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Ammonia Emissions from Broiler Houses in the Southeastern United States

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Abstract. *Continuous monitoring of ammonia (NH_3) emissions from two mechanically ventilated commercial broiler houses located in the southeastern United States was performed during a one-year period over 2005-2006 as a joint effort between Iowa State University and the University of Kentucky. Ammonia concentrations were measured using Innova 1412 photoacoustic NH_3 monitors. Ventilation rates in each house were measured continuously by monitoring the building static pressure and operational status of all ventilation fans in conjunction with individual performance curves developed and verified in situ using a Fan Assessment Numeration System (FANS) unit. Expressed in various units, NH_3 emissions from the two broiler houses over the one-year production period were of the following values: a) 35.4 g per bird marketed (77.9 lb per 1,000 birds marketed), including both grow-out (50-54 d per flock) and downtime (12-25 d between flocks) emissions; b) annual (365-d) emission of 4.63 Mg (5.1 US tons) per house, including both grow-outs and downtime; c) maximum grow-out daily emission of 30.6 kg/d-house (67.4 lb/d-house) for one house and 35.5 kg/d-house (78.2 lb/d-house) for the other; d) mean grow-out daily emission of 14.0 ± 9.1 (S.D.) kg/d-house; e) mean downtime daily emission of 8.8 ± 8.3 kg/d-house. Flocks on new bedding had a lower emission rate of 12.4 ± 9.4 kg/d-house, as compared to 14.5 ± 8.9 kg/d-house for flocks on built-up litter. The NH_3 emission factor of 35.4 g/bird marketed from this study is substantially lower than that cited by US EPA of 100 g/yr-bird (the US EPA yr-bird unit is equivalent to bird marketed).*

Keywords. Ammonia, emissions, air, monitoring, broilers

Introduction

Ammonia (NH_3) 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 recent estimates, broilers constitute 54% of poultry contributions to the U.S. ammonia inventory, and 14.8% of animal agriculture (EPA, 2005). Regulatory agencies have shown increased interest in ammonia as a potential air pollutant, and the U.S. Environmental Protection Agency (US EPA) has entered into a national Air Consent Agreement to collect additional ammonia emissions data from US AFOs (Copeland, 2005). The objective of this study was to accurately quantify the ammonia emissions from two commercial broiler production houses in the Southeastern United States over a one year period. Measurement over a one-year period allowed for delineation of NH_3 emission variations due to seasonal effects, bird growth cycles, and litter conditions. Emissions are presented on a daily, per flock and annual basis. The emissions data from this study will be used by the US EPA as representative NH_3 emissions from broiler production facilities located in the southeastern United States as part of the national Air Consent Agreement. Due to the intended use of the collected emissions data, all data were collected under a US EPA Category I Quality Assurance Project Plan (QAPP). For detailed information concerning the QAPP please

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refer to Moody et al. (2007) and Moody et al. (2006). For this study, two mobile air emission monitoring units were designed and fabricated at Iowa State University. The units utilize a system to quantify NH_3 concentrations of the broiler house exhaust air and the ambient background in conjunction with a system to quantify the air flow rate of the mechanically-ventilated houses, which allows for determination of mass of NH_3 emissions from the source. For a description of the monitoring system design and performance please refer to Burns et al. (2007) and Burns et al. (2006).

Materials and Methods

Broiler Houses and Emissions Monitoring

Two commercial broiler houses, each measuring 13.1 m × 155.5 m (43 × 510 ft), were monitored at two different farm sites in western Kentucky, designated as Tyson 1 and Tyson 2. Each house had an initial placement of approximately 25,800 Cobb-Cobb straight-run (mixed sex) broilers in winter and approximately 24,400 in summer, grown to 50-54 days of age at slaughter. The houses featured insulated drop ceilings, 52 box-inlets (15 × 66 cm each – 26 of them along each sidewall), 26 pancake brooders (30, 000 Btu/h each), three space heaters (225,000 Btu/h each), four 0.9 m (36 inch) diameter sidewall exhaust fans spaced approximately 36.6 m (120 ft) apart, and ten 1.2 m (48 inch) diameter tunnel fans. The two 0.9 m sidewall fans used for minimum ventilation were located in the brood end of the houses. The emission monitoring system consisted of the NH_3 concentration monitoring instrument, a fan operation monitoring system and a data acquisition and control system. All instruments were housed in an environmentally-controlled trailer. As typically practiced, the broiler houses used intermittent operation of the single-speed (0.9 m dia.) fans when the birds were young. The 0.9 m (36 inch) diameter sidewall fans were operated with 5 min duty-cycles with a 30 sec minimum run-time. This unique on/off characteristic of building ventilation made it necessary to associate the in-house gas concentrations with the periods of fan operation in order to determine representative building emissions. It has been observed that NH_3 concentrations could vary more than 10 ppm during a fan on/off cycle. As such, an NH_3 analyzer with a fast response time was selected (Innova model 1412, Innova AirTech Instruments A/S, Denmark) for measuring NH_3 concentrations of the exhaust and background air. The location monitored was cycled among three selected exhaust fan locations in the broiler houses. Spatial variation of the NH_3 concentrations also required fast instrument response time when switching monitoring among several locations.

Ammonia emissions sampling was initiated on Dec 9, 2005 and Oct 7, 2005 for Tyson 1 and Tyson 2, respectively. After 365 days of monitoring at each site, five flocks had been completed for each house and the sixth flocks were ongoing, thus the study was continued through the sixth flock at each house. At the end of the monitoring, six flocks had been monitored from each house with ending dates of Jan 9, 2007 and Nov 27, 2006 for Tyson 1 and Tyson 2, respectively. A bird scale was placed in each house to continuously monitor bird weight. Bird mortality was also recorded, allowing for expression of emissions on the basis of per bird or per 500 kg animal unit (AU).

Old litter was completely removed from both houses and new rice hull bedding was placed at the beginning of the monitoring period. During the one-year period, one cleanout of the litter was performed for Tyson 1 on Aug 26, 2006 (after 4 flocks) and new bedding was placed on Aug 29, 2006; Tyson 2 did not have a litter cleanout during the monitoring period. While monitoring over six flocks, the complete data days (CDDs) were 387 out of 397 days (97.5% data completeness) for Tyson 1 and 398 out of 417 days (95.4% data completeness) for Tyson 2. The 785 CDDs emissions data from both houses (12 flocks) were used to report the daily mean, daily maximum, flock total, and downtime emission rates. Data from the first 365 monitoring days at each house were used to report the annual emissions from each house. Emissions for days with less than 75% data completeness during this first 365 day period were replaced with estimated emissions using the regression of the ER against bird age.

Emission Rate (ER) Calculation

Ammonia emission rate (ER) from a broiler house to the atmosphere is the difference between the mass of NH_3 leaving the house and the mass of NH_3 entering the house. The relationship of ER to NH_3 concentration of inlet and exhaust air and building ventilation rate is shown in Equation 1.

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

where:

ER = NH_3 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 (m^3 hr^{-1} $house^{-1}$)

$[NH_3]_i$ = NH_3 concentration of incoming house ventilation air, parts per million by volume (ppm_v)

$[NH_3]_e$ = NH_3 concentration of exhaust house ventilation air of the portion of the house at location "e" (ppm_v)

w_m = molar weight of NH_3, 17.031 g $mole^{-1}$

V_m = molar volume of NH_3 gas at standard temperature (0°C) and pressure (1 atmosphere) (STP), 0.022414 m^3 $mole^{-1}$

T_{std} = standard temperature, 273.15 K

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

P_{std} = standard barometric pressure, 101.325 kPa

P_a = atmospheric barometric pressure for the site elevation, kPa

ρ_e = air density at exhaust fan location "e", kg dry air m^{-3} moist air

ρ_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.

Results and Discussion

Ammonia Emission Rate (ER)

Figures 1 and 2 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 varied from 0 to 44.8 kg/d-house. When the houses were occupied by birds, the highest ER was 30.1 and 35.5 kg/d-house for Tyson 1 and Tyson 2, respectively. The highest daily emission of 44.8 kg/d-house occurred at Tyson 1 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 1c). Note that the emissions between the vertical dash lines in Figures 1 and 2 represent downtime periods between flocks when no birds were in the houses.

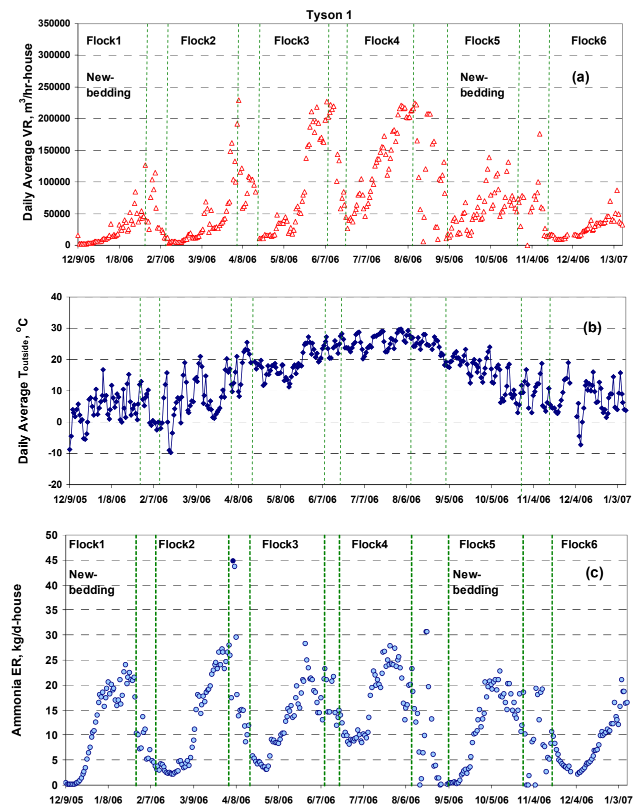

Figure 1. Daily ventilation rate, outside temperature, and ammonia emission over the six flocks for Tyson 1.

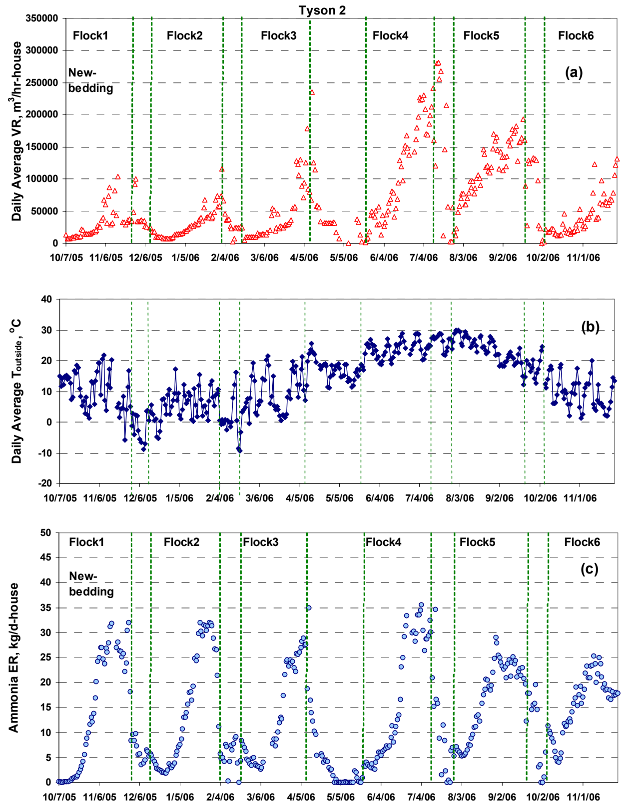

Figure 2. Daily ventilation rate, outside temperature, and ammonia emission over the six flocks for Tyson 2.

The ammonia ER (0.25 ± 0.19 kg/d-house) from the flocks with new bedding was significantly less ($P<0.001$) than those (6.07 ± 2.67 kg/d-house) with built-up litter during the first 6 days of the grow-outs. After that, ERs for flocks on new bedding 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 on new bedding 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 for the ERs to reach a peak after 5-6 weeks and then stabilize until the end of the flock. During the grow-out periods, the ER for the three flocks on new bedding was 12.36 ± 9.36 kg/d-house, which is significantly lower than 14.55 ± 8.99 kg/d-house for the nine flocks raised on built-up litter. The ERs of all flocks varied from 11.68 to 17.14 kg/d-house, except flock 6 in Tyson 1. Flock 6 in Tyson 1 had over 40% cumulative mortality by the end of the flock due to a vaccination complication, leading to a much lower ER of 8.45 kg/d-house for this flock. The average ER for Tyson 1 over the six flocks was 12.55 ± 7.82 kg/d-house which is significantly lower than 15.45 ± 9.95 kg/d-house for Tyson 2 ($P=0.01$). The average NH_3 ER for Tyson 2 downtime between flocks was 6.32 ± 6.82 kg/d-house. In contrast, the average downtime ER at Tyson 1 was 11.91 ± 8.86 kg/d-house. Tyson 1 had two flocks on new bedding while Tyson 2 only had one flock on new bedding. Flock 4 in both houses and flock 5 in Tyson 2 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 overall ER of all 12 flocks was 14.00 ± 9.09 kg/d-house.

Figures 3 and 4 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 on new bedding and built-up litter. The ERs per AU of three flocks on new bedding (Tyson 1 flocks 1 and 5, and Tyson 2 flock 1) increased from very low levels peaked after 28-35 d bird age. The ERs per AU of

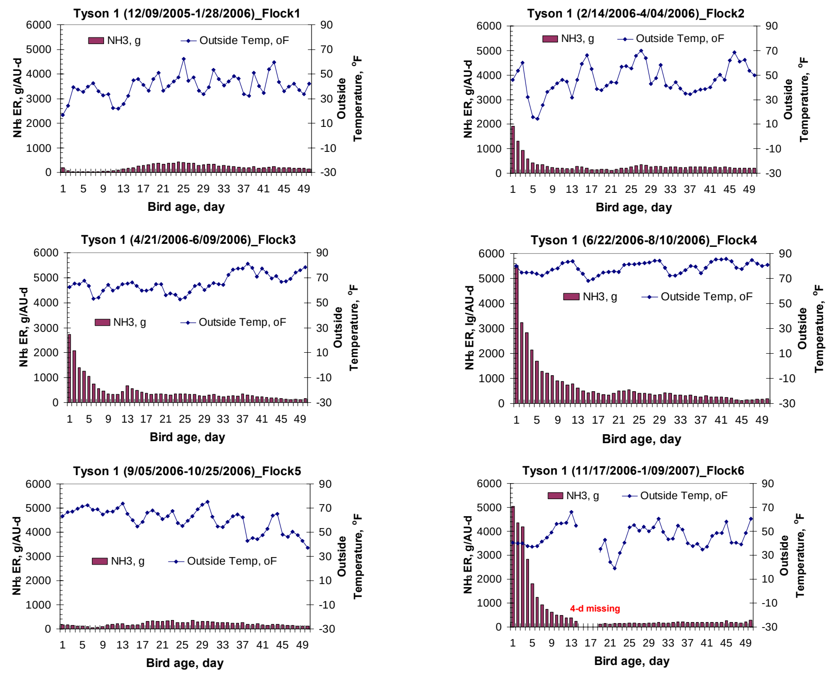

Figure 3. Tyson 1 NH_3 ER per AU (500 kg) mean outside temperature vs. bird age.

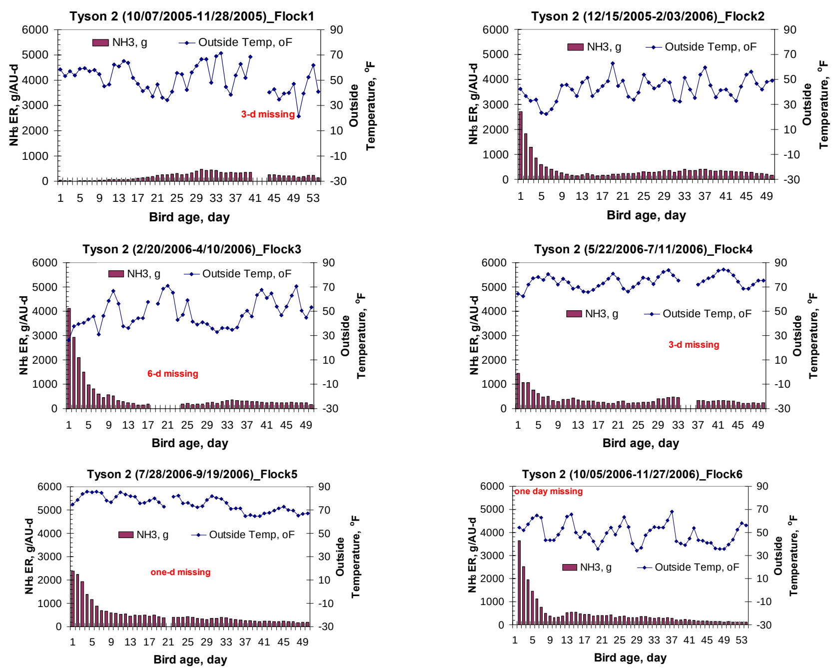

Figure 4. Tyson 2 NH_3 ER per animal unit (AU: 500 kg) and mean outside temperature vs. bird age.

the flocks with built-up litter started high but became relatively stable with bird growth when reported on a per AU basis. This same trend was noted by Wheeler et al. (2006). At the beginning of each flock in our study with built-up litter, ER per AU varied from 1.4 to 5.5 kg/AU-d. There was no significant difference between Tyson 1 and Tyson 2 in ER per AU (P=0.97). The daily ERs per AU from all flocks were 413.5 ± 495.8 and 414.8 ± 661.4 g/AU-d for Tyson 1 and Tyson 2, respectively. The overall ER per AU for all flocks was 414.2 ± 584.6 g/AU-d.

Emission Rate During Downtime Between Flocks

Ammonia emissions from the two houses were continuously monitored during downtime (the period between flocks when the houses were empty). Ventilation rate (VR) of the houses had a significant impact on the ER when the VR was lower than 135,920 $m^3 \cdot hr^{-1}$ (80,000 cfm), as shown in Figure 5. However, it was also related to litter management practices, such as litter decaking. The average downtime ER for Tyson 1 and Tyson 2 was 11.91 ± 8.86 and 6.32 ± 6.82 kg/d-house, respectively. The overall ER for the two houses during downtime conditions was 8.77 ± 8.27 lb/d-house. These values are approximately two-thirds of the mean ER when birds near a 2.7 kg (5.9 lb) market size were present in the houses.

Annual Ammonia Emission

The annual ammonia emission from each house is the accumulation of daily ERs over 365 days. However, emissions data for some days were incomplete due to various reasons such as power outages during adverse weather or instrument malfunctions. There were a total of 10 incomplete days for Tyson 1 and 19 incomplete days for Tyson 2 over the first 365 monitoring days at each house. The monitored annual emissions were 4.358 and 4.449 Mg (4.8 and 4.9 US tons) per year for Tyson 1 and Tyson 2, respectively. Based on the regression of the ER against bird age, the incomplete daily ammonia ERs were predicted for each house. After the incomplete emissions were filled with predicted values, the annual emissions were 4.540 and 4.722 Mg (5.0 and 5.2 US tons) for Tyson 1 and Tyson 2, respectively. The NH_3 emissions on the basis of per 1000 birds marketed were 33.27 and 37.50 kg (73.3 and 82.5 lb) for Tyson 1 and Tyson 2, respectively. Combining both houses, the overall annual ammonia emission was 4.631 Mg (5.1 US tons) per house, 35.41 kg (77.9 lb) per 1000 birds marketed or 35.4 g per bird marketed.

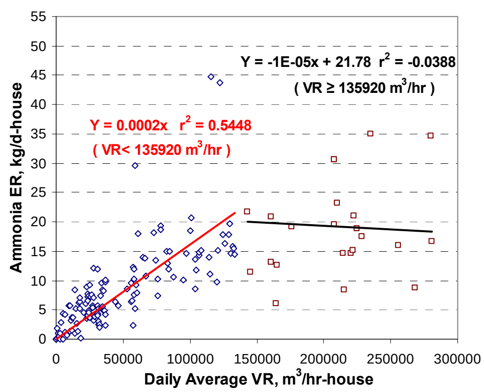

Figure 5. Ammonia emission rate of broiler houses vs. ventilation rate (VR) during downtime.

Implications

Comparison of ER with Literature Data

Comparison of published ammonia emission rates (ER, g/bird-d) reported for broiler production houses (occupied with birds) in the United States are shown in Table 1. The mean ERs from this study expressed in g/bird-day of 0.49 g/bird-day and 0.62 g/bird-day are similar to most of the published NH_3 ER values for US broiler systems. Table 1 presents nine US broiler emission factors (two from this study and seven others from four other US studies). Four of the seven factors from studies reported in Wheeler et. al, 2006 and Lacey et. al, 2003 range from 0.47 to 0.76 g/bird day. Three of the broiler emissions factors reported by Wheeler et. al., 2006, Seifert et al., 2004 and Burns et. al, 2003 range from 0.92 to 1.18 g/bird-day. It is important to note however that the highest Wheeler et. al., 2006 factor of 0.98 g/bird-day was derived from emission measurements for broilers with a 63 day growth period, where the factors from the other reported studies were derived from emissions measurements for flocks with 42 to 54 day growth periods. This leads to the important recognition that emission factors reported on a g/bird-day basis can be very misleading. These factors are highly influenced by the type and size of the bird being produced. More important is knowing what "day" emission factors presented with these units truly represent. Because NH_3 emissions on a per bird basis increase as the birds gain weight in the production cycle, emission factors presented on a bird-day basis are only accurate for a specific given day of the growth cycle. The g/bird-day emission factors presented in this study were derived from continuous monitoring throughout the entire flock growth period. This means that these factors can be multiplied by the number of days in the growth period and will represent the cumulative NH_3 emission on a per bird basis for that flock. It is very important to note however that given the high cost of continuously monitoring broiler NH_3 emissions that many studies base these factors on limited monitoring periods of only hours or days within a given flock production cycle. The calculation of emissions over a full flock or annual period using g/bird-day values derived from limited monitoring periods can result in very erroneous emissions calculations for these longer periods. Because of this limitation, 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. Unfortunately however, the g/bird-day unit has typically been reported in most broiler emission studies, so we have reported the emissions from this study in this manner simply for comparison purposes with other published studies. The use of emission per 1000 birds marketed more realistically captures the events and allows for emission inventory tracking. It should be noted, that the use of an emission factor per bird marked will either over or under predict emissions if applied to birds grown to a lesser or greater slaughter weight or with a lesser or greater number of days in the growth cycle than the bird weight and production length that the emission factor was developed from.

It is worth noting that the ER of 35.4 g/bird marketed from this study is significantly lower that the emission factor of 100 g/bird-year for broilers used by the US EPA. Note that while the US EPA factor uses units of g/bird-year, the value is actually representative of g/bird marketed. Because a typical broiler operation will market six flocks of birds per year from a single house, we have chosen to report emissions in g/bird marketed for clarity. While the US EPA factor also represents emissions from a single marketed bird, rather than from six birds that would actually be marketed over a one year period, use of "year" in these units can be very misleading. We have presented the US EPA values using the original units they were published in, but believe the use of year in the units is misleading and should be dropped by researchers and by the US EPA.

Table 1. Comparison of ammonia emission rates (ER, g/bird-d) of the commercial broiler houses among various U.S. studies

Reference	Growth Period, d	Stocking Density, birds/m^2	Stocking Density, birds/ft^2	No. of Flocks	Litter Status	Mean ER, g/bird-d	Location
This study	52	12.7	1.18	3	New	0.49	KY, U.S.A
This study	52	12.2	1.13	9	Built-up	0.62	
Wheeler et al. (2006)	42	14.7	1.37	10	New	0.47	KY & PN, U.S.A
	42	14.7	1.37	12	Built-up	0.65	
	49	13.4	1.24	24	Built-up	0.76	
	63	10.8	1.00	20	Built-up	0.98	
Burns et al. (2003)	42	16.1	1.50	9	Built-up	0.92	TN, U.S.A
Lacey et al. (2003)	49	13.5	1.25	12	Built-up	0.63	TX, U.S.A
Seifert et al. (2004)	42	20	1.86	1	Built-up	1.18	DE, U.S.A

Conclusions

Ammonia emissions from two representative commercial 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.

- Annual ammonia emission for the two broiler houses (including downtime emissions) averaged 4.631 Mg (5.1 US tons) per house or 35.41 kg (77.9 lb) per 1000 birds marketed at 52 days of age with a stocking density of 12.45 birds/m^2 (0.87 ft^2/bird).

- Maximum daily ammonia emission during the grow-out period was less than 36.36 kg (80 lb) per house.
- Daily ammonia emission during downtime was 8.77 ± 8.27 kg/d-house. The downtime ER tended to be positively related to ventilation rate (up to a point – 47,086 $m^3 \cdot hr^{-1}$ in this case) and was definitely influenced by litter handling.
- Use of new bedding lowered the flock ammonia emissions, but did not seem to impact maximum daily emissions.
- The ammonia emission factor revealed from this study, 35.4 g per bird marketed, is significantly lower than that used by the US EPA, 100 g/bird-year.

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