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Acidifier Dosage Impacts on Ammonia Concentrations and Emissions from Heavy-Broiler Houses

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Abstract. *Broiler production results in the production of ammonia, and at high concentrations, ammonia can affect bird performance, and hence, productivity. When released into the environment through ventilation, ammonia can adversely affect public health and the environment. Because of its environmental and health impacts, ammonia emissions from animal feeding operations may be regulated by the EPA. Acidifying amendments have been shown to be effective in reducing ammonia emissions from poultry operations. The purpose of this study is to evaluate in-house ammonia concentrations and emissions from four commercial heavy-broiler houses in eastern North Carolina receiving four levels of PLT® (a commercial amendment): control (0.37 – 0.49 kg/m^2 center brood area), low (0.37 – 0.49 kg/m^2 whole house), medium (0.73 kg/m^2 whole house), and high (>0.73 kg/m^2 whole house). Ammonia concentrations were measured with acid scrubbers and ammonia emissions were calculated from exhaust ammonia concentrations and ventilation volumes. Based on monitoring of three flocks (September 2007 to May 2008), in-house ammonia-N concentrations decreased with increasing PLT application rates. A medium application rate was adequate for maintaining ammonia levels at or below 25 ppm for 9-wk grow-out period during the spring. Based on data from three flocks, ammonia emission factors (only grow-out) for the control, low, medium, and high treatments were 1.06, 1.12, 0.97, and 0.92 g/bird-d, respectively. These emission factors are mostly higher than those reported in the literature mainly because they represent heavier (>4 kg) and older (9-wk) birds fed a higher protein diet. Acid scrubbers proved to be suitable for measuring time-averaged ammonia concentrations for a wide range of values. Emissions data will be collected for four more flocks and PLT impacts on bird performance and energy use will also be quantified.*

Keywords. Scrubber, Air quality, PLT, Litter, North Carolina, Emission factor

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Introduction

Animal production can result in the production of air pollutants that can affect animal health, and hence, the productivity of the operation. Further, when the pollutants escape into the atmosphere, they can adversely impact public health and the environment. Ammonia is perhaps the most important air pollutant associated with animal production, because of the large quantities in which it is produced as well as its impacts on animal health, public health and the environment. Ammonia is produced when urea or uric acid in the manure are broken down by enzymes (e.g., urease and uricase); some ammonia is also produced when organic nitrogen (N) in the feces and spilled feed is mineralized. The EPA (2004, 2005) attributed an estimated 71% of the total US ammonia emissions of 2.85 million Mg to animal agriculture. The EPA (2004) projected that ammonia emissions from poultry (broilers, layers, and turkeys) houses would be ~0.30 million Mg in 2010 with an additional 0.23 million Mg being released during poultry waste storage and land application.

Ammonia attacks the ocular and respiratory systems and over the longer term, it can affect the course of infectious disease and animal growth (Holland et al., 2002). During brooding, ammonia concentrations of 25 and 50 ppm reduced broiler body weights at 7 weeks by 4 and 8%, respectively, compared with 0 ppm ammonia (Reece et al., 1981). Even in newer genetic stocks, 50 and 75 ppm ammonia significantly reduced body weights of male broilers raised in chambers at 7 weeks by 6 and 9%, respectively, compared with 0 ppm (Miles et al., 2004). Mortality was also significantly higher with 75 ppm ammonia vs. 0 ppm (Miles et al., 2004). Miles et al. (2006) reported that ocular abnormalities increased in broilers (raised in chambers) with increasing ammonia concentration (0, 25, 50, and 100 ppm) for 28 d. As the birds grew bigger and the ventilation rate was increased, ammonia concentrations decreased and there were signs of healing of the broilers' corneas (Miles et al., 2006). Hence, Miles et al. (2006) supported the widely held management practice of maintaining ammonia concentrations to <25 ppm. However, Nagaraja (1983) reported that even 10 ppm of ammonia for 7 weeks stressed the respiratory system of turkeys. Noll et al. (2003) recommended maintaining ammonia and dust levels below 20 ppm and 5 mg/m^3, respectively, in turkey houses. Hence, similar levels of ammonia may produce responses that vary with age and specie. Further, the chamber studies (discussed above), performed using fresh litter and recommended ventilation rates may not represent conditions on commercial broiler farms. Commercial broiler producers use built-up litter and frequently reduce ventilation to save energy during the heating season. Consequently, on commercial farms, particularly with tunnel ventilation and cool cell pads, humidity, dust, and ammonia may interact to impact bird health in ways that may not be observed in chambers.

To correlate in-house ammonia concentration (due to management practices, such as, litter age) on bird performance, it is important to continuously monitor ammonia concentrations at bird level with reliable monitoring methods, preferably for multiple flocks. However, there have been only a few such studies. Most of the above chamber studies involved releasing known ammonia concentrations into the chambers. In other studies (e.g., Wheeler et al., 2006), ammonia concentrations were measured in front of the fan to estimate emissions; such data may not represent 'average' in-house ammonia concentrations. Wathes et al. (1997) measured hourly ammonia concentrations using a chemiluminescence analyzer for 24 h each, in summer and winter in four British broiler houses. Ammonia concentrations in the birds' breathing zone averaged 24 ppm for ages ranging from 24 to 35 d (Wathes et al., 1997). Using measurement methods similar to those used by Wathes et al. (1997), Seedorf and Hartung (1999) reported an average ammonia concentration of 21 ppm in eight houses in Germany. Redwine et al. (2002) monitored ammonia concentrations 1 m above the litter in a broiler house in Texas from June to December, 2000, using a colorimetric method. Ammonia concentrations ranged from 2 to 45

ppm and increased with bird age and winter concentrations were 2 to 3 times higher than the summer concentrations (Redwine et al., 2002). Hence, the ammonia concentrations in many broiler houses were at levels that could affect bird performance. In a survey of 577 poultry houses performed by poultry service company in 2002, 85% of houses had ammonia levels >25 ppm and 10% of houses exceeded 100 ppm.

Traditionally, poultry producers have relied mainly on ventilation to manage ammonia levels inside the houses. However, that may no longer be acceptable since it affects environmental quality. A portion of the ammonia emitted can be deposited nearby while the remainder is converted into ammonium (NH_4^+) aerosols. Ammonium aerosols form $PM_{2.5}$ (particulate matter with aerodynamic equivalent diameter <2.5μm) (NRC, 2003). Because of their small size, $PM_{2.5}$ can be transported into the lungs and can contribute to respiratory ailments. Aerosols can also contribute to haze. When deposited on land or water, NH_4^+ aerosols can contribute to soil acidification and eutrophication. Because ammonia is a precursor of $PM_{2.5}$, the EPA is considering regulating ammonia emissions from animal feeding operations (AFOs) under the Clean Air Act. Towards this end, the EPA entered into a compliance agreement with animal producers and producers groups. One objective of the agreement is to develop baseline emissions data for various air pollutants for different species, waste management systems, and climatic conditions. As part of the agreement, a National Air Emissions Monitoring Study (NAEMS) is currently monitoring emissions for a variety of pollutants (including ammonia) from a number of pig, layer, dairy, and broiler farms.

While there are numerous studies on ammonia emissions from broiler houses (table 1), many were done in Europe, under management and climatic conditions different than those in the 'broiler belt', i.e., southeastern US. Moreover, in most of those studies, the data were collected intermittently, sometimes using methods that may not be considered acceptable for developing emission factors for regulatory purposes. The NAEMS is currently monitoring ammonia emissions from a broiler farm in California that uses no control methods for ammonia management. However, multiple studies have shown that amendments, particularly acidifiers, can reduce ammonia buildup in poultry houses by reducing the litter pH and modifying litter ecology reducing conversion of NH_4^+ to ammonia (Shah et al., 2006). Amendments may play an important role in reducing ammonia emissions by inhibiting ammonia production in poultry houses. Because of ease of use and the benefits, many broiler producers are already using acidifiers, particularly in the brood chamber and during winter to reduce energy use. While NAEMS along with others studies that meet EPA's quality guidelines could provide the basis for regulating emissions from broiler houses, none of these studies measured ammonia emissions continuously for multiple flocks receiving different, including high dosages of litter amendments.

Therefore, the overall objective of this study was to evaluate the impact of different levels of a commercial litter acidifier on ammonia concentrations and emissions from commercial heavy-broiler houses in eastern North Carolina. In this study, the producer raised broilers that weighed >4 kg ea., and hence, they are referred throughout this paper as heavy-broilers. This study is part of a larger 2-year study that also has other objectives such as performing a nitrogen (N) balance in the broiler houses, quantifying bird performance as impacted by amendment levels, and measuring ammonia emission from litter stockpiles. However, this paper only covers ammonia concentrations and emissions measured from three flocks (September 2007 to May 2008). Ammonia concentration and emission data for the first flock (June to August 2007) are presented but not discussed since the first month of data are missing.

Table 1. Summary of selected ammonia emission studies performed in broiler houses

Reference; location/s	Ventilation type	Litter age; type	Duration; time of year	Concentration measurement method; type; location (number)	Emission rate measurement	Ammonia emission rate (g/bird-d)
Burns et al. (2007); KY	Tunnel[a]	Fresh; rice hulls	Oct. and Dec. 05[b]; 1 yr	Photoacoustic sensor; real time; inside (3)[c]	Concentration × ventilation rate (VR)	0.49 (new litter); 0.62 (built-up litter)
Wheeler et al. (2006); PA & KY	Tunnel[a]	Fresh to 5 flocks[d]; wood shavings	≥13 48-h periods; full year	Electrochemical sensor[e]; quasi-real time; inside (2)	Concentration × VR	0.031
Guiziou & Beline (2005); France	Sidewall	Fresh; wood shavings	35 d (1 flock); Jan.-Feb.	Acid scrubber; time-weighted average; inside (1)	Concentration × VR	0.25 or 68 g/AU-d[f]
Siefert et al. (2004); MD	Sidewall	Not reported (NR)	7 d (6-12 h/d); May-Jul.	Ogawa sampler[g]; time-weighted average; outside on masts (multiple)	Inverse Gaussian plume model	1.43 (0.33-2.64)
Lacey et al. (2003); TX	Tunnel[a]	New to 4 flocks; wood shavings	10 d (3 flocks); Jun.-Dec.	Chemical sensor[h]; instantaneous; inside (1)	Concentration × VR	0.63
Groot Koerkamp et al. (1998); 4 European countries	NS[i]	NR	24 h ea., winter & summer	Chemiluminescence; real time; inside (7) & outside (1)	Concentration × modeled VR[j]	0.21 (Denmark); 0.27 (Netherlands); 0.44 (Germany); 0.48 (UK)
Wathes et al. (1997); UK	Sidewall	NR; deep litter	24 h ea., winter & summer	Chemiluminescence; real time; inside (7) & outside (1)	Concentration × modeled VR[j]	~9 g/AU-h

[a] Sidewall ventilation in mild and cold weather
[b] Two houses
[c] Sampling cycled among three monitoring locations
[d] 12 houses with litter of different ages
[e] Draeger electrochemical sensor (0-200 ppm scale; ±3 ppm accuracy)
[f] AU = 500 kg animal live weight
[g] Acid-coated filter
[h] Draeger chip measurement system® (2-50 ppm scale; ±8% accuracy)
[i] Not specified - some of the 18 houses may have been naturally ventilated; the type of ventilation system was not mentioned
[j] Based on heat and CO_2 production by animals and in manure

Materials and Methods

Broiler Farm Location, Construction, and Management

A field study was conducted on a commercial heavy-broiler farm near Tar Heel, NC, about 145 km south of NC State University in Raleigh, NC. The farm had eight tunnel-ventilated broiler houses 12.5 m × 152.4 m aligned N-S (fig. 1). While the houses were identical in design and equipment, four houses were built in 2005 and the remaining in 2006. The houses had drop ceilings and solid sidewalls on one side; the other sidewall had 1-m curtains. Each house had 11 belt-driven 1.22-m fans and three 0.91-m direct drive fans, as shown in figure 1. Minimum ventilation was provided by the 0.91-m fans and one 1.22-m fan located on the end wall. Air for mild and summer ventilations was brought in through 0.15-m thick cool cell pads (21.3 m long and 1.5 m high on both sides at the end of the long walls opposite the tunnel fans). Half of the houses had cool cells on the north end while the other half had cool cells on the south end; similarly, four houses had curtains on the east side while the other four had curtains on the west side. Air for minimum ventilation was brought in through intermittent, sidewall inlets operated on static pressure. Each house was heated with 17 propane radiant brooders and had its own propane tank and gas meter. The operations of the fans, curtains, heaters, cool cells, and foggers were controlled by an environmental controller. The minimum ventilation fans were timer-controlled while all other controller operations were based on temperature.

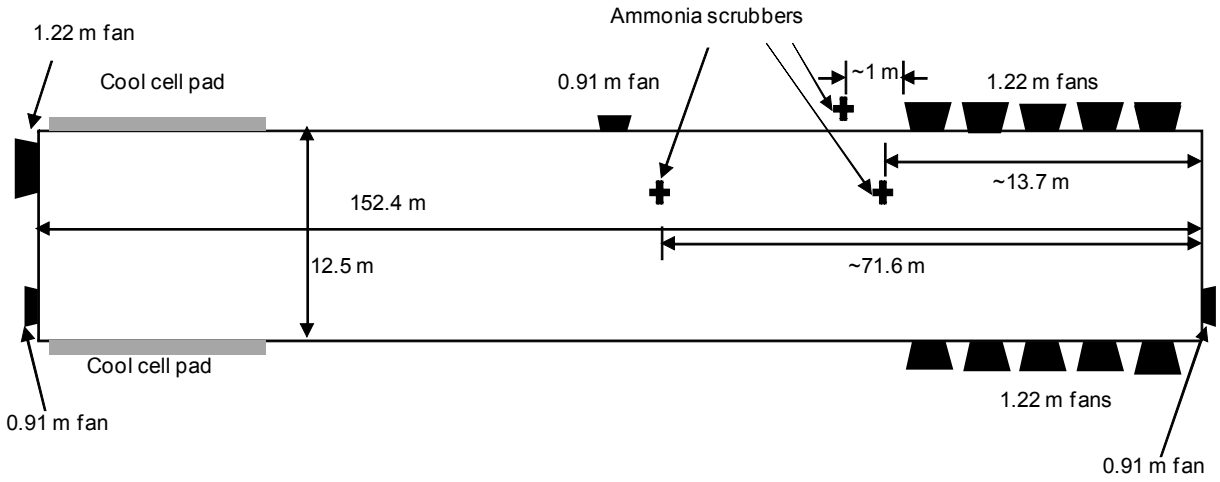

Figure 1. Layout of the broiler house. Drawing not to scale.

Twenty thousand seven hundred (20,700) day-of-hatch chicks were placed in each house and raised to 63.5 d. On average, 4.5 flocks of birds were raised per year with a layout between flocks of 10-21 d. The standard litter treatment program of the poultry integrator consisted of treating the center-brood area with 0.37-0.49 kg/m^2 (75-100 lb/1000 ft^2) per flock, depending on litter age, of PLT® (Sodium bisulfate or $NaHSO_4$), an acidifier. No PLT was applied to the mid-summer flock in their standard program. The chicks were center-brooded in the middle 40% of the house for 12-14 d and then released into the expansion brood area (plus 30%, 15% on each side) for another week. The birds were fed starter, grower, finisher, and withdrawal diets to match their diets to nutrient needs. Mortalities were collected and counted daily for each house. The birds were placed on 50 to 75 mm of fresh litter (pine shavings) on April 21, 2007, after a complete cleanout. However, data collection began only after the next flock was placed in June 22, 2007 since all of the instruments for data collection were not installed until early-July.

Treatment Design

Because houses on both farms were identical in design, all of the houses were assumed to belong to the same population despite being slightly different in age. Based on application rate of PLT, the four treatments assigned were: control (0.37 – 0.49 kg/m^2 center brood area), low (0.37 – 0.49 kg/m^2 whole house), medium (0.73 kg/m^2 whole house), and high (>0.73 kg/m^2 whole house). A treatment was applied to an adjacent pair of houses, except for flock 1, when all houses received the same treatment (table 2). Of the two houses receiving the same treatment, only one house (with the curtain on the east side) was monitored for ammonia concentrations and emissions (methodology described below). However, bird performance was evaluated for both houses receiving the treatment (results not presented here). The amendment was applied to the surface of the litter (except when noted otherwise) 1 d prior to chick placement by a contract applicator using a spinner spreader.

Table 2. Dates, treatment design, and PLT application rates (kg/m^2) in the broiler houses.

Flock #	Grow-out dates (duration), layout duration[a]	House ID (and treatment)			
		I-1 (High)	I-3 (Medium)	J-2 (Control)	J-4 (Low)
1	6/22 - 8/28/07 (66 d), 16 d	0.37[b,c]	0.37[c]	0.37[c]	0.37[c]
2	9/14 - 11/19/07 (65 d), 18 d	0.95[d]	0.73[e]	0.37[c]	0.37[e]
3	12/7/07 - 2/12/08 (66 d)[f], 20 d	1.27[g]	0.73[e]	0.37[c]	0.37[e]
4	3/4 - 5/8/08 (64 d), 13 d	1.46[e]	0.73[e]	0.49[c]	0.49[e]

[a]Flock duration is assumed to include grow-out plus layout period
[b]Application rate in kg/m^2 (1 kg/m^2 = 205 lb/1000 ft^2)
[c]Center brood area only
[d]0.73 kg/m^2 to center 2/3 of house with remaining 1/6th at each end receiving 1.46 kg/m^2; PLT in half of the area at each end was superficially incorporated
[e]Whole house
[f]J-4 birds were removed early morning on 2/13/08
[g]0.98 kg/m^2 to center brood area with rest of the house receiving 1.46 kg/m^2

To evaluate if there were house factors that affected ammonia levels, ventilation, or bird performance, all of the houses received the same PLT application rate for the first flock (table 2). The coefficient of variation (CV) of the bird weights of the four houses was 0.74%, indicating that bird performance was unlikely to have been affected by house factors. The average temperature for the four houses was 27.6°C (±0.8°C) during 7/26 to 8/16/07 and the average ventilation volume for the four houses during the period 7/26 to 8/28/07 was 249e+6 m^3 with a CV of 14.9%. While J-4 (the westernmost house) had 18% greater ventilation than the average, I-3 was 6% above average.

In house I-1, the application rate was gradually increased in the brood chamber with each successive flock to balance the PLT application rate to the ammonia challenge in the house as is standard industry practice. The maximum planned application rate of 1.46 kg/m^2 (table 2) in I-1 was only applied to the whole house beginning the fourth flock when visual observations of the litter and gas tube ammonia readings taken at the litter surface indicated that the amount of ammonia present in the litter in the brood chamber was high enough to warrant the maximum application rate. In house I-1, for the second flock, Jones-Hamilton Co. observed that superficially incorporating the PLT in the non-brood section (vs. surface broadcasting) did not change surface conditions and was therefore unnecessary. Hence, PLT was not incorporated thereafter. In houses J-2 and J-4, beginning with the fourth flock, the PLT application rate was increased due to increased litter age as was the standard practice for this poultry integrator.

Instrumentation and Data Collection

Some temperature, relative humidity, and CO_2 concentration data and all fan speed and static pressure data collected in each house were recorded in a dedicated CR1000 data logger and AM16/32 multiplexer combination (Campbell Scientific Instruments, Orem, UT). Temperature measurements made inside the four coolers in each house that housed the scrubbers and circuit boards, were also stored in the data logger. Operation of the vacuum pumps for the scrubbers (described below) used for ammonia concentration measurements was controlled by the data logger. The CR 1000 data logger was powered by a 12-VDC automotive battery connected to a trickle charger. The text files generated by the data logger were imported into PostgreSQL, an open source, operational database system; extraction of relevant information, e.g., averages and totals were performed within PostgreSQL using structured query language (SQL). Quasi real-time ammonia concentrations measured during the first two flocks (discussed below) were recorded separately.

Relative humidity (RH) and temperature were measured every 15 min. mid-house 0.15-0.3 m above the litter surface with a Model 657-1 transmitter (Dwyer Instruments, Michigan City, IN) to assess the impact of the treatment on ventilation. Broiler houses are ventilated based on relative humidity during brooding and winter. Further, because PLT is hygroscopic and high rates can cause slick conditions under high RH conditions, monitoring RH and ventilating accordingly was important. The poultry house equipment broke the power and signal cables of the Dwyer transmitter on two occasions and the corrosive environment inside the houses affected the sensor circuit boards. Therefore, in mid-December 2007, one stand-alone Cox Tracer® temperature – RH data logger (Sensitech, Beverly, MA) was placed next to the Dwyer transmitter in each house. The Cox Tracer® was programmed to collect temperature and RH data every 5 min. during brooding (21 d) and every hour thereafter. In end-February 2008, all of the Dwyer transmitters were removed and only the Cox sensors were used for temperature and RH measurement.

Fan airflow rate was measured using the Hall Effect sensor with the magnet installed on the fan shaft. Each fan was polled by the data logger every 15 s and the speed (rpm) was recorded; to calculate total airflow, the fan speed (also differential pressure, see below) for each minute was obtained by averaging the four 15-s values. For the first flock, in house I-1, another system of indirectly measuring the fan speed was tried on the 1.22 m fans; this consisted of a computer fan's propeller (equipped with a Hall Effect sensor and magnet) housed in a 6-in. PVC pipe (hitherto referred to as the pipe anemometer). When evaluated in the lab with the center of the pipe anemometer about 0.2 m away from the lower edge of the fan blades, the speeds of the pipe anemometer and fan were highly correlated at different static pressures (or airflow rates). While the lab test indicated that the fan anemometer could be a reliable predictor of fan airflow rate, its performance was seriously degraded when the broiler house foggers were turned on to cool the birds. The wet residue (including feathers) accumulated on the blades of the pipe anemometer, resulting in highly variable readings. Hence, the pipe anemometers were discarded.

Based on the fan speed (rpm) and differential pressure (discussed below), airflow rate (m^3/s) for each fan was calculated using the BESS Laboratory (2008) fan curve and the fan laws. Based on actual time of operation of each fan during a sampling duration (discussed below), airflow (m^3) through the fan for the duration was calculated. Beginning August 2008, the procedure for measuring fan airflow rate will be further improved by developing the fan curves for 25% of the fans (total 14, including three 0.91 m fans) using the Fan Assessment Numeration System (FANS) (Gates et al., 2004).

Two Model 668 differential pressure transmitters (Dwyer Instruments, Michigan City, IN; range: 0-63 Pa) were installed in each house, one on each sidewall, upstream of the tunnel fans to measure differential pressure across the wall every 15 s. For a tunnel fan, differential pressure measured on that fan's sidewall was used to calculate airflow rate. For minimum ventilation fans, the average of the two differential pressure readings was used.

Ammonia concentrations in the exhaust of all 14 fans, two locations inside the house (fig. 1), and one location outside the house (ambient) were measured with acid scrubbers. Exhaust air from the 1.22-m fan was sampled by attaching a length of 4.8-mm ID flexible PVC tubing with the open end facing downward at a fixed distance vertically above the center of the fan hub. Exhaust air from the 0.91-m fan was sampled upwind of the fan by securing the tubing to the twin-angle supports of the fan (at a fixed location). The outlet end of the sampling tube was connected to the scrubber as discussed below. Cutting the inlet end of the tube at an angle of ~45° reduced the amount of water pulled into the scrubber when the foggers were operating in the house. Inside air was sampled at the mid-house (~71.6 m from tunnel fan end) and end-house (~13.7 m from the end wall, immediately upwind of the tunnel fans) locations, in between the feeder and water lines. The height of these air inlets were raised from ~0.15 m at the beginning of the flock to ~0.3 m at the end of the flock. The inlet for the ambient air was located close to the wall of broiler house (fig. 1) ~2.5 m above the ground. For each house, the 17 scrubbers were placed in one of four coolers (two large and two small). Each cooler had a thermocouple that was used to turn on a 4-W bulb (12-VDC) when the temperature decreased below 4.4 C. The large cooler had a computer fan that pulled in fresh air and exhausted warm air through screened ports when the temperature exceeded 32.2 C. The small cooler had screened top and bottom vents that allowed for natural convection.

The acid scrubber consisted of a polycarbonate flask containing 250 mL of 2% boric acid solution. When ammonia-laden air was pulled into the scrubber, the ammonia immediately dissolved in the boric acid solution and converted into ammonium borate. Stochiometrically, this scrubber could neutralize 1.375 g of ammonia; alternatively, at an airflow rate of 1 L/min, for 100 h of continuous operation with an average ammonia concentration of 24 mg/m^3, only 10.5% of the scrubber's neutralizing capacity would be exhausted. However, after the third flock was removed in mid-February 2008, very high ammonia-N levels were measured in the scrubbers deployed inside the houses, particularly in J-2. Hence, there could have been off-gassing of ammonia from the scrubbers due to saturation. To prevent this from happening in future, apart from reducing the scrubber duty cycle (discussed below), beginning June 2008, 3% boric acid solutions were used, effectively raising the scrubber's trapping capacity by 50%. Preliminary testing had indicated that such a scrubber system (with two scrubbers in series), when evaluated downwind of an exhaust fan in a turkey house, had an ammonia-trapping efficiency of 99.5% in the first scrubber. The scrubbed air was then routed through a moisture trap (empty 125 mL polycarbonate flask) into a 4.5-VDC vacuum pump. Gross airflow rate through the scrubber was obtained by averaging the measured values of the VA 10410 flowmeter (Dwyer Instruments, Michigan City, IN; ±2% full-scale accuracy, maximum flow rate: 1.946 L/min) readings at the beginning and end of the sampling duration. Since air emerging from the scrubber is at a pressure lower than 1 atm, a lab test was performed using one flowmeter upstream of the scrubber and moisture trap and another downstream of the pump. By changing the settings of the valve downstream of the pump, a linear equation that correlated the upstream and downstream flowmeter readings was obtained. This calibration curve was used to correct airflow rate through the scrubber for location. The airflow rate through the scrubber was also corrected for average temperature using the Gas Law. Airflow rate through the scrubbers ranged between 0.8 to 1.0 L/min, depending on length of tubing, residue buildup in the tube, and temperature. The 'used' scrubbers were replaced with fresh scrubbers biweekly (Monday/Thursday or Tuesday/Friday), resulting in an average sampling duration of ~3.5 d.

The vacuum pumps drawing air through the scrubber only operated when the fans were running. The duration of run of each fan (or scrubber) was output by the data logger to the nearest 0.25 min. For the first three flocks, all other scrubbers ran on a 10% duty cycle, i.e., 3 min. out of 30 min. with their operations being controlled by a PIC (programmable integrated chip). Beginning the fourth flock, the inside and ambient scrubbers were operated on a 33% duty cycle (3 min. out of 9 min.) and their run times were logged by the data logger.

Ammonium-N concentrations in the scrubber solution were determined in the BAE Department's Environmental Analysis Lab (EAL) by an auto analyzer using colorimetry (MDL = 0.05 mg-N/L) and the volume of the scrubber solution was determined gravimetrically. Background NH_4^+-N concentration in the scrubber solution as determined in a blank sample placed in one of the enclosures was subtracted from the NH_4^+-N concentration in the scrubber. The corrected ammonia-N concentration (C_G, mg-N/m^3) through any scrubber was calculated as:

$$C_G = \frac{C_L \cdot V}{q \cdot \Delta t} \quad [1]$$

where C_L is NH_4^+-N concentration (mg-N/L) in the scrubber solution; V is scrubber volume (L); q is airflow rate through the scrubber (m^3/min) and Δt is sampling duration (min). The ammonia-N concentration in the fan exhaust was further corrected for ambient ammonia-N concentration. When ambient scrubber concentration was missing for a particular house, the corresponding value from the closest house was used.

Ammonia-N emission from a fan for a sampling duration was calculated by multiplying its airflow rate by the sampling duration and its corrected C_G. The total emission from a house for a sampling duration was calculated by adding up the emissions from the individual fans. The total emission from a flock was calculated by adding the emissions for all sampling durations from that flock. There were times when the scrubber solution had to be discarded because the pump or the circuit board failed (particularly during the first three flocks). Because of intermittent problems with the PIC in J-2, scrubber concentration data for the mid-house scrubber were discarded for the first two flocks. Due to delay in diagnosing the PIC problems, the end-house and ambient scrubber data for J-2 had to be discarded for the first three flocks.

When data for one of the two 0.91-m minimum ventilation fans (installed on opposite end-walls) was lost, emission calculated for the other 0.91-m fan was used provided the run times were within 5% of one-another. This approach was use because these two 0.91-m fans were located on opposite end-walls and ran simultaneously; further, most of the time, during minimum ventilation, these were the only two fans in operation. When data for one of the tunnel fans had to be discarded, the emission from the tunnel fan at the same location, but on the opposite sidewall was used, provided the run times were within 5%. This approach for filling missing tunnel fan data was considered valid because of the way the tunnel fans were staged. While ammonia-N emission is not quantified based on percent ventilation sampled in this paper, final emissions will be reported based on percent ventilation volume sampled. When run time is lost for a fan, it will be estimated using data from similar fans in the house or from another house with similar PLT treatment, after validating that earlier run times of the fan with the missing data and the reference fan are similar.

Efforts were also made to calculate ammonia emissions during the layout period (between flocks). However, frequently, the sidewall curtains were lowered or the doors were left open and the fans were not operated which made ammonia emission calculation impossible. Additional efforts will be made during the summer of 2008 and the winter of 2008-2009 to quantify ammonia emissions during the layout period by operating one 1.22 m fan and measuring ammonia emissions through it.

A real time ammonia monitoring system was used to monitor in-house ammonia concentration at the same location as the scrubber sampling the inside air at mid-house. This consisted of an electrochemical sensor (Dräger XSNH3; range: 0-200 ppm; accuracy: ±3% full scale) connected to a monitor with data logging capabilities (Dräger PAC III Hygiene). Since electrochemical sensors saturate when exposed to the gas of interest for long periods, periodic purging of the sensor with clean air was recommended (Xin et al., 2002). The first attempt at purging was made by running the air for 6 min through a scrubber located upstream of the Dräger. In the test cycle, a solenoid controlled by the PIC switched the air from the acid scrubber to a 250 mL 0.5% NaOH solution for 6 min; the NaOH solution removed all particulates but desorbed all ammonia and released it back into the airstream. Ammonia concentrations were recorded every 2 min and the concentration measured during the second duration measurement (i.e., 2-4 min) was recorded. However, this method of purging resulted in negative values and the sensor never recovered during the test cycle. So, during July-August 2007, ambient air passed through an activated C filter (~250 mL pellets) was used to purge the sensor. However, even this method produced negative values that usually did not recover except with very high ammonia concentrations observed during bird catch-out and also during layout. Because the Dräger electrochemical sensor did not work for continuous ammonia monitoring, they were removed from all the houses on September 20, 2007. The Dräger ammonia data are not reported here.

For the first two flocks, a CO_2 monitor (Telaire 7000; range: 0 - 4,000 ppm) was used to measure real time CO_2 concentrations at the mid-house location. Air from inside the house was pulled into an airtight plastic enclosure containing the CO_2 monitor. The CO_2 data were obtained to see if the litter treatment affected ventilation rate. However, the diffusion based CO_2 monitors' circuit boards were damaged by the corrosive air in the broiler houses. An attempt to scrub the air of ammonia by running the air through ~75 mm depth of silica gel beads upstream of the CO_2 did not work. Hence, beginning the third flock, the CO_2 monitor was removed from all four houses. The CO_2 concentration data are not reported here.

Results and Discussion

In-house Ammonia Concentrations

Ammonia-N concentrations inside the houses are shown in figures 2 (mid-house) and 3 (end-house). While the first flock was placed in all the houses on 6/22/2007, data collection started later and did not begin in all four houses at the same time. Hence, data for flock 1 (figs. 2 & 3) are presented beginning 7/26/2007. Further, because of problems with the PIC controlling the in-house scrubbers in J-2, the mid-house scrubber data are only available beginning 12/24/07 and the end-house scrubber data are available beginning 2/8/08. For both sampling locations (figs. 2 & 3), for flock 1, ammonia-N concentrations remained below 14.3 mg-N/m^3 (25 ppm ammonia at 25°C), generally considered to be acceptable for bird performance. While PLT was applied at only 0.37 kg/m^2 in the center brood area in all four houses for the first flock, high ventilation rates (due to an excessively hot summer), probably resulted in "acceptable" ammonia levels, except during the layout periods when very high ammonia-N concentrations were observed. Further, only two flocks had been raised on that litter. During the first layout period, the highest mid-house and end-house ammonia-N concentrations were >300 mg/m^3 in houses I-1, I-3, and J-4 (data for J-2 were discarded due to faulty PIC). However, these high numbers are not shown in figures 2 and 3 to obtain better resolutions at the lower concentrations.

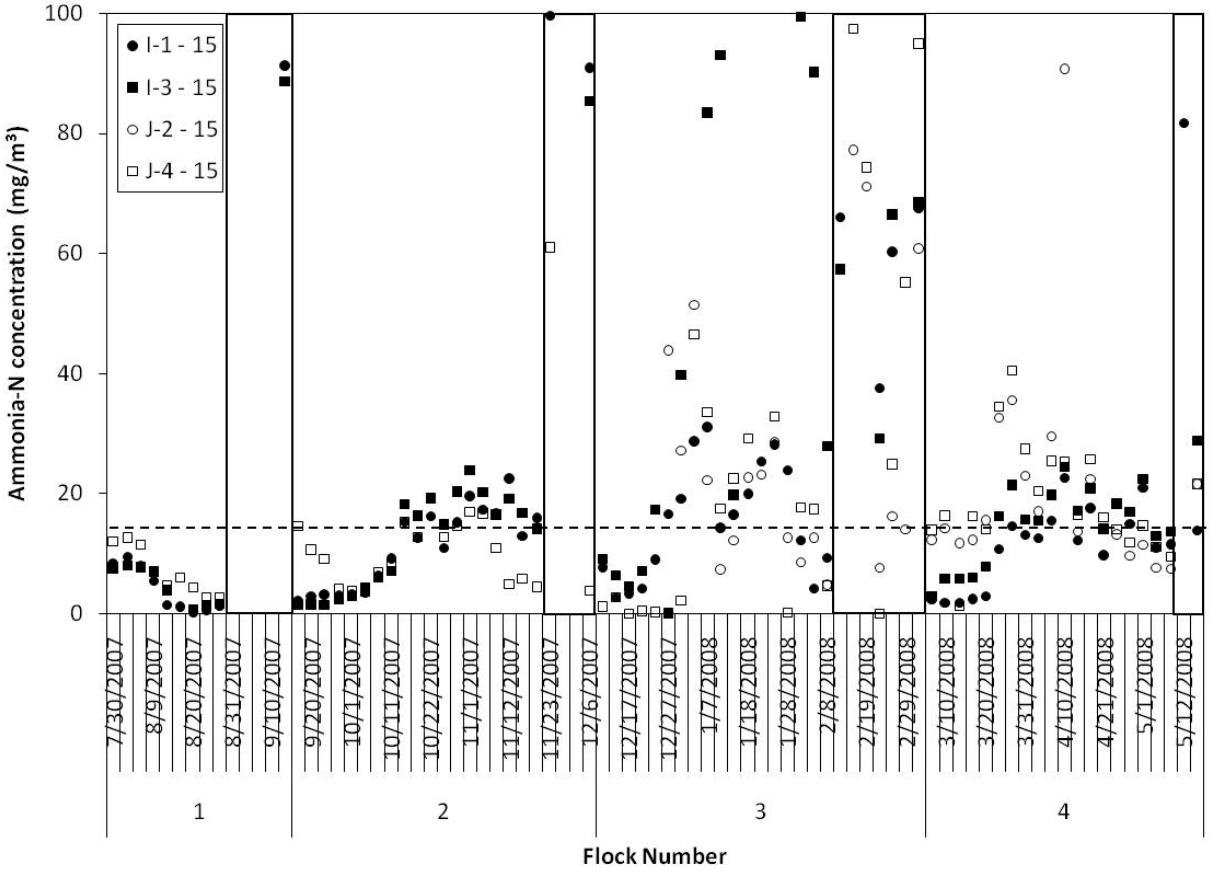

Figure 2. Ammonia-N concentrations at the mid-house location in the four houses. The house-treatment combinations were: I-1 (high), I-3 (medium), J-2 (control), and J-4 (low). Each data point represents the weighted average ammonia-N concentration for a 3 to 4 d period with the date indicating the day when the scrubber was removed for N analysis. The data points inside the rectangular boxes represent concentrations during the layout. The dashed line indicates the ammonia-N concentration of 14.3 mg-N/m^3 (25 ppm ammonia at 25°C).

Application of PLT just prior to flock 2 placement resulted in immediate reduction in ammonia levels (figs. 2 & 3). Higher PLT application rates (in I-1 and I-3) prior to placement of flock 2 seemed to have been more effective in reducing ammonia levels (figs. 2 & 3). As expected, during the first month of the second flock, houses (I-1 and I-3) that received heavier PLT application rates had lower ammonia levels than J-4,that received less PLT. During the second flock, ammonia-N concentrations increased as the birds grew older until 11/1/07. After that date, because of increasing ventilation rates, ammonia-N concentrations declined in both locations (figs. 2 & 3). This trend of ammonia-N concentration increasing in the beginning and decreasing with increasing ventilation rates, also observed in the other flocks, has been widely reported (e.g., Redwine et al., 2002). Ammonia-N concentrations in all houses reached or exceeded the 14.3 mg/m^3 4-5 weeks after PLT application in flock 2. Once the PLT has reacted with the ammonia and formed ammonium sulfate, there is no further suppression in ammonia production, and the normal variation seen in ammonia flux between houses occurs. During the flock 2 layout, the highest ammonia concentrations (in both mid- and end-house scrubbers) were observed in J-4 but because the y-axes of figs. 2 & 3 are truncated, the figures give the misleading impression that I-1 and I-3 had higher internal ammonia concentrations.

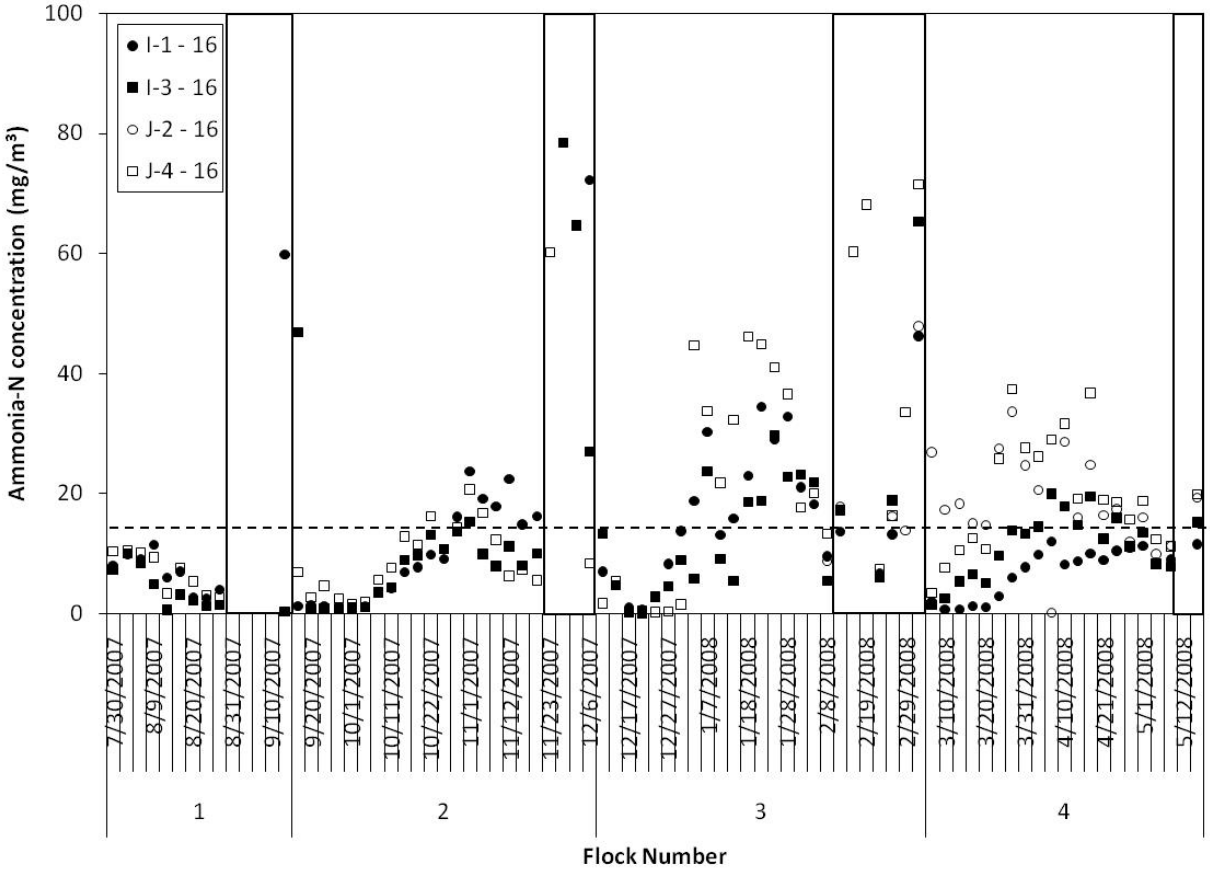

Figure 3. Ammonia-N concentrations at the end-house location in the four houses. The house-treatment combinations were: I-1 (high), I-3 (medium), J-2 (control), and J-4 (low). Each data point represents the weighted average ammonia-N concentration for a 3 to 4 d period with the date indicating the day when the scrubber was removed for N analysis. The data points inside the rectangular boxes represent concentrations during the layout. The dashed line indicates the ammonia-N concentration of 14.3 mg-N/m^3 (25 ppm ammonia at 25°C).

During the third flock, as with flock 2, ammonia concentrations increased for about 4-5 weeks and then declined due to higher ventilation rates. As with flock 2, in flock 3, the ability of PLT to suppress ammonia formation declined after 4-5 weeks. Surprisingly, in flock 3, J-2 (control) had lower ammonia-N concentrations in the mid-house location than the other treatments (fig. 2), though there was considerable scatter in the data. Further excessively high ammonia-N concentrations (from bird health standpoint) were observed during Jan. 2008 (figs. 2 & 3), particularly at the mid-house location. Concentrations were higher at the mid-house location in I-3 (fig. 2) while J-4 had higher end-house concentrations (fig. 3). While higher internal ammonia concentrations can be expected under winter conditions because of lower ventilation rates, slightly lower ventilation rates in I-3 (vs. J-4) (discussed below) may have contributed to elevated concentrations during Jan. 2008. Compared with the previous layouts, during the layout of flock 3, ammonia-N concentrations were lower but still quite high, with all treatments contributing at one or both scrubber locations (figs. 2 & 3).

The fourth flock (figs. 2 & 3) experienced the most consistent trends in ammonia-N concentrations in terms of both time (age of birds) and treatment. Ammonia-N concentrations

were, generally, negatively correlated with PLT application rates (figs. 2 & 3). In flock 4, the heaviest PLT application rate of 1.43 kg/m^2 in I-1 never allowed ammonia-N concentrations to exceed 14.3 mg/m^3 in the end-house location (fig. 3). In the mid-house location, towards the end of the grow-out period for the fourth flock, for reasons that are unclear, ammonia-N concentrations were slightly higher in the I-1 and I-3 houses than in the J-2 and J-4 houses that received lower PLT dosages. The ammonia-N concentrations measured in this time frame are out of the range of normal for flocks of the same age and will need to be scrutinized further. On 5/12/08, during layout, ammonia-N concentration in the mid-house scrubber in I-1 was >80 mg/m^3; the concentrations for the other houses were >100 mg/m^3 and are, hence, not visible because of the scale used.

Using the PIC to control the operation of the electrochemical sensors and scrubbers (simultaneously) resulted in loss of data, particularly in J-2. Data collection was simplified and made more robust during the layout period of the third flock by discarding the PIC in all houses and hence, the data collected during the fourth flock was the most complete. Average ammonia-N concentrations during the fourth flock (only grow-out period) for the four houses in the two in-house scrubber locations and their arithmetic mean are presented in table 3. Average ammonia-N concentrations were inversely correlated with the PLT application rate (as expected). However, the end-house ammonia-N concentration in J-4 was higher than J-2 even though the non-brood area in J-4 was treated with PLT while it was not treated in J-2. This is discussed in further detail later in the paper. Based solely on the results of the fourth flock, a PLT application rate of 0.73 kg/m^2 (150 lb/1,000 ft^2) seemed adequate for keeping ammonia ≤25 ppm (14.3 mg-N/m^3) throughout the grow-out period.

Table 3. In-house ammonia-N concentrations (n = 19) in the grow-out period for the fourth flock.

House (PLT application rate, kg/m^2)	Ammonia-N concentration (mg/m^3)		
	Mid-house scrubber	End-house scrubber	Average[a]
I-1 (1.46[b])	11.0[c]	6.9	9.0
I-3 (0.73[b])	14.6[c]	11.2	12.9
J-2 (0.49[d])	20.7	18.4	19.6
J-4 (0.49[b])	18.6	19.6	19.1

[a]Arithmetic average of mid-house and end-house scrubber concentrations
[b]Whole house
[c]One data point missing
[d]Center brood only

In France, Guiziou and Beline (2005) measured ammonia concentrations ranging from 0.8 to 32 ppm (0.7 to 27 mg-N/m^3 at 25°C) using acid scrubbers, in a sidewall-ventilated broiler house with birds raised for 35 d on fresh litter. Redwine et al. (2002) reported that summer and winter ammonia concentrations ranged from 2 to 9.6 ppm and 12 to 45 ppm, respectively, with 49-d birds raised in a tunnel-ventilated house in Texas. While the above studies were conducted under conditions different than this study and Redwine et al. (2002) used the electrochemical sensor for measuring ammonia concentration, the results obtained in this study are comparable to the published studies.

Fairchild et al. (2006) evaluated the impact of different (0.24, 0.49, and 0.73 kg/m^2) PLT application rates in Georgia broiler houses raising broilers ≤2-kg birds. They reported ammonia concentrations of 8 and 24 ppm in weeks 1 and 2, respectively, of flock 3 in the house receiving 0.49 kg/m^2. Ammonia concentrations in weeks 1 and 2 of flock 3 in the house receiving 0.73 kg/m^2 were 8 and 15 ppm, respectively (Fairchild et al., 2006). While a side-by-side comparison is difficult because of the large variation in bird weights, fecal load in the litter, different management and measurement methods used, in this study, ammonia concentrations during

weeks 1, 2, and 3 in flock 4 in J-4 (0.49 kg/m^2) in the mid-house scrubbers were approximately 26, 15, and 42 ppm, respectively. In I-3 (0.73 kg/m^2 PLT), the ammonia concentrations were 8, 10, and 21 ppm, respectively, during weeks 1, 2, and 3. In I-1 (1.46 kg/m^2 PLT), the ammonia concentrations during weeks 1 to 3 of flock 4 were 3, 2, and 12 ppm, respectively. Hence, the high PLT treatment provides better ammonia suppression than the medium PLT treatment.

Ammonia Emissions

Ammonia-N emissions from the four broiler flocks (only grow-out periods) are shown in Figure 4. Data for flock 1 does not include the period from 6/22 to 7/26/07. While there were missing data points (for one or more fans), the large difference between the houses were partly attributable to wide variation in ambient ammonia-N concentrations measured in each house. For example, during the period 8/20-8/24/07, ambient ammonia-N concentrations for I-1, I-3, and J-4 houses were 0.3, 1.2, and 0.3 mg/m^3, respectively. Because the intakes for the ambient scrubber were identically located, the reasons for these large differences were unclear. During flock 4 (3/4 - 5/8/08), the average ambient ammonia-N concentrations were 0.2, 0.7, 0.5, and 0.3 mg/m^3, respectively, for houses I-1, I-3, J-2, and J-4.

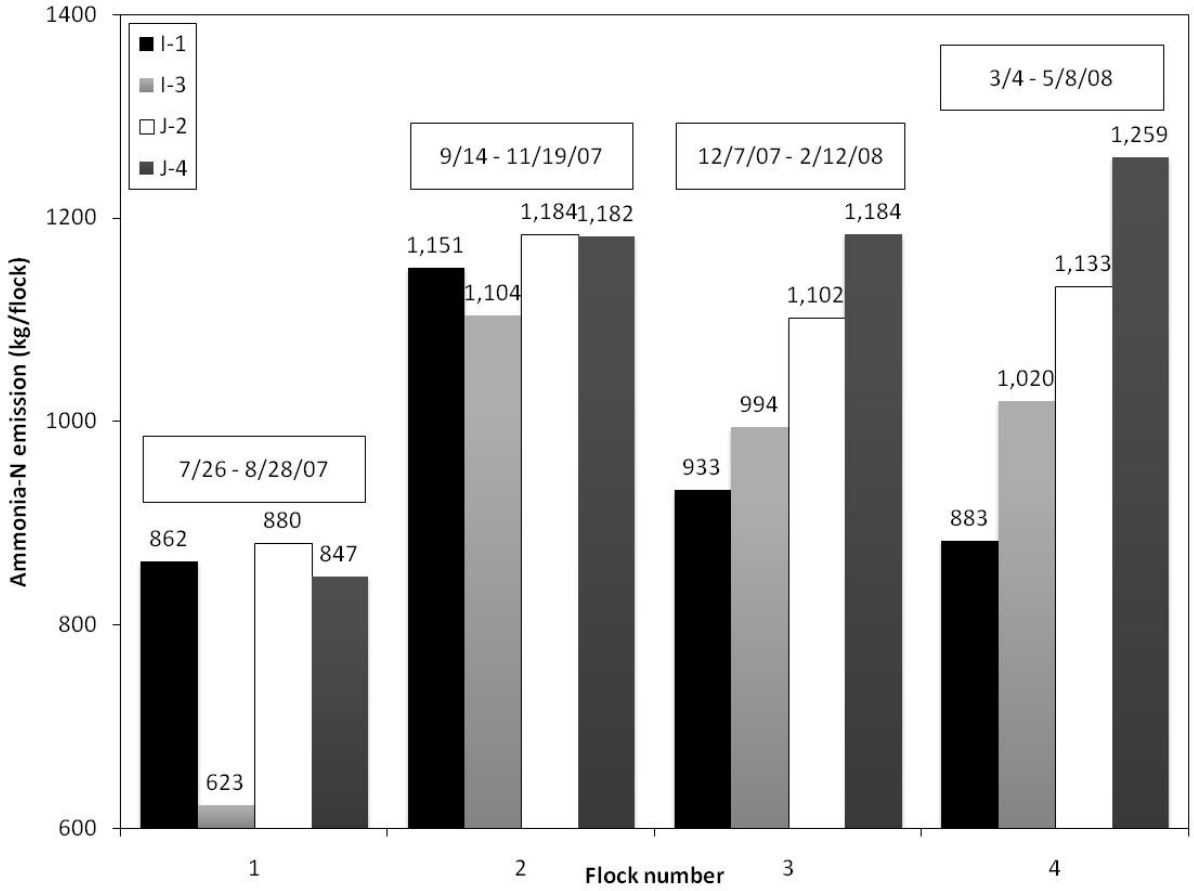

Figure 4. Ammonia-N emissions as impacted by PLT application rate, litter age, and season. Except the first flock, the house-treatment combinations were: I-1 (high), I-3 (medium), J-2 (control), and J-4 (low). All houses received the identical control treatment during the first flock. Ammonia-N emissions for the first flock does not include data from 6/22 to 7/26/07.

For flock 2, comparable ammonia-N emissions (fig. 4) from I-1, J-2, and J-4 was unexpected despite large differences in PLT amounts applied (table 2); however, the reasons for this are

discussed below. Lower ammonia emission from I-3 may have been due to no emissions during the first week; this may seem surprising since I-1, which received more PLT (table 2) had ~1.2 kg of ammonia-N emission during the same period. An attempt was made to correlate the ammonia-N emissions with the total ventilation volumes (fig. 5). No attempt was made to separate the minimum ventilation volume from the mild and summer ventilation volumes even though the type of ventilation may impact ammonia-N emissions.

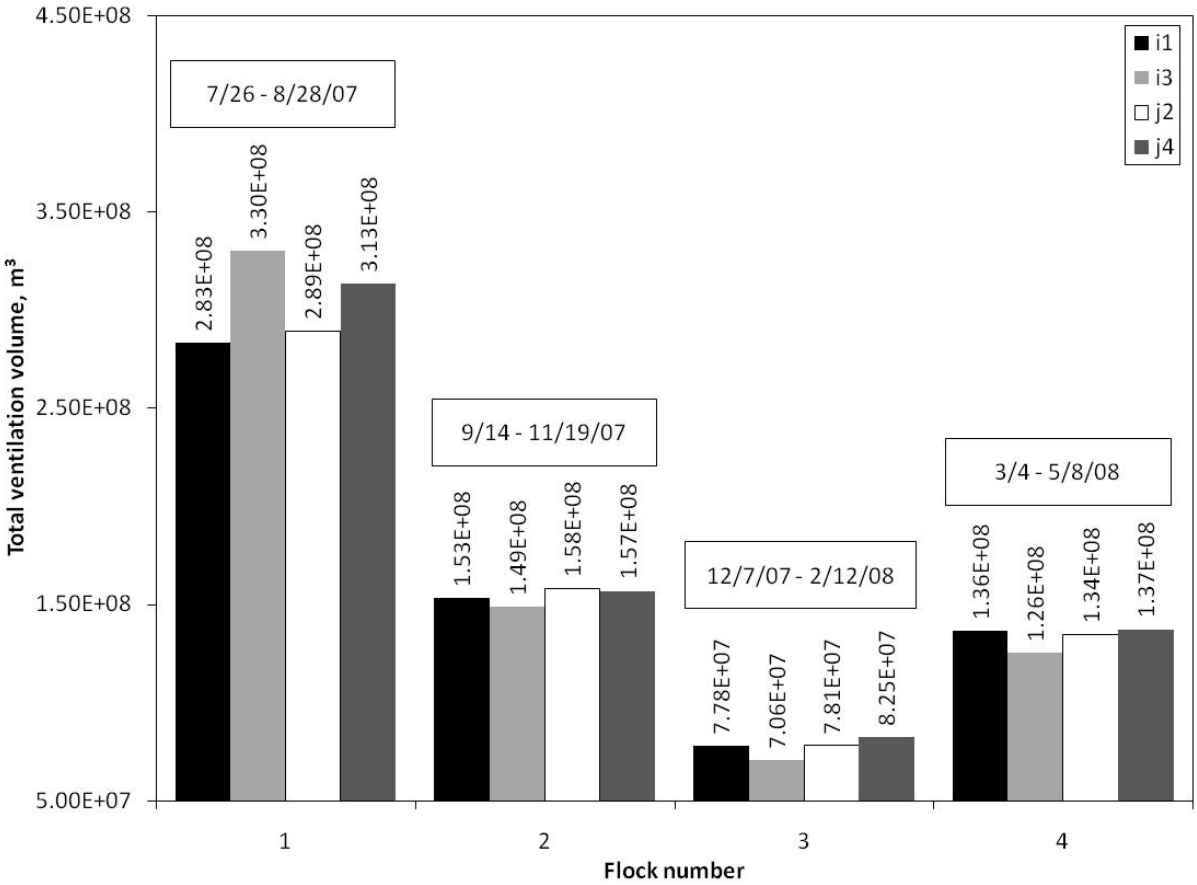

Figure 5. Total ventilation volumes from the four test houses. Except the first flock, the house-treatment combinations were: I-1 (high), I-3 (medium), J-2 (control), and J-4 (low). All houses received the identical control treatment during the first flock. Ventilation volume for the first flock does not include data from 6/22 to 7/26/07.

Ammonia-N emission would be expected to increase with ventilation within a reasonable range of values, other factors being held constant. For flock 2, since the ordinal rankings of the four houses in terms of ammonia-N emissions and ventilation are identical and the CV among the treatments for emissions (3.2%) and ventilation (2.7%) are similar, it would seem that ventilation volume directly impacted emission. However, the implication that the treatment had no effect, does not seem reasonable. Hence, other factors such as mass of birds produced need to be investigated to explain the results better.

During the third flock, ammonia-N emissions from I-1 and I-3 that received the highest and second highest PLT application rates, respectively, were much lower than the houses that received lower PLT application rates (fig. 4). Because ventilation volumes were similar (CV of 6.1%) in all four houses (fig. 5) in flock 3, it seems that the PLT application rate and ammonia-N emission were inversely correlated (on an ordinal basis) for I-1, I-3, and J-2, as would be

expected. However, J-4 had higher ammonia-N emissions than J-2 (fig. 4) which may partly be explained by higher ventilation volume in J-4 in flock 3 (fig. 5). It was unclear why ammonia-N emission from I-1 was only 6% lower than I-3 even though it received 74% more PLT. This indicates that other factors may also be contributing and highlights the difficulty of trying to evaluate the dose-response relationship in a complex population, even when the experimental units (house) appear to be identical (age, ventilation system, etc.).

Flock 4 ammonia-N emissions from I-1 and I-3, that had received more PLT, were lower than J-2 and J-4 (fig. 4). However, ammonia-N emission from J-4 was higher than J-2 by 11% (fig. 4) while the ventilation volume in J-4 was higher than J-2 by only 2% (fig. 5), indicating that ventilation probably played a minor role. Higher ammonia-N emission from J-4 vs. J-2 may have been due to the high ammonia load contained in heavy-broiler litter of this age when compared to the amount of PLT applied. This is indicated by the end-house concentration data (fig. 3) that showed that all of the PLT applied in the end of J-4 was consumed within the first 10-12 d as indicated by continually increasing ammonia-N concentrations. The ammonia purge from the litter in J-2 due to increased floor temperatures had stabilized by day 10-12 as indicated by the continued decrease of ammonia-N concentrations in the end-house scrubber over this time period (fig. 3). The variability from that time point onwards in the flock is most likely due to normal ammonia litter flux variation between houses.

Flock 4 ammonia-N emissions were higher than flock 3 emissions for all the treatments (fig. 4). While flock 3 was raised during winter, flock 4 was raised during spring and the resulting warmer conditions required greater ventilation (fig. 5), increasing ammonia production and emission. Further, the flock 4 birds were raised on older litter with higher fecal content. Between flocks 3 and 4, ammonia emissions increased only slightly for I-1 but it increased by bigger percentages for the other houses. This may be due to the fact that I-1 received 15% more PLT in flock 4 vs. flock 3 (table 2). While the PLT application rates were increased for J-2 and J-4 for flock 4 (vs. flock 3) by 32%, the additional PLT mass may have been inadequate in reducing ammonia emissions on older litter and warmer weather, resulting in higher ammonia emissions in flock 4 vs. flock 3. Flock 4 ammonia emissions with bird age (or time) showed trends (fig. 6) similar to those reported in published data (e.g., Guiziou and Beline, 2005).

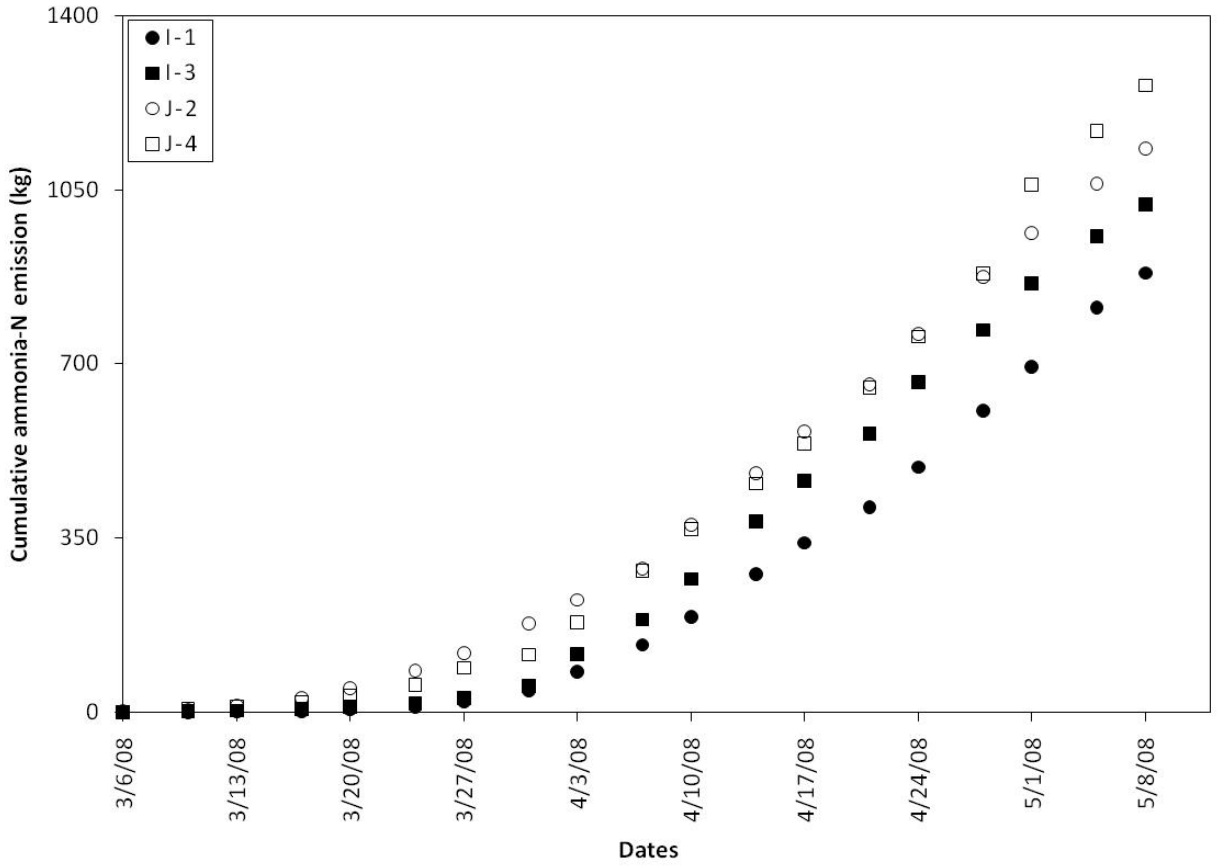

Figure 6. Ammonia-N emission trend from four broiler houses (flock 4, only grow-out period) receiving different levels of PLT. Each data point represents the mass emitted from one house over a 3-4 d period. The house-treatment combinations were: I-1 (high), I-3 (medium), J-2 (control), and J-4 (low).

Ammonia emission factors for the four treatments and three flocks (only grow-out) are presented in table 4; flock 1 was excluded because all the houses received the same PLT treatment and therefore, emissions from that flock do not represent treatment effects. The emission factors were calculated based on the number of surviving birds in each flock.

Table 4. Ammonia emission factors[a] (g/bird-d) for the four treatments and three flocks.

Flock #	Season	House ID (and treatment)			
		I-1 (High)	I-3 (Medium)	J-2 (Control)	J-4 (Low)
2	Summer/fall	1.07	1.03	1.10	1.10
3	Winter	0.86	0.91	1.01	1.06
4	Spring	0.83	0.96	1.07	1.19
	Average of three flocks	0.92	0.97	1.06	1.12
Average PLT application (kg/m^2-flock)		1.23	0.73	0.16	0.41

[a]Excludes layout period

Emission factors seemed to be seasonal with the lowest emission factors observed in winter (table 4). Compared with published studies (table 1), emission factors calculated in this study appear to be higher despite use of acidifiers mainly because of the much larger bird weight compared to the smaller broilers represented in the cited studies. In the last two weeks of the grow-out, a heavy-broiler will consume 33% of the total feed it will consume during its entire

lifetime, resulting in heavier fecal output. Further, the heavy-broiler is fed a diet higher in protein (to increase breast meat yield) than the smaller bird; a higher protein diet translates into more N excretion and emission.

Compared with emission factors developed in Europe (e.g., Guiziou and Beline, 2005; Groot Koerkamp et al., 1998), values reported in table 4 are higher not only because of the larger bird size and higher-N diet but also because Europe has a more temperate climate and broiler houses are cleaned out with every flock. Higher values in this study vs. emission factors of 0.63 g/bird-d in tunnel-ventilated houses in Texas (Lacey et al., 2003) were mostly due to >2 week longer grow-out period in this study. When calculated for 7-wk old birds, the emission factors in this study were 0.50, 0.69, 0.81, and 0.81 g/bird-d for I-1, I-3, J-2, and J-4 houses, respectively, for the fourth flock. Of all the published literature presented in table 1, only Siefert et al. (2004) reported an average emission factor (g/bird-d) higher than this study. Siefert et al. (2004) used inverse Gaussian plume modeling with passive filter packs (Ogawa samplers) deployed downwind of the houses for intermittent monitoring during weeks 3-5 during a 6-wk grow-out compared with a direct emission measurement method used in this study. Siefert et al. (2004) provided no information on litter age or amendment use. In addition to management factors (e.g., litter age) and age of birds, emission factors may also be affected by the measurement method used.

From table 4, it seems that emission factors decreased with increasing PLT application rates; however, higher emission factor of J-4 vs. J-2 was noted. As has been stated earlier, other factors, such as mass of birds produced, mortalities, etc. will have to be considered.

Conclusions

The impact of varying PLT application rates (average of 1.23, 0.73, 0.16, and 0.41 kg/m^2) on in-house ammonia-N concentrations and emissions in/from four broiler houses were evaluated during September 2007 to May 2008 in eastern NC. The length of grow-out was ~9 weeks. Key study findings are reported below.

- In-house ammonia-N concentrations decreased with increasing PLT application rates.
- A PLT application rate of 0.73 kg/m^2 (150 lb/1,000 ft^2) seemed to be adequate to maintain ammonia levels at or below 25 ppm (14.3 mg-N/m^3) for a 9-wk grow-out on litter that had been used to raised four flocks of heavy-broilers previously.
- Ammonia-N concentrations inside the houses during the layout periods were extremely high, sometimes exceeding 400 mg/m^3.
- Based on data from three flocks, ammonia emission factors (only grow-out) for the control, low, medium, and high treatments were 1.06, 1.12, 0.97, and 0.92 g/bird-d, respectively. Ammonia emission factors decreased with increasing PLT application rate (0.73 kg/m^2 or higher). However, emission factor was higher with low PLT (0.41 kg/m^2) vs. control (0.41 kg/m^2 in the center brood area only). Emissions were slightly lower in winter than the other seasons.
- Ammonia emission factors (only during grow-out) calculated in this study were mostly higher than those reported in the literature. One reason for this was the heavier birds (longer grow-out period) in this study.
- The acid scrubbers proved to be robust for measuring time-averaged ammonia concentrations for a wide range of concentrations that may not be possible with other methods. However, controlling the operation of the scrubbers (based on time or fan status) proved to be difficult in the beginning.

These results are based on an ongoing study that will continue until August 2009. Other aspects of this study involve evaluating the impact of PLT application rate on bird performance and energy use. An N balance will also be performed. Ammonia emissions will also be monitored from stockpiled broiler litter.

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