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Tyson Broiler Ammonia Emission Monitoring Project: Final Report

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Tyson Broiler Ammonia Emission Monitoring Project: Final Report

Abstract
This report describes the measurement methodologies and results of ammonia (NH3) emissions from two typical Tyson broiler production houses located in western Kentucky. During this study, comprised over 13 months and with six flocks per house, a total of 12 flocks of high quality emissions data were collected. Continuous measurement over a one-year period allowed for delineation of variations in emissions due to seasonal effects, animal growth cycles, and litter conditions. The study was led by Iowa State University (ISU), in collaboration with the University of Kentucky (UK). Data from this study add to and improve the national inventory on ammonia emissions from animal feeding operations (AFOs), especially broiler houses in the southeastern United States.

The two broiler houses monitored in this study are designated as Tyson 1-5 or T1-5 and Tyson 3-3 or T3-3 in this report. The monitoring periods reported are 10/07/05 – 11/27/06 for T3-3 and 12/09/05 – 1/09/07 for T1-5. Note that ammonia monitoring began on 10/01/05 in both houses, but no birds were placed in T1-5 until 12/09/05, explaining the different emissions reporting periods. The ammonia emissions reported in this study are based on continuous measurements of ammonia concentration in the inlet and exhaust air and the corresponding mechanical ventilation rate at each broiler house. Two Mobile Air Emissions Monitoring Units (MAEMUs), housing state-of-the-art measurement equipment, calibration accessories, and data acquisition systems, were developed at Iowa State University and used for this monitoring project.

Prior to the initiation of monitoring, a series of performance tests were conducted to confirm that the monitoring systems were working as designed and to determine representative locations for air sampling points. An EPA Category 1 Quality Assurance Project Plan (QAPP) – a substantial, 400-page document that outlines the methodologies for the project – was developed by the monitoring team. This Category 1 QAPP was reviewed and approved by EPA. In addition, the project underwent and passed two technical audits: a technical audit by Battelle personnel (contractors hired by EPA) confirming conformance of the project implementation with our QAPP, and an additional technical audit conducted by two nationally prominent agriculture air quality scientists.

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Poultry or Avian Science

Comments
The magnitude of ammonia emissions in this study is expressed as annual total on the basis of per bird, per animal unit (AU, = 500 kg or 1100 lb live body weight) or per 1,000 birds marketed, daily mean, daily maximum, flock total, during downtime (i.e., between flocks), and, with a 10% or less uncertainty. These respective values are: a) annual (365-d) emission (including downtime emissions) of 5.1 US tons per house or 77.9 lb/1,000 birds marketed (or 35.4 g/bird marketed); b) 12-flock daily mean (± standard deviation) emission of 30.8 ± 20.0 lb/d-house or 0.91 ± 1.29 lb/AU-d; c) maximum grow-out daily emission of 67.4 lb/d-house for T1-5 and 78.2 lb/d-house for T3-3; d) mean (± SD) flock total emission of 1545 ± 298 lb/flock; and e) mean (± SD) downtime emission of 19.3 ± 18.2 lb/d-house. Flocks on new litter had a lower emission rate of 27.2 ± 20.6 lb/d-house, as compared to 32.0 ± 19.6 lb/d-house for flocks on built-up litter. Ammonia emission tended to be higher during the warmer weather. Bird age is the predominant influencing factor on ammonia emissions. As such, an empirical equation has been established that relates ammonia emission to...
bird age for the monitored broiler houses. Compared with the US EPA ammonia emission factor of 100 g/yr-bird (100 g/bird marketed), the magnitude of emission reported from this study is 35.4% of the EPA cited value. The use of an emission factor is not advised for systems such as broiler facilities in which substantial progressive daily variation occurs as birds grow and then are removed repeatedly over a year. The use of emission per 1000 birds marketed more realistically captures the events and allows for emission inventory tracking.

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Tyson Broiler Ammonia Emission Monitoring Project:

Final Report

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Date of Report: May 1, 2007
Executive Summary

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**Introduction**

Ammonia emissions from animal feeding operations (AFOs) have been estimated to represent the largest portion of the national ammonia emissions inventory in the United States (Battye et al. 1994). According to the most recent estimates by EPA (2005), broilers constitute 54% of poultry contributions to the U.S. ammonia inventory, and 14.8% of animal agriculture emissions. A comprehensive review by the National Academy of Science (NAS, 2003) regarding air emissions data pertaining to the U.S. AFOs concluded that such data are lacking for U.S. animal production conditions. The review called for collection of baseline emission data and development of process-based models to predict such air emissions. The objective of this study was to determine and report NH$_3$ emissions based on continuous measurement of NH$_3$ concentrations and fan flow data over a one-year period from two broiler houses representative of commercial broiler production in the southeastern United States. The emissions data presented in this report were collected using continuous ammonia emissions monitoring over a 13+ month period at two Tyson broiler production houses in western Kentucky.

**Monitoring System Description**

**Study Sites and Monitoring System Overview**

Two broiler houses associated with Tyson Foods broiler operations in western Kentucky were monitored for NH$_3$ emissions. The locations of the monitored facilities in Kentucky are shown in Figure 1, and the location of the specific house at each site is shown in aerial photos in Figure 2. The monitored broiler production houses use tunnel ventilation and static pressure controlled box air inlets along the sidewalls (Figure 3), which is representative of the typical production practices in terms of housing style (for example, tunnel ventilation) and environmental control strategy (for example, pancake brooder along with space heaters), bird management (for example, half-house brooding), and typical litter management and handling schemes (for example, de-caking houses between flocks and approximately annual litter removal).

To continuously quantify dynamic NH$_3$ emissions from broiler production systems, an accurate and responsive measurement system was needed. The mass of NH$_3$ emitted from a facility is the product of the NH$_3$ concentration and volume of air exchanged through the facility. The use of intermittent ventilation by cycling ventilation fans off and on, especially when the birds were young, made it necessary to coincide in-house pollutant concentrations to periods of fan operation in order to properly calculate representative emissions.
The NH₃ emission measurement system for this project used a photoacoustic NH₃ analyzer (0-2000 ±0.2 ppm; INNOVA model 1412, INNOVA AirTech Instruments A/S, Denmark) in conjunction with a custom-fabricated multi-point sample acquisition system and calculation of exhausted air volumes based on fan curves obtained on-site using the Fan Assessment Numeration System (FANS) developed in the US (Gates et al., 2004).

Each broiler house had its own Mobile Air Emissions Monitoring Unit (MAEMU) that housed air pollutant and fan flow monitoring systems, and provided an environment-controlled instrument space as shown in Figure 4. Air sampling lines from the broiler house sampling points (representing the exhaust air streams) to the instrument trailer/analyzers were protected against in-line moisture condensation with insulation and temperature-controlled resistive heating cable. Fan operational status and building static pressure were both continuously monitored (1-second intervals). These data were used in conjunction with individual fan operation curves to calculate the flow rate exhausted by each fan during operation. A real-time data acquisition system (DAQ) program was developed using LabView 7 software (National Instruments, Corporation, Austin, TX) and used to acquire data, automate sampling location control, display real-time data, and deliver data and system operation status as shown in Figures 5 and 6. The system was connected to the internet via high-speed satellite.

Each MAEMU housed a gas sampling system, gas analyzers, environmental instrumentation, a computer, data acquisition system, and other peripheral devices and equipment needed for the study. The sampling periods were 13 and 13.6 months for Tyson 1-5 and Tyson 3-3, respectively. Gaseous samples were continuously collected and analyzed every 30 seconds, with every fourth concentration value used in the emission calculation. Using this approach gaseous emissions were sampled continuously on a 120-second interval. Emissions were calculated using the concentrations measured when the house ventilation system was in operation. The 13-plus months duration assured that the project characterized long-term emissions, hence the impacts of climatic conditions of different seasons and grow-out cycles (litter age and condition).
Figure 1. Broiler house air emission measurement sites in Kentucky.

Figure 2. Aerial photos indicating the locations of each monitored broiler house.
Figure 3. Tunnel ventilation fans and static pressure-controlled box air inlets representative of typical southeastern broiler facilities.

Figure 4. Environmentally-controlled Mobile Air Emissions Monitoring Units (MAEMU).
Broiler House Characteristics

The two broiler houses each measured 13.1 m x 155.5 m (43 x 510 ft), were built in the early 1990s, and were located at two farm sites 40 miles apart in western Kentucky. The houses had insulated drop ceilings (about R19), box air inlets (15 x 66 cm or 6 x 26 inch) along the sidewalls (26 per sidewall), 26 pancake brooders (8.8 kW or 30,000 Btu/hr each), three space furnaces (65.9 kW or 225,000 Btu/hr each), four 91-cm (36-in) diameter sidewall exhaust fans spaced...
about 36.6 m (120 ft) apart, and ten 123-cm (48-in) diameter tunnel fans. The 91-cm (36-in) fan (SW1) for minimum ventilation was located in the brood end of the houses away from the tunnel end. Two 24-m (80-ft) sections of evaporative cooling pads were located in the opposite end of the tunnel fans. The houses were also equipped with foggers for additional cooling, if needed. Rice hulls were used as litter bedding in both Tyson 1-5 and Tyson 3-3.

**Flock Characteristics**

The starting times of the ammonia emission monitoring were Oct 7, 2005 and Dec 9, 2005 for Tyson 3-3 and Tyson 1-5, respectively. After 365 days of continuous monitoring at each site, five flocks had been completed for each house and the sixth flocks were ongoing in the two houses (Table 1). The study was continued through the sixth flock at both houses. At the end of the monitoring, six flocks were monitored from each house and ending dates were Nov 27, 2007 and Jan 9, 2007 for Tyson 3-3 and Tyson 1-5, respectively. Each house had an initial placement of 25,800 Cobb-Cobb straight-run (mixed sex) broilers in winter and 24,400 in summer. The average grow-out periods were 51 d and 52 d for Tyson 1-5 and Tyson 3-3 respectively. A bird scale was placed in each house to continuously monitor bird weight. Bird mortality was also recorded, allowing for expression of emission on the basis of per bird or per 500 kg animal unit (AU). Both houses had new litter at the beginning of the monitoring. During the one-year period, one cleanout of the litter was performed for Tyson 1-5 on Aug 26, 2006 (after 4 flocks) and new bedding was placed on Aug 29, 2006; Tyson 3-3 did not have a litter cleanout during the monitoring period.
Table 1. Description of in-flock and between-flock information during the ammonia emission monitoring period.

<table>
<thead>
<tr>
<th>Start Date</th>
<th>End Date</th>
<th>Flock name</th>
<th>House Condition</th>
<th>Litter condition</th>
<th># of birds placed</th>
<th>Total # of days</th>
<th>Monitored # of days</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/9/05</td>
<td>1/28/06</td>
<td>Flock 1</td>
<td>Occupied</td>
<td>New</td>
<td>25,810</td>
<td>51</td>
<td>51</td>
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<tr>
<td>1/29/06</td>
<td>2/13/06</td>
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<td>built-up</td>
<td></td>
<td>16</td>
<td>15</td>
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<tr>
<td>2/14/06</td>
<td>4/4/06</td>
<td>Flock 2</td>
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<td>built-up</td>
<td>25,830</td>
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<td>50</td>
</tr>
<tr>
<td>4/5/06</td>
<td>4/20/06</td>
<td></td>
<td>Empty</td>
<td>built-up</td>
<td></td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>4/21/06</td>
<td>Flock 3</td>
<td>Occupied</td>
<td>built-up</td>
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<td>50</td>
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<tr>
<td>6/10/06</td>
<td>6/21/06</td>
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<td>Empty</td>
<td>built-up</td>
<td></td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>6/22/06</td>
<td>8/10/06</td>
<td>Flock 4</td>
<td>Occupied</td>
<td>built-up</td>
<td>24,465</td>
<td>50</td>
<td>50</td>
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<tr>
<td>8/11/06</td>
<td>9/4/06</td>
<td></td>
<td>Empty</td>
<td>New/built-up</td>
<td></td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>9/5/06</td>
<td>Flock 5</td>
<td>Occupied</td>
<td>New</td>
<td>25,695</td>
<td>51</td>
<td>51</td>
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<td>10/26/06</td>
<td>11/16/06</td>
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<td>22</td>
<td>21</td>
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<tr>
<td></td>
<td>11/17/06</td>
<td>Flock 6</td>
<td>Occupied</td>
<td>built-up</td>
<td>25,080 *</td>
<td>54</td>
<td>50</td>
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<tr>
<td>10/7/05</td>
<td>11/29/05</td>
<td>Flock 1</td>
<td>Occupied</td>
<td>New</td>
<td>25,794</td>
<td>54</td>
<td>51</td>
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<td>11/30/05</td>
<td>12/14/05</td>
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<td>Empty</td>
<td>built-up</td>
<td></td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>12/15/05</td>
<td>2/3/06</td>
<td>Flock 2</td>
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<td>built-up</td>
<td>25,180</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>2/4/06</td>
<td>2/19/06</td>
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<td>Empty</td>
<td>built-up</td>
<td></td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>2/20/06</td>
<td>4/10/06</td>
<td>Flock 3</td>
<td>Occupied</td>
<td>built-up</td>
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<td>41</td>
<td>39</td>
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<tr>
<td>5/22/06</td>
<td>7/11/06</td>
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<td>built-up</td>
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<td>51</td>
<td>48</td>
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<tr>
<td>7/12/06</td>
<td>7/27/06</td>
<td></td>
<td>Empty</td>
<td>built-up</td>
<td></td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>7/28/06</td>
<td>9/19/06</td>
<td>Flock 5</td>
<td>Occupied</td>
<td>built-up</td>
<td>24,380</td>
<td>54</td>
<td>53</td>
</tr>
<tr>
<td>9/20/06</td>
<td>10/4/06</td>
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<td>Empty</td>
<td>built-up</td>
<td></td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>10/5/06</td>
<td>11/27/06</td>
<td>Flock 6</td>
<td>Occupied</td>
<td>built-up</td>
<td>25,778</td>
<td>54</td>
<td>53</td>
</tr>
</tbody>
</table>

* This flock had unexpected high mortality due to the improper vaccine procedure at the hatchery.

Monitoring System Specifics

Ammonia concentrations of the background and exhaust air were measured with an advanced photoacoustic NH₃ analyzer (INNOVA model 1412, INNOVA AirTech Instruments A/S, Denmark), an EPA-accepted measurement equipment for AFO NH₃ emission monitoring. This type of analyzer has been widely used by European scientists and recently used by U.S. scientists in AFO air emission studies (Fenyvesi, et al., 2001, Nicks et al., 2003, Guarino et al., 2003). These units proved to be accurate, responsive and stable over a one-year period of use. The INNOVA 1412 multi-gas analyzer was setup with a 1-second (s) sampling integration time and fixed flushing time: 2 s for the chamber and 3 s for the tubing; and the required time to complete one sampling cycle for NH₃, carbon dioxide and dew-point temperature measurements was approximately 22 s. The response time of the analyzer to step changes in gas
concentrations was tested. The response time for the measured concentration to reach 98% of the calibration gas value (T-98) for the given NH$_3$ calibration gas was 88 seconds using NH$_3$ calibration gas of both 22.8 and 60.8 ppm (±2% accuracy) (Matheson Gas Products, Inc., Montgomeryville, PA). Thus, four measurement cycles (88 seconds) were required to reach the 98% response level for NH$_3$. Using this approach, the first three readings were discarded and only the fourth reading was used for emission calculations. In April, 2006 hydrocarbon and nitrous oxide filters were added to the INNOVA 1412s. The time to complete a single measurement cycle increased from 22 seconds to 30 seconds. In turn this increased the time to complete four cycles from 88 seconds to 120 seconds. As before, only the fourth cycle measurements were used for emissions calculations.

Air samples were drawn from three locations in each house as well as from an outside location to provide ambient background data (Figure 7). One sampling location was near the primary minimum ventilation (36-in) sidewall fan (SW1) used for cold weather ventilation (in the brooding half of the house). The second sampling location was near the third sidewall (36-in) fan (SW3, non-brooding end). The third location was at the tunnel end (TE). The ambient sample location (A) was between the inlet boxes opposite of the sidewall with the exhaust fans. The quantity of gas in the background (inlet) air was subtracted from that in the exhaust air when calculating aerial emissions from the house.

Placement of the air sampling ports were as follows: for the two sidewall sampling locations, the sampling ports and temperature sensors were located 1.2 m (4.0 ft) away from the fan in the axial direction, 2.3 m (7.5 ft) in the radial direction, and 1 m (3 ft) above the floor. For the tunnel-end sampling location, the sampling port and temperature sensor were located at the center across the house (for example, 6.6 m or 21.5 ft from each sidewall) and 7.3 m (24.0 ft) from the end wall. Sampling locations and placement of the sampling ports were chosen to maximize representation of the air leaving the houses. Each sample inlet point was equipped with dust filters to keep large particulate matter from plugging the sample tubing, servo valves and ultimately the measurement instrument.

A positive pressure gas sampling system (PP-GSS) was used in the MAEMU for measurement of broiler house air emissions (Figure 8). The PP-GSS continuously pumps sample air from all locations using individual pumps. The sample air is bypassed when not analyzed. The schedules of sampling events and sequences are as follows. If the ventilation fans at the three in-house sampling locations (SW1-location 1, SW3-location 2 and TE-location 3) were all running, air samples from each location were collected sequentially via the controlled operation of the servo values of the PP-GSS. In this case, sampling/analysis sequence was SW1, SW3, and TE, and the cycle repeated. If fans at SW3 or TE were not running (for example, during half-house brooding), sample analysis was repeated for the SW1 location only, and the same was true for TE sampling when fans at SW1 and SW3 were not running (for example, during tunnel ventilation mode). Every two hours, air samples from the ambient (background) location were collected and analyzed for 8 minutes. The longer sample analysis time for the ambient point was to account for the longer response time of the instrument when measuring a large step change in gas concentration. Selection of the 2-hour interval for the analysis of the ambient
concentrations was due to the fact that the ambient conditions remained relatively constant, as compared to the in-house conditions. This arrangement helped maximize the number of data points collected from the exhaust air and thus provided more data for determination of house emissions.

Figure 7. Schematic layout of Tyson 1-5 and Tyson 3-3 broiler houses.
Figure 8. Schematic representation of the positive pressure gas sampling system (PP-GSS) used in the MAEMU for measurement of broiler house air emissions.

The PP-GSS continuously collected air from all locations with location-specific pumps. Teflon tubing (Fluorotherm FEP tubing) of 0.95-cm (3/8-inch) o.d. and 0.64-cm (1/4-inch) i.d. was used to deliver the sample air. The sample air was bypassed when not analyzed. Use of individual pumps to continuously draw air from the respective sampling locations reduced line-purging time and eliminated possible cross-location residual effect, especially between ambient/background air and exhaust air samples. The choice of sequential sampling was based on the assumption that any concentration changes at the given location during the two adjacent measurements (maximum of 360 seconds) followed a linear pattern. Hence, linear interpolation from the two adjacent measured values was used to determine intermediate values for the location, as needed. The use of one sampling location at the tunnel fan end of the house assumed good mixing of air and thus uniform distribution of the aerial concentrations during tunnel ventilation conditions. Examination of ammonia concentrations across the house in this section, through concurrent measurements using four INNOVA 1412 analyzers, confirmed the validity of this assumption. Moreover, it was assumed and validated that the vertical stratifications in aerial concentrations were negligible when the exhaust fans were in operation. Incidentally, appreciable vertical stratifications existed when the fans were off. Only samples collected when fans were operating were used for the calculation of ammonia emissions from the broiler houses.

Ventilation rates of the houses were measured using the following procedure. First, all the exhaust fans were calibrated in situ, individually and in combined operational stages, with a state-of-the-art fan assessment numeration system (FANS) to obtain the actual ventilation
curves (airflow rate vs. static pressure) (Gates et al., 2004). This calibration was essential to the accurate measurement of the house ventilation rate because actual fan airflow rates can vary in excess of 25% from one another and from the nominal values supplied by the fan manufacturer (Figure 9). The deviation arises from the field operational conditions that differ drastically from those under which the default values were established, for example, loose motor belts, and dirty shutter or fan blades. After the actual airflow curves were established for all of the exhaust fans and their combinations, runtime of each fan was monitored and recorded continuously using an inductive current switch (with analog output) attached to the power supply cord of each fan motor (Figure 10). Analog output from the current switches was connected to the compact Fieldpoint modules. Concurrent measurement of the house static pressure was made with two static pressure sensors (Model 264, Setra, Boxborough, MA), each for half of the house. While the pressure differential was not expected to differ at the two locations, two sensors were used to provide redundancy in this critical measurement. Summation of airflows from the individual fans during each monitoring cycle or sampling interval produced the overall house ventilation rate. This method of determining dynamic ventilation rates of mechanically ventilated animal confinement has been successfully used in recent AFO air emission studies in the United States.

![Variation in airflow rates among the 36-in and 48-in fans in Tyson 1-5 broiler house.](image)

**Figure 9.** Variation in fan airflow rates among the 36-in and 48-in fans in Tyson 1-5 broiler house.
Fan runtime sensor

Fan calibration by FANS unit

Figure 10. Photographical views of the fan operational sensor and the FANS unit.

Indoor and outdoor temperature and relative humidity (RH) were measured with robust and stable temperature (Type T thermocouple, Cole-Parmer, Vernon Hills, IL) and RH probes (HMW60, Vaisala, Woburn, MA) that were connected to the PC-based data acquisition system (DAQ). In addition, portable temperature/RH loggers were used as back-ups. Analog output of the static pressure sensors was also connected to the DAQ.

All the variables of NH₃ concentration, fan runtime, static pressure, air temperature and RH were continuously measured and recorded at one-second interval throughout the one-year study period. The collected raw data were archived and backed up each day.

**Emission Rate Determination**

Ammonia emission rate (ER) from a broiler house to the atmosphere is the difference between the quantity of ammonia leaving the house and the quantity of ammonia entering the house. The relationship of ER to NH₃ concentration of inlet and exhaust air and building ventilation rate may be expressed as following:

\[
ER = \sum_{e=1}^{3} Q_e \left( \frac{[NH_3]_e}{\rho_i} - \frac{[NH_3]_i}{\rho_i} \right) \times 10^{-6} \times \frac{w_m}{V_m} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}}
\]

where

- \( ER \) = NH₃ emission rate for the house (g hr⁻¹ house⁻¹)
- \( Q_e \) = ventilation rate of the portion of the house at location “e” (SW1, SW3 or TE) at field temperature and barometric pressure (m³ hr⁻¹ house⁻¹)
- \([NH_3]_i\) = NH₃ concentration of incoming house ventilation air, parts per million by volume (ppmv)
- \([NH_3]_e\) = NH₃ concentration of exhaust house ventilation air of the portion of the house at location “e” (ppmv)
- \( w_m \) = molar weight of NH₃, 17.031 g mole⁻¹
\( V_m = \) molar volume of \( \text{NH}_3 \) gas at standard temperature (0°C) and pressure (1 atmosphere) (STP), 0.022414 m\(^3\) mole\(^{-1}\)

\( T_{\text{std}} = \) standard temperature, 273.15 K

\( T_a = \) absolute house temperature, (°C+273.15) K

\( P_{\text{std}} = \) standard barometric pressure, 101.325 kPa

\( P_a = \) atmospheric barometric pressure for the site elevation, kPa

\( \rho_e = \) air density at exhaust fan location “e”, kg dry air m\(^{-3}\) moist air

\( \rho_i = \) air density at outside conditions, kg dry air m\(^{-3}\) moist air

As can be seen from equation [1] and description of the variables shown above, multiple measurements were required to determine the ammonia emission rate.

**System Checks**

Accuracy is defined as the degree of agreement between an observed value and an accepted reference value and includes a combination of random error (precision) and systematic error (bias). In this study, the following accuracy checks were implemented:

- Gas analyzers
- Exhaust fan flow rates
- Static pressure sensors
- Temperature and relative humidity sensors
- Barometric pressure sensor
- PP-GSS leakage and pump flow rates

The response times of the analyzers were tested in the lab prior to installation in the field. The actual on-site performance of the sampling system was further tested. Tests were performed by injecting ammonia span gas into the in-house sampling port of the longest sampling line (tunnel end, see Figure 11). The results of INNOVA 1412 analyzers from both houses are shown in Figures 12 and 13. For both sampling systems, the fourth ammonia concentration readings (30 s X 4=120 s) reached 96% and 97% of the span concentration.
Figure 11. Picture of span gas injection at the in-house sampling point.

Figure 12. Response time check of the sampling system and INNOVA analyzer at Tyson 1-5.
In addition to span gas challenge of the entire system at the farthest in-house sampling location, tests were conducted to compare the readings of a calibrated INNOVA 1412 analyzer located inside the monitoring trailer with three other calibrated INNOVA 1412 analyzers located at three sampling locations in the broiler house (SW1, SW3 and TE). The three in-house INNOVA 1412 analyzers continuously took samples during the entire testing period (Figure 14). All INNOVA 1412 analyzers were synchronized and calibrated with the same NH₃ calibration gases before the test.

Figure 14. One of the three in-house INNOVA analyzers used to compare readings to its counterpart inside the MAEMU.
At Tyson 1-5, the number of sampling cycles for the INNOVA in the MAEMU per location was set to 4, 6 or 8 cycles per location to test the response time effect. The NH₃ readings by the INNOVA 1412 in the MAEMU were compared with the respective readings by the three in-house INNOVA 1412s (Figure 15). Only the last readings from the MAEMU in each sampling cycle for each location were compared with the most recent readings from the INNOVA in the house. Five pairs of readings for each sampling cycle setting at each location were taken. A two-way ANOVA test was used for the statistic analysis. There was neither a sampling number effect nor location effect (P = 0.37). Table 2 provides a comparison of continuous in-house NH₃ readings with those obtained from location cycling by the MAEMU INNOVA at 4, 6, and 8 sampling iterations for Tyson 1-5 (unit: ppm). The results indicate that the NH₃ reading in the MAEMU matched the reading in the house at all three locations and there was no difference in using 4, 6 and 8 sampling iterations at each location. Hence, four sampling iterations were chosen to maximize the sampling frequency for each location. Because the fan operation period could be as short as 30 seconds while the birds were young and during cold weather, it was essential to quickly move between the sample locations to capture the temporal variability in ammonia concentration arising from the intermittent (on/off) operation of the fans. Since the NH₃ reading in the MAEMU matched the reading in the house at each location, it indicated that there was no leakage in the entire sampling system. The same test was conducted for Tyson 3-3 and yielded the same results.

During weekly field visits, each sampling line was checked by connecting a flow meter at the pump-end and blocking the in-house sampling port (Figure 16). If the flow meter read zero, it indicated no leakage in the sampling line under the negative pressure (from the in-house sampling port to the corresponding sampling pump inside the MAEMU). No leakage was detected throughout the monitoring period.

<table>
<thead>
<tr>
<th>No. of sampling Iterations</th>
<th>NH₃(in-house) – NH₃(MAEMU) (ppm)</th>
<th>P=0.37</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For sampling locations of SW1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SW3</td>
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<td></td>
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<td>SD</td>
<td></td>
<td></td>
</tr>
<tr>
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</tr>
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<td>0.46</td>
</tr>
<tr>
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<td>0.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.19&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>SD</td>
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<td>0.33</td>
<td>0.40</td>
</tr>
</tbody>
</table>

*Column or row means with the same superscript letter are not significantly different (P>0.10)

<table>
<thead>
<tr>
<th>Location</th>
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<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>SW3</td>
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</tr>
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<td>Tunnel</td>
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</table>

*Column means with the same superscript letter are not significantly different (P>0.10)
Figure 15. Comparison of ammonia readings from the MAEMU and in-house INNOVAs.

Figure 16. Schematic representation of the gas sampling system integrity (leakage) check.

Quality Assurance/Quality Control of Data Collection and Analysis

Strict Quality Assurance/Quality Control (QA/QC) procedures were followed throughout the data collection and data analysis processes. All measurement instruments underwent initial checks and calibrations, followed by regular operational checks and follow-up calibrations as dictated
by the QAPP. The frequency of such check/calibration depended on the instrument. For instance, the NH3 gas analyzer was checked with calibration gases weekly or semi-weekly, even though our past experience had indicated that this type of photo-acoustic NH3 analyzer has excellent stability. Calibration gases were certified with concentration of 22.6, 22.8, or 25 ppm ammonia (Balanced in air, certified grade with 2% accuracy, Matheson Tri-gas, PA). The INNOVA 1412 analyzers were checked once a week before February 2006 and then were checked twice a week after February 2006 to meet our data quality goal. The QC standard of instrument calibration is 5%. Based on the regular check results, the INNOVA 1412 analyzers were calibrated twice at Tyson 1-5 and three times at Tyson 3-3 during the grow-out periods. Internal technical system performance evaluations were performed between flocks.

The broiler houses had approximately two weeks of downtime between flocks. However, the downtime at Tyson 3-3 was 41 days after the first flock due to change of the managerial personnel at the site. During each downtime, ISU and UK project personnel conducted a thorough internal technical systems audit at each site. This audit included a visual inspection of all system components, and a flow check at each of the four sample points. During the system performance evaluation, the INNOVA 1412 analyzers were recalibrated. All temperature sensors were checked against a certified thermometer for every flock. The RH sensors and pressure sensors were checked or calibrated against a calibrated sensor or a RH sensor calibration kit (HMK 15, Vaisala, Woburn, MA) every six months. If the check result fell outside of 5% QC standard, recalibration would be performed and the corresponding data would be corrected, following a linear relationship between values from the previous check and current check.

The performance curves of the ventilation fans were checked after each flock. All exhaust fans were cleaned before the start of a new flock. An uninterrupted power supply (UPS) was used for the DAQ system to avoid loss of data due to power outage.

Two external technical systems audits were conducted by independent personnel during the project. Battelle personnel (commissioned by EPA) audited the systems on September 25-26, 2006 and agricultural air monitoring experts, Drs. Larry Jacobson and David Parker, (commissioned by Iowa State University) audited the systems on January 8 – 10, 2007. Both audits found that the QAPP was being fully and successfully implemented at both sites. As described in the QAPP, a data processing program was run daily to process the data collected on the previous day. This program calculated data completeness and automatically flagged out-of-range data. ISU project personnel reviewed the flagged data within two working days to confirm that the data were either invalid and should be excluded or valid and should be kept. To avoid errors introduced into determination of average values due to partial data days, which would result in biased time weights, only complete-data days (CDD) that included over 75% valid data were used in calculating average daily means (ADM). Based on the on-site surveillance and daily data flagging/review, daily data completeness for each variable was calculated.

**Uncertainty Analysis of Emission Rate**
Component error analysis is used to quantify uncertainty when a quantity such as daily emission rate is calculated from multiple measurements, each with its own degree of accuracy or uncertainty. A component error analysis (Doeblin, 1990) provides statistical meaning to a statement on the magnitude of error in the calculation of daily emission rate. This analysis had been performed for an earlier project that measured broiler house ammonia emissions and documented in a copyrighted Ph.D. dissertation (Casey, 2005) and a manuscript in preparation (Casey et al., 2007). The uncertainty analysis of ER for this study is described in detail in the project QAPP. The resultant ER uncertainty was 10% or less based on the accuracies of the associated measurement components and operating ranges for ventilation fans. Consequently, data quality objectives (DQOs) and measurement quality objectives (MQOs) were developed in the QAPP to guide the achievement of 10% or less ER uncertainty.

**Results and Discussion**

**Data Completeness**

“Data completeness is a measure of the amount of valid data obtained from a measurement system, expressed as a percentage of the number of valid measurements that should have been collected” (USEPA, 2002. EPA Guidance for Quality Assurance Project Plans. EPA QA/G-5). In this study, a data completeness goal of 75% of the scheduled sampling was established. The data completeness is primarily affected by unpredictable field events, including instrument malfunction, power outages due to adverse weather, and broiler house maintenance. When any of these events occurred, the corresponding emission data were flagged. The starting times of ammonia emission monitoring were Oct. 7, 2005 and Dec. 9, 2005 for Tyson 3-3 and Tyson 1-5, respectively. By the one-year mark (Oct. 6, 2006 for Tyson 3-3 and Dec. 8, 2006 for Tyson 1-5), five full flocks had been monitored at each site; the 6th flock had been monitored for 22 days for Tyson 1-5 and two days for Tyson 3-3. For the 365-d annual emission calculation, the CDDs to date are 355 out of 365 days (97.2% data completeness) and 346 out of 365 days (94.8% data completeness), respectively, for Tyson 1-5 and Tyson 3-3. Therefore, a total of 701 house-day emission data were used for the analysis of the annual emission. The monitoring was continued through the sixth flock at both houses for a full set of the sixth flock data; the ending dates of the monitoring were Nov 27, 2006 and Jan 9, 2007 for Tyson 3-3 and Tyson 1-5, respectively. By the end of the six flocks, the CDDs were 387 out of 397 days (97.5% data completeness) for Tyson 1-5 and 398 out of 417 days (95.4% data completeness) for Tyson 3-3. The 785 house-day (12 flocks) emission data were used for the emission rate of daily mean, daily maximum, flock total, and during downtime. The complete-data days (CDD) for each flock and in-between are summarized in Table 1.

**Diurnal Variation of Ammonia Emission Rate**

The ammonia ER is a combination of the difference in ammonia concentration between the exhaust air and the inlet air and building ventilation rate (VR). The diurnal variation of ammonia ER, concentration and VR, expressed as hourly averages for two growth periods on cold and warm days are shown in Figure 17. The hourly ammonia ER on the warm days had a clear
diurnal pattern following the VR. During cold weather, the hourly ammonia ER had less variation. The coefficient of variation (CV) of hourly ER on Day 38 of Flock 4 for Tyson 1-5 on July 29, 2006 was 16%. In contrast, the CV on Day 39 of Flock 6 for Tyson 1-5 was 6.2% on December 25, 2006. The CV of hourly ER on Day 5 for flock 5 and flock 6 for Tyson 1-5 was 79.6% and 8.1%, respectively. The considerable diurnal variation in flock 5 coincided with a warm day and the lower CV in flock 6 corresponded to a cold day with only minimum ventilation. Liang et al. (2005) reported similar daily ammonia ER variation trends for laying hen houses.
Figure 17. Diurnal patterns of exhaust ammonia concentration, ventilation rate (VR), and ammonia emission from Tyson 1-5.
Emission Rate

Figures 18 and 19 provide the daily ammonia ER for the two houses for the entire monitoring period with six full flocks and downtime between flocks. The daily ER (lb/d-house) varied from 0 to 98.6 lb/d-house. When the houses were occupied by birds, the highest ER was 67.4 and 78.2 lb/d-house for Tyson 1-5 and Tyson 3-3, respectively. The highest daily emission of 98.6 lb/d-house occurred at Tyson 1-5 between flock 2 and flock 3. The highest emission happened on April 6, 2006 when the litter was disturbed during litter-decaking operation (see Figure 18 c). Note that the emissions between the vertical dashed lines in Figures 18 and 19 represent periods between flocks when no birds were in the houses (i.e., downtime).

The ammonia ERs (0.55 ± 0.42 lb/d-house) from the flocks with new litter were significantly less (P<0.001) than those (13.36 ± 5.88 lb/d-house) with built-up litter during the first 6 days of grow-out. After that, ERs with new litter began to increase rapidly with bird age. For the flocks with built-up litter, the ammonia ERs were relatively stable during the first 2-3 weeks and then increased. The flocks with new litter did not show significantly higher ER than those with built-up litter (P=0.86) when the bird age was 7-d or older. There was a trend that the ERs reached the peak after 5-6 weeks and tended to stabilize through the end of the flock. During the grow-out periods, the ERs for the three flocks on new litter was 27.2 ± 20.6 lb/d-house, which is significantly lower than 32.0 ± 19.6 lb/d-house for the nine flocks raised on built-up litter. The ERs of all flocks varied from 25.7 lb/d-house to 37.7 lb/d-house, except flock 6 in Tyson 1-5 (Table 3). Flock 6 in Tyson 1-5 had over 40% of cumulative mortality by the end of the flock due to a vaccination complication, leading to a much lower ER of 18.6 lb/d-house. The average ER for Tyson 1-5 over the six flocks was 27.6 ± 17.2 lb/d-house which is significantly lower (from statistical standpoint) than 34 ± 21.9 lb/d-house for Tyson 3-3 (P=0.01). The average NH₃ ER for Tyson 3-3 downtime between flocks was 13.9 ± 15.0 lb/d-house. In contrast, the average ER at Tyson 1-5 for downtime between flocks was 26.2 ± 19.5 lb/d-house. Tyson 1-5 had two flocks with new litter while Tyson 3-3 only had one flock with new litter. Flock 4 in both houses and flock 5 in Tyson 3-3 had higher ERs than the other flocks under the warm weather conditions when the house ventilation system was in the tunnel mode to keep the birds cool. The average ER of all 12 flocks was 30.8± 20.0 lb/d-house.
Figure 18. Daily ammonia emission, ventilation rate and outside temperature over the six flocks for Tyson 1-5.
Figure 19. Daily ammonia emission, ventilation rate and outside temperature over the six flocks for Tyson 3-3.
Table 3. Summary of ammonia emission rates for the two broiler houses monitored.

<table>
<thead>
<tr>
<th>Starting time</th>
<th>Ending time</th>
<th>Flock name</th>
<th>House</th>
<th>Emission, lb/house(s)</th>
<th>Cumulative Emission, lb/house(s)</th>
<th>ER, lb/d-house</th>
<th>ER, g/bird-d</th>
<th>ER, g/AU-d</th>
<th>All 12 flocks (two houses)</th>
</tr>
</thead>
<tbody>
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<td>12/9/05</td>
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<td>302.0</td>
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<td>480.9</td>
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Tyson 1-5

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<th>Emission, lb/house(s)</th>
<th>Cumulative Emission, lb/house(s)</th>
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<th>ER, g/bird-d</th>
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Tyson 3-3

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<th>Cumulative Emission, lb/house(s)</th>
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<th>ER, g/bird-d</th>
<th>ER, g/AU-d</th>
<th>All 12 flocks (two houses)</th>
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<tr>
<td>10/7/05</td>
<td>11/29/05</td>
<td>Flock 1</td>
<td>O</td>
<td>1586</td>
<td>31.1</td>
<td>0.57</td>
<td>206.1</td>
<td>132.7</td>
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<td>2/3/06</td>
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<td>520.0</td>
<td>764.6</td>
<td>4117</td>
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<td>2/4/06</td>
<td>2/19/06</td>
<td>E</td>
<td>192</td>
<td></td>
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<td>0.57</td>
<td>386.2</td>
<td>242.1</td>
<td>1441</td>
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<tr>
<td>2/20/06</td>
<td>4/10/06</td>
<td>Flock 3</td>
<td>O</td>
<td>1372</td>
<td>31.2</td>
<td>0.69</td>
<td>499.7</td>
<td>477.9</td>
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<td>4/11/06</td>
<td>5/21/06</td>
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<td>8.3</td>
<td>0.69</td>
<td>413.5</td>
<td>495.8</td>
<td>4117</td>
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<td>5/22/06</td>
<td>7/11/06</td>
<td>Flock 4</td>
<td>O</td>
<td>1747</td>
<td>36.4</td>
<td>0.71</td>
<td>482.1</td>
<td>621.1</td>
<td>3639</td>
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<tr>
<td>7/12/06</td>
<td>7/27/06</td>
<td>E</td>
<td>330</td>
<td></td>
<td>22.0</td>
<td>0.63</td>
<td>482.1</td>
<td>621.1</td>
<td>3639</td>
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<tr>
<td>7/28/06</td>
<td>9/19/06</td>
<td>Flock 5</td>
<td>O</td>
<td>1978</td>
<td>37.3</td>
<td>0.63</td>
<td>482.1</td>
<td>621.1</td>
<td>3639</td>
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<tr>
<td>9/20/06</td>
<td>10/4/06</td>
<td>E</td>
<td>313</td>
<td></td>
<td>22.3</td>
<td>0.63</td>
<td>482.1</td>
<td>621.1</td>
<td>3639</td>
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<td>10/5/06</td>
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<td>Flock 6</td>
<td>O</td>
<td>1851</td>
<td>34.9</td>
<td>0.63</td>
<td>482.1</td>
<td>621.1</td>
<td>3639</td>
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</tbody>
</table>

[1] House condition: O: Occupied; E: Empty
[b] AU: 500 kg animal unit
[c] This flock had unexpected high mortality due to the improper vaccine procedure at the hatchery
Emission rate per animal unit

Figures 20 and 21 present ammonia ER in terms of 500 kg animal unit (g/AU-d) for all 12 flocks from the two houses. The ERs per AU versus bird age show the different trends for the flocks with new litter and built-up litter. The ERs per AU of three flocks with new litter (Tyson 1-5 flocks 1 and 5, and Tyson 3-3 flock 1) increased from very lower levels and the peak occurred after 28-35 d bird age. The ERs per AU of the flocks with built-up litter started high but relatively trended to be stable with bird growth. Specifically, at the beginning of each flock with built-up litter, ER per AU varied from 1.4 to 5.5 kg/AU-d (Table 3). There was no significant difference between Tyson 1-5 and Tyson 3-3 in ER per AU (P=0.97). The daily ERs per AU were 413.5 ± 495.8 and 414.8 ± 661.4 g/AU-d for Tyson 1-5 and Tyson 3-3, respectively. The overall ER per AU was 414.2 ± 584.6 g/AU-d.

Figure 20. Tyson 1-5 NH₃ ER per AU (500 kg) mean outside temperature vs. bird age
Emmission rate during downtime between flocks

Ammonia emissions from the two houses were continuously monitored when the houses were empty between flocks or during downtime. Ventilation rate (VR) of the houses had a significant impact on the ER when the VR was lower than 80,000 cfm (Figure 22). However, it was also related to the litter management practice, e.g. litter decaking. The average ER for Tyson 1-5 and Tyson 3-3 downtime between flock periods was 26.2 ± 19.5 and 13.9 ± 15.0 lb/d-house, respectively. The average ER for the two houses during downtime was 19.3 ± 18.2 lb/d-house. These values are approximately two-thirds of the mean ER when birds were present in the houses.
Ammonia emission rate (ER) vs. ventilation rate (VR) during downtime.

**Ammonia Emission Rate Estimation/Prediction**

Ammonia emission from the flocks with new litter and bird age less than 7 days (d) was significantly lower than later periods in the flock production cycle. Therefore, the ERs of the first 6 d with new litter would not fit the relationship of ER vs. bird age, body weight, VR, air temperature and relative humidity (RH). Excluding the first 6 days of ERs for the new litter flocks, the relationship of ER, bird age, body weight, VR, air temperature and RH was investigated.

Ammonia ER was highly correlated to the bird age, body weight and VR (Figure 23), but was weakly correlated with inside RH and not correlated with outside temperature and RH and inside temperature. Moreover, there exists a very strong positive relationship among bird age, body weight and VR. Among the three variables, bird age is predominant. Because of the large mortality in flock 6 at Tyson 1-5, this flock was not used to predict the ER. The NH$_3$ ER per house or per bird from all data except for the flock 6 ERs at Tyson 1-5, as shown in Figures 24 and 25, may be estimated using the following predictive regression equations:
\[ NH_3 \text{ ER, lb/d-house} = a + b \, X + c \, X^2 + d \, X^3 \]  

where

\( X = \) bird age, d, if built-up litter is used;

and \( X = (\text{bird age} - 6) \) if new litter and bird age is \( \geq 7 \) d;

\( NH_3 \text{ ER} = 0.55 \text{ lb/d-house} \) if bird age < 7 d.

![Figure 23. Multivariate matrix of ammonia ER vs. bird age, body weight, ventilation rate, air temperature and relative humidity.](image)

Table 4 provides the prediction parameter estimates for the two houses, individually, and overall 11 flocks. The correlation coefficients (\( r^2 \)) of prediction models vary from 0.75 to 0.83 and show the strongest relationship between ER and bird age.

<table>
<thead>
<tr>
<th>House</th>
<th>( a ) (± SE)</th>
<th>( b ) (± SE)</th>
<th>( c ) (± SE)</th>
<th>( d ) (± SE)</th>
<th>( r^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>6.91 (± 1.11)</td>
<td>0.0773 (± 0.0045)</td>
<td>-0.0013 (± 0.0001)</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>3-3</td>
<td>15.4 (± 2.25)</td>
<td>-2.18 (± 0.363)</td>
<td>0.180 (± 0.016)</td>
<td>-2.46E-03</td>
<td>0.83</td>
</tr>
<tr>
<td>Overall</td>
<td>10.7 (± 1.74)</td>
<td>-0.99 (± 0.285)</td>
<td>0.123 (± 0.013)</td>
<td>-1.76E-03</td>
<td>0.77</td>
</tr>
</tbody>
</table>

For the flocks on new litter, there was no clear bird age effect of bird age, VR, air temperature or RH on ER. Therefore, the first 6-d ERs could be estimated by using the actual average ER (standard deviation), 0.55 lb/d-house (± 0.42) for the first 6-d ERs from three flocks on new litter.
Figure 24. Relationship between ammonia ER per house vs. bird age for Tyson 1-5 and Tyson 3-3. The solid line is the regression line; dash lines are 95% prediction limit. In the prediction equation, the coefficient values are mean ± standard error.
Annual Ammonia Emission

The annual ammonia emission from each house is the accumulation of daily ERs over 365 days. However, some daily emissions were missing due to various reasons (for example, power outage from adverse weather and instrument malfunctions). There were a total of 10 missing days for Tyson 1-5 and 19 missing days for Tyson 3-3 over the one year monitoring period. The monitored annual emissions were 4.8 and 4.9 US tons per year from Tyson 1-5 and Tyson 3-3, respectively. Based on the regression of the ER on bird age from Equation [2], the missing daily ammonia emissions could be predicted for each house. After the missing emissions were filled with predicted values, the annual emissions were 5.0 and 5.2 US tons for Tyson 1-5 and Tyson 3-3, respectively. On a per 1000 birds marketed basis the average ammonia emissions over a six-flock period were 73.3 and 82.5 lb per 1000 birds marketed from Tyson 1-5 and Tyson 3-3, respectively. Combining both houses, the average annual ammonia emission was 5.1 US tons per year per house or 77.9 lb per 1000 birds marketed. It is worth noting that the annual mean emission of 77.9 lb per 1,000 birds marketed (including downtime emissions) obtained from this study is equivalent to 35.4 g/bird-marketed and is significantly lower than the emission factor of 100 g/bird-year (100 g/bird-marketed) for broilers used by the U.S. EPA.

Comparison of ER with Literature Data

Comparison of the reported ammonia emission rate (ER, g/bird-d) for broiler production houses (occupied with birds) in the United States is given in Table 5.
Table 5. Comparison of ammonia emission rates (ER, g/bird-d) of the commercial broiler houses among various U.S. studies.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Growth Period, d</th>
<th>Stocking Density, birds/m²</th>
<th>Stocking Density, birds/ft²</th>
<th>Flocks</th>
<th>Litter</th>
<th>Mean ER, g/bird-d</th>
<th>Location</th>
</tr>
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<tbody>
<tr>
<td>This study</td>
<td>52</td>
<td>12.7</td>
<td>1.18</td>
<td>3</td>
<td>New</td>
<td>0.49</td>
<td>Kentucky, U.S.A</td>
</tr>
<tr>
<td>This study</td>
<td>52</td>
<td>12.2</td>
<td>1.13</td>
<td>9</td>
<td>Built-up</td>
<td>0.62</td>
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<tr>
<td>Wheeler et al. (2006)</td>
<td>42</td>
<td>14.7</td>
<td>1.37</td>
<td>10</td>
<td>New</td>
<td>0.47</td>
<td>Kentucky and Pennsylvania, U.S.A</td>
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<tr>
<td></td>
<td>42</td>
<td>14.7</td>
<td>1.37</td>
<td>12</td>
<td>Built-up</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>13.4</td>
<td>1.24</td>
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<td>Built-up</td>
<td>0.76</td>
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<tr>
<td></td>
<td>63</td>
<td>10.8</td>
<td>1.00</td>
<td>20</td>
<td>Built-up</td>
<td>0.98</td>
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<tr>
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<td>Lacey et al. (2003)</td>
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<td>13.5</td>
<td>1.25</td>
<td>12</td>
<td>Built-up</td>
<td>0.63</td>
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<tr>
<td>Seifert et al. (2004)</td>
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<td>20</td>
<td>1.86</td>
<td>1</td>
<td>Built-up</td>
<td>1.18</td>
<td>Delaware, U.S.A</td>
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</tbody>
</table>

Conclusions

Ammonia emissions from two representative broiler houses in western Kentucky were continuously measured for a full year, involving a total of 12 grow-out flocks (6 flocks per house). The following conclusions were drawn.

- There were both diurnal and seasonal variations in ammonia emission from the broiler houses.
- During grow-out period, ammonia emission rate (mean ± S.D.) was 27.2 ± 20.6 lb/d-house for flocks grown on new litter but 32.0 ± 19.6 lb/d-house for flocks grown on built-up litter. The large variation, as expressed by the standard deviation (S.D.), is attributed to the large range of bird age (1 to 52 d).
- The overall mean ammonia emission rate for the 12 flocks was 30.8± 20.0 lb/d-house. The maximum daily ammonia emission during the grow-out period was less than 80 lb/d-house (67.4 lb/d-house for T1-5 and 78.2 lb/d-house for T3-3).
- Ammonia emission rates during downtime (empty house between flocks) (mean ± S.D.) was 19.3 ± 18.2 lb/d-house. The downtime emission rate tends to be positively related to ventilation rate of the house and is significantly influenced by litter handling.
- Annual ammonia emission for the two broiler houses (including downtime emissions) averaged 5.1 US tons per house or 77.9 lb per 1000 birds marketed or 35.4 g per bird marketed when the bird was marketed at 52 days of age with a stocking density of 1.1 bird/ ft². The ammonia emission factor for broilers revealed from this study, 35.4 g/bird-marketed, is significantly lower than that of 100 g/bird-year used by EPA.
Regression equations have been developed that relate ammonia emission rate to broiler age. The first 6-d ER for flocks grown on new litter is relatively independent of the bird age at 0.55 ± 0.42 lb/d-house.
Acknowledgements

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References


**Recent Literature**


