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Ammonia Emissions from Two Empty Broiler Houses with Built-Up Litter

Abstract
Ammonia (NH3) emissions from broiler houses have been monitored almost exclusively while the house is populated with live birds. Many American growers utilize litter for more than one flock. Between flocks, various litter management practices are used to prepare this "built-up" litter for the next flock, including some degree of house ventilation to keep the indoor ammonia concentration low. Ammonia volatilized from the litter is emitted to the environment during the downtime. This ammonia emission should be accounted for in the determination of a facility's annual ammonia emission inventory. In the study reported here, ammonia emissions were monitored from two recently depopulated broiler houses in Pennsylvania using built-up litter managed for five consecutive flocks. Average house air temperature during the monitoring period was 10.2°C, well below the typical temperature during flock production. Emission was calculated whenever a house exhaust fan was running. The results revealed ammonia emissions from the houses ranging from 212 to 1107 g h⁻¹. The daily emission rate (ER) was highest on day 2, coinciding with the first harrowing of the litter, and then decreased over subsequent days. These average values during downtime were about one-quarter of the ER values for market-size birds observed during flock grow-out in the same houses over the previous year. The reduced ER during the cleanout period was anticipated, since the built-up litter was at a lower temperature than during grow-out and there was no further fresh manure addition contributing to potential ammonia volatilization. Observed variation between these two houses with identical management and construction showed that monitoring a single house may not accurately predict empty house emissions, with unidentified factors other than management being responsible for this variability.

Keywords
Air quality, Chicken, Manure management, NH3, Poultry, Ventilation

Disciplines
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AMMONIA EMISSIONS FROM TWO EMPTY BROILER HOUSES WITH BUILT-UP LITTER

P. A. Topper, E. F. Wheeler, J. S. Zajaczkowski, R. S. Gates, H. Xin, Y. Liang, K. D. Casey

ABSTRACT: Ammonia (NH₃) emissions from broiler houses have been monitored almost exclusively while the house is populated with live birds. Many American growers utilize litter for more than one flock. Between flocks, various litter management practices are used to prepare this “built-up” litter for the next flock, including some degree of house ventilation to keep the indoor ammonia concentration low. Ammonia volatilized from the litter is emitted to the environment during the downtime. This ammonia emission should be accounted for in the determination of a facility’s annual ammonia emission inventory. In the study reported here, ammonia emissions were monitored from two recently depopulated broiler houses in Pennsylvania using built-up litter managed for five consecutive flocks. Average house air temperature during the monitoring period was 10.2 °C, well below the typical temperature during flock production. Emission was calculated whenever a house exhaust fan was running. The results revealed ammonia emissions from the houses ranging from 212 to 1107 g h⁻¹. The daily emission rate (ER) was highest on day 2, coinciding with the first harrowing of the litter, and then decreased over subsequent days. These average values during downtime were about one-quarter of the ER values for market-size birds observed during flock grow-out in the same houses over the previous year. The reduced ER during the cleanout period was anticipated, since the built-up litter was at a lower temperature than during grow-out and there was no further fresh manure addition contributing to potential ammonia volatilization. Observed variation between these two houses with identical management and construction showed that monitoring a single house may not accurately predict empty house emissions, with unidentified factors other than management being responsible for this variability.

Keywords. Air quality, Chicken, Manure management, NH₃, Poultry, Ventilation.

A multi-state, multi-disciplinary project has developed a database of ammonia emissions from various types of poultry facilities located in the U.S. (Liang et al., 2005; Wheeler et al., 2006). The database reported emission rates for populated laying houses and broiler houses during grow-out. Gates et al. (2008) developed a model for estimating annual NH₃ emissions from U.S. broiler operations that accounted for the varying market weight (1 to 3 kg) of broiler chickens, typical litter management strategies, and idle cleanout periods. Groot Koerkamp et al. (1998) cautioned that although an emission rate per animal seems to be the most appropriate expression, reporting methods need to account for the non-production periods. Demmers et al. (1999) reported that if only emissions during grow-out are used without adding the contribution during unpopulated times, the estimated annual emission could be underestimated by 12%.

Many U.S. broiler managers reuse chicken litter for more than one flock; such litter is known as “built-up” litter. Various litter management techniques are used between flocks to prepare built-up litter for the next flock. The two goals of the built-up litter preparation are: (1) to loosen the compacted litter after each flock to allow drying by air movement, and (2) to release the stored ammonia generated from the previous flock’s manure. The litter management techniques include removal of the thick layer of higher-moisture, caked litter under the water and feed delivery systems, followed by blading to achieve a uniform litter depth, and then disking and harrowing for further homogenization. An optional pH-reducing litter treatment may be applied prior to chick placement to reduce ammonia volatilization early in the next grow-out period. Some managers add a thin layer of fresh bedding materials to replace the removed caked litter. Prior to placement of the next flock, the house is pre-heated for 48 h (in cold climates) to reach a floor temperature of 32 °C for chick comfort upon arrival. This pre-heat is also known as a “cook-off” period, in which high temperatures encourage the release of more ammonia than lower temperatures practiced during most of the broiler grow-out period. The emissions caused during the litter management and during cook-off have not been measured or recorded. These emissions should be added to the facilities’ annual ammonia emission inventory.
The objective of this research was to determine ammonia emission rates from two typical broiler chicken houses that utilize built-up litter during the period when the house was depopulated and litter management techniques were being employed.

**MATERIALS AND METHODS**

**Overview**

Two recently depopulated, mechanically ventilated broiler houses managed with built-up litter were monitored continuously over six days of data collection. Emission rates were calculated as the product of the exhaust ammonia concentration and the ventilation fan exhaust airflow, with instrumentation systems developed specifically for emission measurement in poultry environments. Data are expressed in terms of standard conditions (STP; 0 °C temperature and 101.325 kPa pressure). Ammonia concentrations were measured at the operating exhaust fan(s) using an electrochemical sensor system with a fresh air purge cycle, called the Portable Monitoring Unit (PMU), as described in detail by Xin et al. (2002), Xin et al. (2003), and Gates et al. (2005). Exhaust fan flow rates at various static pressures were determined using an anemometer array designed for in situ fan airflow rate evaluation, called the Fan Assessment Numeration System (FANS; Gates et al., 2004; Wheeler et al., 2002). Fan run-times during the monitoring period were recorded using electric motor on/off loggers.

**Instrumentation**

Each PMU had two electrochemical ammonia sensors (0 to 200 ppm; PAC III, Draeger Safety, Inc., Pittsburgh, Pa.) with plumbing and controls for cycling fresh outside (purge) air (20 min duration) and poultry house air (10 min duration) past the sensors. The instruments were purged with fresh air to reduce sensor saturation from continuous ammonia exposure. In the PMU, the ammonia sensing units were connected in series for exposure to the air stream under positive pressure. Either purge or house air was collected via two lengths of transparent, flexible PVC tubing. Attached on one end of the tubing was a filter paper (20 micron, Grade No. 41, Whatman quantitative) housed inside a holder (Pall 47 mm in-line polycarbonate filter holder, No. 1119) with the other end attached to the PMU. The house air collection tubing of about 1 m length was positioned in front of the fan, 1/3 of the fan diameter down from the top, 15 cm horizontal offset from fan center, and 45 cm in front of fan intake. Two PMUs were used in each house: one monitoring a 127 cm tunnel exhaust fan that was expected to run during house litter management, and the other monitoring a 91.5 cm sidewall fan. Only the tunnel fan was used during the 6-day monitoring, so only emission data from the PMU next to the tunnel fan are reported. Fresh outside air used for PMU purging was collected at the poultry house eaves in between the ventilation inlet boxes on the house sidewalk that did not have exhaust fans.

The Draeger PAC III instrument was equipped with its own data logger and stored the previous 2 min average ammonia concentration data. Two-minute PAC III data storage was required for this study because of the limited data storage capacity in the PAC III (approx. 50 h if logging every 1 min). The 2 min building NH3 concentrations were calculated by taking the maximum of the recorded average concentrations of the two instruments.

The PAC III ammonia instruments were replaced halfway through the monitoring session because the data storage memory would be exceeded after four days. The ammonia instruments were calibrated prior to being deployed for this monitoring session and checked with calibration gas (master standard mixture, Messer MG Industries, Morrisville, Pa.) for compliance upon retrieval from the field.

The PMUs also monitored the building static pressure difference (0 to 125 Pa; model 264, Setra Systems, Inc, Boxborough, Mass.), which was used in the calculation of ventilation rate and carbon dioxide concentration (infrared transmitter, 0 to 5000 ppm ± 20 ppm; model GMT222, Vaisala, Inc., Woburn, Mass.). An external data logger (HOBO, 4-channel external, Onset Computer Corp., Bourne, Mass.) inside the PMU stored carbon dioxide, static pressure, and PMU internal air temperature data at 1 min intervals.

Fan ventilation rate during each 30 min data collection interval was determined via total fan motor-data logger run time (HOBO on/off motor, Onset Computer Corp.), average static pressure difference, and in situ evaluation of fan capacity versus static pressure determined with the FANS unit, corrected to standard conditions (STP).

House air temperature was measured (HOBO Pro Series, Onset Computer Corp.) near the house center about 30 cm above the floor and used for calculations of standard conditions for both emission instrumentation locations. Local site elevation was used to adjust to standard pressure.

**Broiler House Characteristics**

The houses were located in central Pennsylvania; a portion of the U.S. considered a cold climate with about 3250 heating degree days (18.3 °C base). The houses were identical in design and operated by an experienced broiler manager. Each house was 14.6 m wide × 152.4 m long and housed a nominal 32,000 birds (Cobb-Cobb strain) while populated. For emissions expressed in terms of 500 kg animal unit (AU), a typical final house population of 32,000 birds at 2.0 kg final weight was used for these study houses, resulting in 128 AU. Houses had fully insulated suspended ceilings and walls. Ventilation system design was identical, including fan models, inlet design (automatically static pressure controlled), and electronic controller. Partial house brooding was practiced. Ventilation system detail is available in Wheeler et al. (2006) but in summary consisted of sidewall exhaust fans with intermittent box inlets at the eave for cold and mild weather ventilation and tunnel ventilation for the warmest weather and/or older birds. Wood shavings (15 cm) were used as the base for the litter when installed new eight months earlier in March 2003. The built-up litter reported here was utilized by the last five of six broiler flocks monitored as part of the study by Wheeler et al. (2006). During this monitoring session, a 127 cm fan was normally running any time a person was in the building, generally between 8:00 a.m. until 6:00 p.m. (one exception to this occurred in house 2 on day 1, explained in detail later). Whenever a fan was running, one drive-through end door was open with the building sidewall eave ventilation inlets also open. When a fan was not running, the building ventilation inlets remained open and both drive-through end doors were shut.

Litter samples were taken on day 1 of the downtime period for nutrient and moisture content. Thirty litter samples were collected throughout the house floor in proportion to the floor area occupied by water-feed lines, radiant heaters, and open
resting space, according to the litter sampling protocols of Singh et al. (2004). All 30 litter samples made up a composite litter sample that was mixed thoroughly and then subsampled, sealed in a manure sample container, and analyzed via standardized methods by the Agricultural Analytical Services Laboratory on the Pennsylvania State University campus for total nitrogen (N), ammonium-N, organic N, and dry matter. This same procedure was used to collect litter samples from both study houses one week prior to the end of the previous flock. Composite samples from both houses were combined for a pH analysis.

RESULTS AND DISCUSSION

HOUSE CONDITIONS

During day 1 of the monitoring period, both houses underwent caked litter removal and blading to redistribute the litter evenly. During the second and fifth day, the remaining litter was harrowed and disked. Pressurized air cleaning of feed and water lines and fans occurred on day 4. There was no in-house work performed on days 3 and 6. Results of the litter sample analysis are presented in table 1. Built-up litter pH was determined to be 8.1 from a composite sample from both houses taken one week prior to bird removal. House temperature averaged 10.2 °C (table 2), well below typical grow-out temperatures of 20 °C to 30 °C. There was no house temperature control during the monitoring period; one exhaust fan was controlled manually to ensure fresh air for the operators.

EMPTY-HOUSE EMISSIONS DURING FAN OPERATION

Figures 1 and 2 show ammonia concentration in house 2 and house 3, respectively, and emission rate (ER) during times when mechanical ventilation was in use. ER is shown as zero during times when no fan was operating even though in reality there was an unmeasured ER via natural ventilation (infiltration/exfiltration). Table 3 provides emission data in terms of actual emission during fan ventilation periods. In table 3, the total ER per period used the average NH₃ concentration during fan run-time and the actual time the exhaust fan was running. The estimated daily ER was calculated using the average NH₃ concentration during fan run-time and 24 h of exhaust fan operation. The highest period emission rates per unit time in both houses were observed on day 2, which included the first harrowing of the built-up litter. The highest emission rate in house 3 was 1.1 kg NH₃ h⁻¹ on day 2, with a 6-day total monitored ammonia emission of 29.3 kg. The highest emission rate in house 2 was 0.71 kg NH₃ h⁻¹ on day 2, with a 6-day total monitored ammonia emission of 21.5 kg. Hourly emission rates in the two houses ranged from 0.21 to 0.71 kg NH₃ h⁻¹ in house 2 and from 0.21 to 1.1 kg NH₃ h⁻¹ in house 3. Trends of time periods having generally higher or lower ER were similar between the two houses since litter management was the same.

The average ammonia concentration in a house during the day while a fan was running was 23 ppm for house 2 and 27 ppm for house 3. Two weeks prior to these measurements, with both houses still populated with birds, during a 48 h emissions monitoring period the average (standard deviation [SD]) ammonia level in house 2 was 75 (15) ppm (bird age 5 weeks) and 65 (8) ppm in house 3 (bird age 4.4 weeks). These populated-house ammonia levels were higher than desirable in this final week of bird production. The ventilation rate during that final monitoring period averaged (SD) 35,040 (9720) m³ h⁻¹ for house 2 and 29,700 (8160) m³ h⁻¹ for house 3, or about 1.01 m³ h⁻¹ bird⁻¹. The house interior temperature averaged (SD) 24.9 °C (0.9 °C) and 25.8 °C (0.8 °C) in houses 2 and 3, respectively, and 9.1 °C (2.6 °C) outdoors. During the litter management period, the house ammonia level was lower due to a combination of lower environment temperature, reduced ventilation rate and associated lower velocities over the manure surface, and lack of fresh manure droppings. In addition, because of the tendency for reduced ammonia emission from manure/litter storage over time (Li, 2006), if an extended downtime between flocks is encountered, then the average daily ER value from the litter, as obtained in this study (based on 6 days), may not be appropriate to extrapolate in determining the total downtime emission. Moreover, ER during a summer downtime period will likely be higher because of warmer environmental temperature in the poultry house.

EMISSION DURING NATURAL VENTILATION

Emissions when a fan was running during the monitoring period only tell part of the between-flock emissions story of the house, since emissions can occur during times when a fan was not running. In addition, during times when the farm operators were working in the houses, one large endwall door (for machinery access) and the sidewall eave ventilation inlets were open. This practice could allow additional ventilation of the buildings that was not captured by monitoring ER only at the fan exhaust. Natural ventilation and emission would depend on wind forces acting on the house openings during those times. This natural ventilation during the time the fan was running was presumed insignificant for analysis due to reduced cross-flow ventilation with only one endwall door open and the operators’ use of the ventilation fan to improve their working conditions.

HOUSE 2 DAY 1 EXCEPTION

It is worth noting that day 1 for house 2 was a non-typical day. The ventilation fan only ran for 1 h because it was noted by the farm operators that during litter removal with both endwall doors open, a strong crosswind ventilated the house adequately. They decided to conserve electrical energy and turned off the fan. Without a fan running but with both end-

Table 1. Broiler litter nutrient content on day 1 of monitored downtime period (as-is basis), The pH of composite litter samples taken one week prior to bird removal from both houses averaged 8.1.

<table>
<thead>
<tr>
<th>House</th>
<th>Total N, g kg⁻¹ (lb ton⁻¹)</th>
<th>Ammonium-N, (NH₄-N), g kg⁻¹ (lb ton⁻¹)</th>
<th>Calculated Organic N, g kg⁻¹ (lb ton⁻¹)</th>
<th>Dry Matter Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>23.2 (46.4)</td>
<td>5.6 (11.2)</td>
<td>17.6 (35.2)</td>
<td>75.4</td>
</tr>
<tr>
<td>3</td>
<td>26.2 (52.3)</td>
<td>5.5 (11.0)</td>
<td>20.7 (41.3)</td>
<td>72.0</td>
</tr>
</tbody>
</table>

Table 2. House air temperatures (°C) during monitoring period.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.2 (3.7)</td>
<td>14.9</td>
<td>2.5</td>
<td>9.7 (2.6)</td>
<td>14.5</td>
<td>4.6</td>
</tr>
<tr>
<td>2</td>
<td>10.3 (1.9)</td>
<td>12.5</td>
<td>6.6</td>
<td>10.6 (2.4)</td>
<td>13.7</td>
<td>6.2</td>
</tr>
<tr>
<td>3</td>
<td>14.1 (1.2)</td>
<td>16.0</td>
<td>12.2</td>
<td>13.0 (1.2)</td>
<td>15.2</td>
<td>11.0</td>
</tr>
<tr>
<td>4</td>
<td>14.4 (1.7)</td>
<td>16.8</td>
<td>10.6</td>
<td>13.9 (1.5)</td>
<td>16.4</td>
<td>10.2</td>
</tr>
<tr>
<td>5</td>
<td>8.3 (2.1)</td>
<td>12.5</td>
<td>5.0</td>
<td>8.0 (1.9)</td>
<td>11.8</td>
<td>4.6</td>
</tr>
<tr>
<td>6</td>
<td>9.1 (1.2)</td>
<td>10.6</td>
<td>5.8</td>
<td>8.8 (1.2)</td>
<td>10.6</td>
<td>5.4</td>
</tr>
</tbody>
</table>
wall doors open, a substantial, but unmeasured, emission occurred. Outside wind velocities and direction were not recorded during this monitoring period, but it is recommended that they be included in future studies.

**DISKING, HARROWING, AND DUST EVOLUTIONS**

The litter management practices of disking and harrowing caused peaks in ammonia emission rates, as shown in figures 1 and 2. For example, disking and harrowing on day 2 caused the highest ammonia emission rates recorded during the 6-day monitoring period, 28.6 g NH$_3$ min$^{-1}$ in house 2 and...
27.9 g NH₃ min⁻¹ in house 3. Similar evolutions occurred twice a day for about 1 h each. Once the litter was harrowed on day 2, ammonia concentration decreased over the course of each day and for each subsequent day. This trend is more evident with the house 3 data in figure 2. Figures 1 and 2 reveal that following harrowing, and after the fan was turned off on day 2, the NH₃ concentration was 153 ppm in house 2 and 138 ppm in house 3, but it gradually decreased over time. The most probable explanations for the reduction in concentration was the NH₃ leaving the building through limited ventilation or reduced volatilization. Over the course of the monitoring period following harrowing, the peak NH₃ concentrations decreased over each following day.

It should be noted that dust-causing events, such as pressurized air cleaning of feed lines and water pressure-washing of the ventilation fans, did cause a slight increase in measured ammonia levels.

### Emission Rates (ER)

Expressed in terms of ER per market weight bird, the values calculated during litter management periods between flocks ranged from 6.6 to 34.6 mg NH₃ bird⁻¹ h⁻¹, with a 6-day average (SD) of 13.9 (7.1) and 17.2 (11.4) mg NH₃ bird⁻¹ h⁻¹ for houses 2 and 3, respectively, during the study period. For the six flocks at this farm studied over one year as part of the multi-state ammonia emissions project (Wheel er et al., 2006), an estimated emission relationship was developed:

\[
ER \ (\text{g} \ \text{NH}_3 \ \text{bird}^{-1} \ \text{d}^{-1}) = 0.038 \times \text{age (d)} - 0.098
\]

\[r^2 = 0.82\] (1)

Assuming a steady ER over a 24 h period due to the controlled environment conditions within these houses, an hourly ER can be estimated from the above equation. For comparison, at the end of a 42-day flock cycle on this farm, the ER estimate from the above relationship would be 63 mg NH₃ bird⁻¹ h⁻¹ (1.5 g NH₃ bird⁻¹ d⁻¹). The average ER found during the cleanout period was 22% and 27% of that observed at the end of a grow-out with market weight birds in houses 2 and 3, respectively. The reduced ER during the clean-out period was anticipated, since the built-up litter was at a lower temperature than during grow-out and there was no further fresh manure addition contributing to potential ammonia volatilization. Additionally, the ER variation between these two identical houses demonstrated the need for data collection from more than one representative house.

Emission rates found during the empty house study period were lower than ammonia emission rates of U.S. broilers raised under typical commercial conditions to 42 days on built-up litter. Ammonia emission data have been fairly consistent among studies, ranging from 0.63 (Lacey et al., 2003) and 0.70 g NH₃ bird⁻¹ d⁻¹ (Wheel er et al., 2006) to 0.92 (Burns et al., 2003) and 1.18 g NH₃ bird⁻¹ d⁻¹ (Seifert et al., 2004). The above values represent ER of mid-weight birds (for example, at 21 days for a 42-day flock) during the flock cycle.

When expressed in terms of 500 kg animal unit (AU), ER ranged from 1.66 to 8.65 g NH₃ AU⁻¹ h⁻¹, with a daily average (SD) of 3.48 (1.77) and 4.30 (2.85) g NH₃ AU⁻¹ h⁻¹ for houses 2 and 3, respectively. These values were 20% to 25% of emissions during the six flocks monitored on this farm during the multi-state ammonia emission project (Wheel er et al., 2006), where ER per AU was estimated at 17.4 g NH₃ AU⁻¹ h⁻¹ (418 g NH₃ AU⁻¹ d⁻¹) after the flock was 10 days old (higher ER per AU were observed for younger birds).

Another way of expressing emission rate is in terms of the emitting surface or floor area. ER during the study period averaged 0.200 and 0.247 g NH₃ m⁻² h⁻¹ for houses 2 and 3, respectively, over the 6-day study period. These values are 25% and 31%, respectively, of the 0.802 g NH₃ m⁻² h⁻¹ (19.24 g NH₃ m⁻² d⁻¹) ER of market weight birds determined during the six flocks monitored on this farm (Wheel er et al., 2006).

The temptation will be to use the hourly data from this study for daily estimates of emission rate. This may be useful considering the following discussion points. From figures 1

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**Table 3. Ammonia emission rates (ER) from depopulated 14.6 × 152.4 m broiler houses.**

(AU calculations based on 2.0 kg bird weight and 32,000 bird population).

<table>
<thead>
<tr>
<th>Avg. (SD) Ammonia Conc. (ppm)</th>
<th>Fan Run-Time (min d⁻¹)</th>
<th>Ventilation Rate at STP (m³ h⁻¹)</th>
<th>Fan Run-Time ER (kg NH₃ d⁻¹)</th>
<th>ER per Bird (g NH₃ h⁻¹)</th>
<th>ER per AU (g NH₃ AU⁻¹ h⁻¹)</th>
<th>ER per Floor Area (g NH₃ m⁻² h⁻¹)</th>
<th>Estimated Daily ER (w/24 h fan) (kg NH₃ d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>House 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td>17 (18)</td>
<td>64</td>
<td>30485 (1124)</td>
<td>0.4</td>
<td>398</td>
<td>12.4</td>
<td>3.11</td>
</tr>
<tr>
<td>Day 2</td>
<td>32 (28)</td>
<td>652</td>
<td>32792 (308)</td>
<td>7.7</td>
<td>707</td>
<td>22.1</td>
<td>5.52</td>
</tr>
<tr>
<td>Day 3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Day 4</td>
<td>29 (8)</td>
<td>776</td>
<td>31605 (951)</td>
<td>8.5</td>
<td>655</td>
<td>20.5</td>
<td>5.12</td>
</tr>
<tr>
<td>Day 5</td>
<td>21 (9)</td>
<td>660</td>
<td>31205 (1717)</td>
<td>2.8</td>
<td>253</td>
<td>7.9</td>
<td>1.98</td>
</tr>
<tr>
<td>Day 6</td>
<td>17 (4)</td>
<td>610</td>
<td>32349 (636)</td>
<td>2.2</td>
<td>213</td>
<td>6.6</td>
<td>1.66</td>
</tr>
<tr>
<td>Avg.</td>
<td>23</td>
<td></td>
<td>13.9</td>
<td>3.48</td>
<td>200</td>
<td>13.4</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2762 min/6 d</td>
<td>21.5 kg/6 d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>House 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td>21 (7)</td>
<td>326</td>
<td>31559 (326)</td>
<td>2.9</td>
<td>529</td>
<td>16.5</td>
<td>4.13</td>
</tr>
<tr>
<td>Day 2</td>
<td>48 (20)</td>
<td>710</td>
<td>31606 (153)</td>
<td>13.1</td>
<td>1107</td>
<td>34.6</td>
<td>8.65</td>
</tr>
<tr>
<td>Day 3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Day 4</td>
<td>28 (5)</td>
<td>776</td>
<td>31097 (352)</td>
<td>8.5</td>
<td>660</td>
<td>20.6</td>
<td>5.16</td>
</tr>
<tr>
<td>Day 5</td>
<td>19 (5)</td>
<td>664</td>
<td>31587 (867)</td>
<td>2.7</td>
<td>243</td>
<td>7.6</td>
<td>1.90</td>
</tr>
<tr>
<td>Day 6</td>
<td>16 (2)</td>
<td>604</td>
<td>31503 (508)</td>
<td>2.2</td>
<td>212</td>
<td>6.6</td>
<td>1.66</td>
</tr>
<tr>
<td>Avg.</td>
<td>27</td>
<td></td>
<td>17.2</td>
<td>4.30</td>
<td>247</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3080 min/6 d</td>
<td>29.3 kg/6 d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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and 2, it can be seen that during times when the houses were mechanically ventilated (MV) (mid-day hours with one open drive-through door and fan running), the ammonia concentration in the house was substantially lower than at night when only the box inlets were open for natural ventilation (NV) (fan off and house doors closed). There was a consistent inverse relationship between ammonia concentration and ventilation rate (VR) observed during the yearlong study of the 12 broiler houses when populated with birds (Wheeler et al., 2006). Although this trial during house depopulation was unable to measure natural ventilation rates for use in estimating emissions during times when the fan was not operating, the authors conclude that the VR was substantially lower than that experienced during the MV periods, as indicated by the elevated ammonia level in the houses. Over time, during the NV times, the ammonia concentration declined slowly, indicating that air exchange reduced aerial concentration and/or suppressed ammonia volatilization from the built-up litter surface occurred. If the average hourly ER during the fan run-time is used during the naturally ventilated times to make a 24 h day, then estimated daily ammonia emission rates ranged from 9.6 to 27.8 kg d⁻¹, with a daily average of 13.4 and 15.3 kg d⁻¹ for houses 2 and 3, respectively. The higher ERs were observed on days during which litter was harrowed. The above extrapolation of data assumes that NV periods with high ammonia concentration and reduced VR affected the same ER as MV time periods when higher VR were coupled to lower ammonia concentration. The above assumption may not always hold true, so the daily ER values must be used as rough estimates compared with the greater certainty of the measured hourly ER values.

**SUMMARY AND CONCLUSIONS**

Reusing broiler litter between flocks requires management practices to improve the environment for the next flock of chickens. The built-up litter in this study had been used for five broiler flocks. Emission rates were calculated during times that ventilation fans were running in two identical commercial broiler houses. Emission rates were not calculated during house natural ventilation (times when ventilation fans were not running) or during the two days prior to placing the next flock (cook-off period). House temperatures during the monitored cleanout period averaged about 10°C, in contrast to the typical 20°C to 30°C when birds are present. This study was conducted during cool outdoor weather; during warmer weather, an increase in ammonia volatilization would likely contribute to a higher emission rate.

The common management practices of de-caking, diskng, harrowing, and removing some of the used litter from the building results in the release of ammonia to the atmosphere. The ammonia emission rates during periods when these litter management practices were used with no birds in the house ranged from 212 to 1107 g NH₃ h⁻¹. Emission rate expressed per market weight bird (2.0 kg) that had occupied the houses ranged from 6.6 to 34.6 mg NH₃ bird⁻¹ h⁻¹, with an average (standard deviation) of 13.9 (7.1) and 17.2 (11.4) mg NH₃ bird⁻¹ h⁻¹ for houses 2 and 3, respectively. The daily ER was highest on day 2, coinciding with the first harrowing of the litter, and then decreased over subsequent days. Average ER values were about one-fourth (25%) of the typical ER values for market weight birds observed during flock grow-out in these same houses over the six flocks.

There is need for data collection from more than one representative house, as evidenced by ER variation between these two identical houses. The litter management practices achieved the goal of releasing ammonia from the litter for a healthier growing media for the next flock of chickens. This was indicated by the declining house ammonia concentration and emission rates over the 6-day study period between flocks.

When calculating total flock or annual house emissions, the period during house depopulation needs to be included. This study suggests that an emission value for an unheated house during cool weather litter management can be estimated as about one-fourth of the typical house emissions experienced during the final days of grow-out. Further studies are recommended to document emissions during naturally ventilated conditions, add periods of warmer weather, and collect data from the pre-heat period prior to placement of the next flock.

**REFERENCES**


