–55%), whereas litter near sidewalls contributes 25 to 33% of the total NH$_3$ and litter near feeders contributes 13 to 20%. Litter between waterers on either side of the middle feeder/water set would need to be considered for developing mitigation strategies for the entire litter footprint. However, these findings support consideration of zone litter treatments near waterers during a growout.

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REFERENCES


