2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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# Greenhouse Gas (GHG) Emissions from Broiler Houses in the Southeastern United States

**Robert T. Burns, Ph.D., P.E., Associate Professor**
Agricultural and Biosystems Engineering, Iowa State University,
3224 NSRIC, Ames, IA 50011, rburns@iastate.edu

**Hong Li, Ph.D., Assistant Scientist**
Agricultural and Biosystems Engineering, Iowa State University,
1242A NSRIC, Ames, IA 50011, lwblue@iastate.edu

**Hongwei Xin, Ph.D., Professor**
Agricultural and Biosystems Engineering, Iowa State University,
3204 NSRIC, Ames, IA 50011, hxin@iastate.edu

**Richard S. Gates, Ph.D., P.E., Professor**
Biosystems and Agricultural Engineering, University of Kentucky,
128 CE Barnhart Building, Lexington, KY 40546, gates@bae.uky.edu

**Douglas G. Overhults, Ph.D., P.E., Associate Professor**
Biosystems and Agricultural Engineering, University of Kentucky,
P.O. Box 469. Princeton, KY 42445, doverhul@email.uky.edu

**John Earnest, Engineering Technician**
Biosystems and Agricultural Engineering, University of Kentucky,
P.O. Box 469. Princeton, KY 42445, jearnest@uky.edu

**Lara Moody, P.E., Extension Program Specialist**
Agricultural and Biosystems Engineering, Iowa State University,
3165 NSRIC, Ames, IA 50011, lmoody@iastate.edu

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**Abstract.** *Greenhouse gas (GHG) emissions, including carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$), from broiler houses located in the southeastern United States were continuously monitored over a one-year period. The birds were grown to 52 days of age at an average stocking density of 11.8 birds/$m^2$ (1.1 birds/$ft^2$). Methane and $CO_2$ emissions were measured in two broiler houses while $N_2O$ emissions were measured in one house. Carbon dioxide and $N_2O$ concentrations were measured using a photoacoustic multi-gas analyzer and $CH_4$ concentrations were measured using a dual-channel methane/non-methane-hydrocarbon (NMHC)/total hydrocarbon analyzer with dual flame ionization detectors. Ventilation rates in each house were continuously calculated by monitoring the building static pressure and operational status of all ventilation fans in conjunction with individual fan performance curves developed and verified in situ using a Fan Assessment Numeration System (FANS) unit. Annual $CO_2$ emissions measured from the two broiler houses averaged 606 Mg (668 US tons) per house. On a marketed bird basis the $CO_2$ emissions averaged 4.64 Mg (5.49 US tons) per 1,000 birds marketed. Annual $CH_4$ emissions averaged 445 kg (982 lbs) per house, or 3.41 kg (7.52 lbs) per 1,000 birds marketed. Annual $N_2O$ emissions measured from one broiler house was 225 kg (496 lbs) per house, or 1.72 kg (3.8 lbs) per 1,000 birds marketed. The $CO_2$ equivalents of the $CH_4$ and $N_2O$ emissions were, respectively, 85.3 kg (188 lb) and 512.6 kg (1,128 lb) per 1,000 birds marketed. Hence the total $CO_2$ equivalent GHG emissions for the broiler operations monitored in this study were 5.238 Mg per 1,000 birds marketed, with 88.6% contributed by $CO_2$.*

**Keywords.** Greenhouse gas (GHG), methane, carbon dioxide, nitrous oxide, emissions, broilers

## Introduction

Agriculture has been identified by the USEPA as contributing 6% of the total US greenhouse gas (GHG) emissions in 2006. During 2006 all agricultural sources were estimated to have generated 454.1 teragrams ($10^{12}$ g) of $CO_2$ equivalent GHG emissions in the United States. The USEPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (2008) identifies manure management as generating 24 % and 5 % of the methane ($CH_4$) and nitrous oxide ($N_2O$) emissions, respectively, from agricultural sources. A review of published literature identified reports of $CH_4$ and $N_2O$ emissions from fattening pigs on slatted floors in Denmark (Osada, et al., 1998), from swine farrowing house in China (Dong et al., 2007), swine hoop structures (Singh, et al., 2003), GHG emissions from stored swine manure (Lagu, et al., 2005) and $CH_4$ and $N_2O$ emissions data from dairy farms (Singurindy, et al., 2007, Sedorovich, et al., 2007). Very limited published information quantifying GHG emissions from U.S. broiler production systems was found in the literature, however.

This paper reports GHG emissions from two broiler houses representative of commercial broiler production in the southeastern United States, based on 13-month continuous measurements. The GHG emissions measured and reported here include $CO_2$, $CH_4$ and $N_2O$.

## Materials and Methods

### *Characteristics of the Monitored Broiler Houses*

Two broiler houses (T-1 and T-2) each measuring 13.1 m x 155.5 m (43 x 510 ft) in western Kentucky were selected for emissions monitoring. The monitored broiler houses used tunnel ventilation and static pressure controlled box air inlets along the sidewalls. The houses had insulated drop ceilings, 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 from the tunnel fans. The houses were also equipped with foggers for additional cooling, if needed. Rice hulls were used as litter bedding in both houses.

### *Broiler Flock Characteristics*

Monitoring of GHG emissions began on February 14, 2005 and February 20, 2005 for T-1 and T-2, respectively; and concluded on March 14, 2007 and March 5, 2007 for T-1 and T-2, respectively. During this period, six flocks of broilers were produced in each house. 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 period was 52 days. A bird scale (Model RSC-2, Rotem, Petach Tikva, Israel[1]) 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 study. During the one-year period, one cleanout of the litter was performed for T-1 on August 26, 2006 (after 3 flocks) and new bedding was placed on August 29, 2006; T-2 had a litter cleanout after five flocks, on February 3, 2007 and new bedding was placed on February 5, 2007. The birds had free access to standard diets (provided by the integrator) and water (nipple drinkers) during the grow-out.

### *Monitoring System*

Each broiler house had its own Mobile Air Emissions Monitoring Unit (MAEMU) that housed air pollutant and fan flow monitoring systems in an environmentally-controlled instrument space. Air sampling lines from the broiler house sampling points (representing the exhaust air streams) to the instrument trailer/analyzers were protected from in-line moisture condensation with insulation and temperature-controlled resistive heating cable.

Air samples were drawn from three locations in each house to account for potential spatial variations. One sampling was near the primary minimum ventilation (36-in) sidewall fan (SW1) in the brooding half of the house; the second sampling near the third sidewall (36-in) exhaust fan (SW3) (non-brooding end); and the third sampling near the center of the tunnel end of the house between the first two sets of tunnel fans. The ambient sample intake line was located between the inlet boxes opposite of the sidewall with the exhaust fans. The background GHG concentrations were subtracted from the exhaust amount in calculating air emissions from the house.

A positive pressure gas sampling system (P-P GSS) was used to draw all air samples from the broiler houses. Use of the P-P GSS eliminates any undesirable dilution of the samples should any sample line leakage exist. The air samples from each location were analyzed for 120 s. Selection of the 120 s measurement cycles were based on extensive testing of the instrument response time, both in the laboratory and in the field (injecting calibration gases into the most distant in-house air sampling port). If fans at all three in-house sampling locations were running, the time interval of a complete sampling cycle would be 360 s (120 × 3 = 360 s). To account for

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[1] Mention of product or company names is for presentation clarity and does not imply endorsement by the authors or their affiliation nor exclusion of other suitable products.

potential concentration changes during this period, linear interpolation between the two adjacent readings of the same location was performed to determine the concentrations in between sampling events. If SW4 and/or TF1 fans were not operating, sampling of these locations would be skipped, and the sampling would either remain at SW1 or switch to the background air. Fan airflow rates concomitant with the measured concentrations were used in the calculation of the house emission rate. Only the concentrations at the end of the sampling cycle (fourth readings at any given in-house location) were considered as valid measurements and used to calculate emissions. The outside ambient air sample was taken at 2-hour intervals because of its relatively constant concentration levels. Burns et al. (2006), Moody et al. (2006) and Burns et al. (2007) give a more detailed description of the monitoring system design and operation.

A photoacoustic multi-gas analyzer (INNOVA model 1412, INNOVA AirTech Instruments A/S, Denmark) was used to measure both $CO_2$ and $N_2O$ concentrations of the air samples. Methane concentrations were measured using a dual-channel methane/non-methane hydrocarbon (NMHC)/total hydrocarbon analyzer with dual flame ionization detectors (FID) (Model 200, VIG Industries Inc., Anaheim, CA). The VIG model 200 methane/NMHC/total hydrocarbon analyzer uses column technology to separate methane and non-methane from total hydrocarbons and uses dual FID to measure each component in the air sample.

Ventilation rates of the houses were derived by using *in situ* calibrated fan curves from a fan assessment numeration system (FANS) (Gates et al., 2004). After the actual airflow curves were established for all the exhaust fans and their combinations, runtime of each fan was monitored and recorded continuously using an inductive current switch attached to the power supply cord of each fan motor (Muhlbauer et al., 2006). Analog output from each current switch 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. Summation of airflows from the individual fans during each monitoring cycle or sampling interval produced the overall house ventilation rate.

### Emission Rate Determination

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

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

where $ER_G$ = gaseous emission rate of 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 ($m^3$ $hr^{-1}$ $house^{-1}$)
$[G]_i$ = gaseous concentration of incoming house ventilation air, parts per million by volume ($ppm_v$)
$[G]_e$ = gaseous concentration of exhaust house ventilation air of the portion of the house at location “e” ($ppm_v$)
$w_m$ = molar weight of air pollutants, g $mole^{-1}$
$V_m$ = molar volume of 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
$\rho_e$ = 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

# Results and Discussion

## *Carbon Dioxide ($CO_2$) Emissions*

### $CO_2$ Emission Rate Estimation/Prediction

The $CO_2$ ER was highly correlated to bird age. The $CO_2$ ER per house or per bird from all data except for flock 6 at T-1, as shown in Figures 1 and 2, may be estimated using the predictive regression equation given as Equation 1, where $X$ = bird age in days.

$$CO_2\ ER,\ ton\ d^{-1}\ house^{-1} = a + b\,X \qquad [1]$$

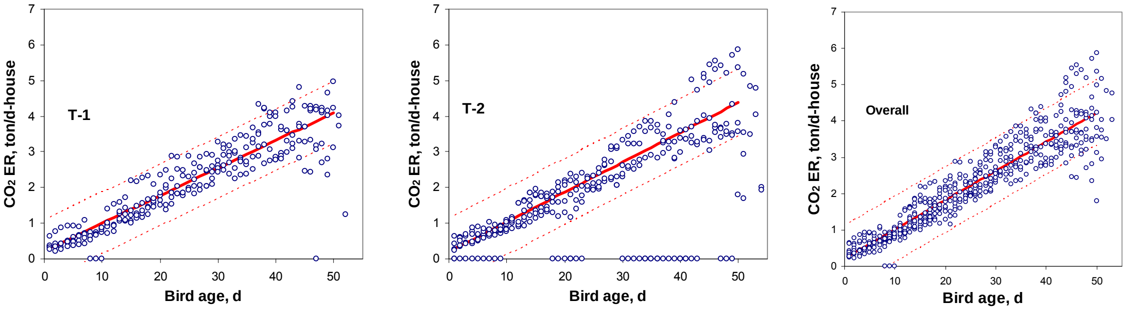

**Figure 1. Relationship between $CO_2$ ER and bird age for T-1 (a), T-2 (b) and Overall (c). The solid line is the regression line; dash lines are 95% prediction limit.**

Table 1 provides the prediction parameter estimates for the two houses, individually, and overall 11 flocks. The correlation coefficients ($r^2$) of prediction models vary from 0.64 to 0.80 and show the strongest relationship between ER and bird age.

**Table 1. Coefficient estimates of $CO_2$ ER (ton/d-house) prediction models for the houses, T-1 and T-2.**

| House | SE of ER | **a** (± SE) | **b** (± SE) | $r^2$ |
|---|---|---|---|---|
| T-1 | 0.44 | 0.23 (± 0.057) | 0.077 (± 0.0019) | 0.87 |
| T-2 | 0.47 | 0.20 (± 0.059) | 0.083 (± 0.0021) | 0.83 |
| Overall | 0.44 | 0.23 (± 0.041) | 0.079(± 0.0012) | 0.87 |

Figure 3 provides the daily $CO_2$ ER for the two houses for the entire monitoring period with six flocks and downtime between flocks. The daily ER varied from nearly 0 to 5.83 ton/d-house (6.47 US ton/d-house). During the grow-out period, the highest ER was 5.0 ton/d-house (5.51 US ton/d-house) and 5.83 ton/d-house (6.47 US ton/d-house) for T-1 and T-2, respectively. The average ER for T-1 over the six flocks was 2.28 ± 1.17 ton/d-house (2.51 ± 1.29 US ton/d-house) which is not significantly different from 2.41 ± 1.27 ton/d-house (2.66 ± 1.4 US ton/d-house) for T-2 (P=0.32). The average ER of 12 flocks was 2.31 ± 1.20 ton/d-house (2.55 ± 1.32 US ton/d-house).

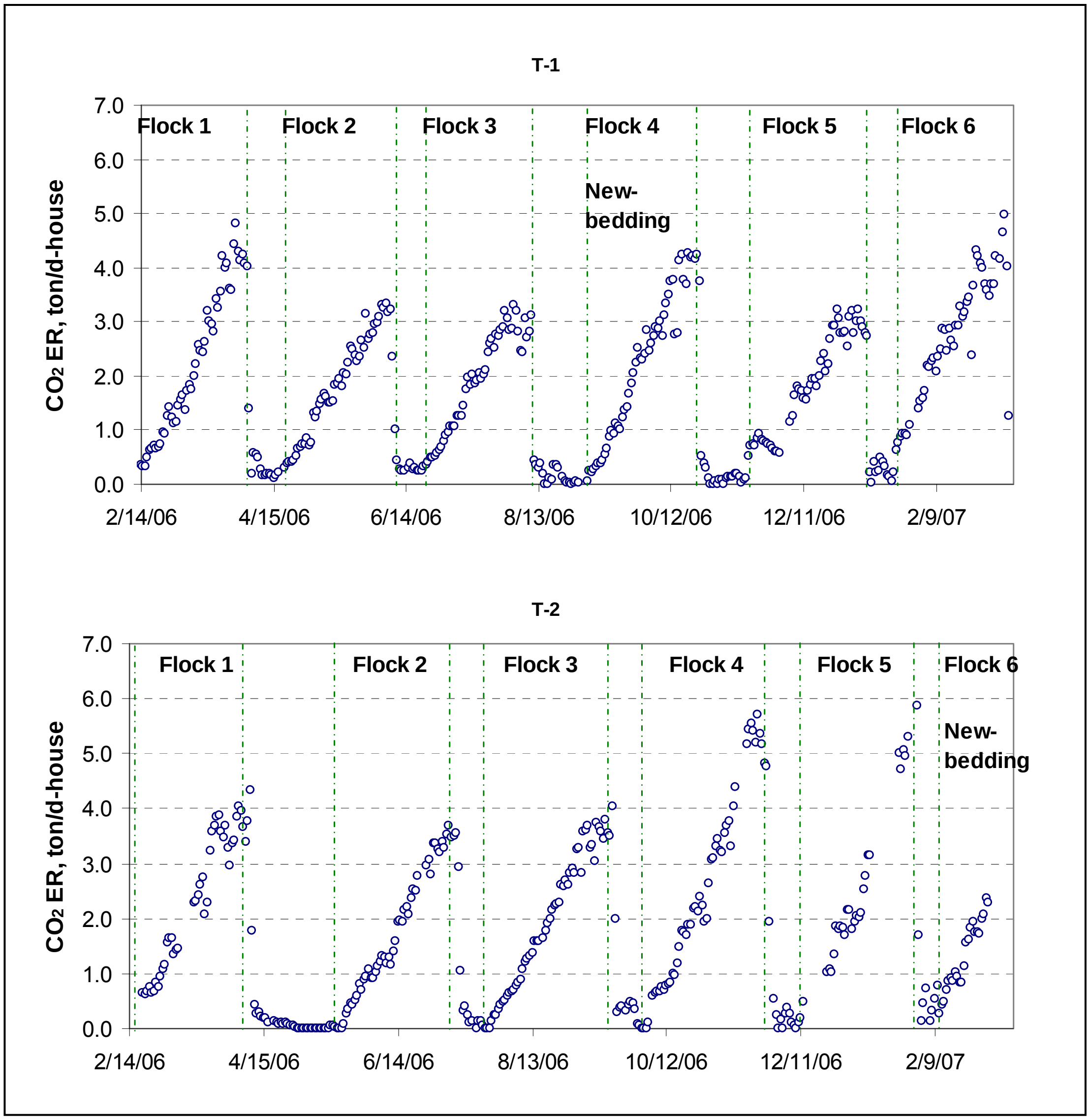

**Figure 3. Daily $CO_2$ emission over the six flocks for T-1 and T-2.**

In addition to continuous monitoring during grow-out, $CO_2$ emissions from the broiler houses were continuously monitored when the houses were empty between flocks or during downtime. As can be seen from that data in Figure 4, there was no noticeable relationship between the downtime $CO_2$ emissions and ventilation rate, although such relationship was observed for downtime $NH_3$ emissions from the litter (Burns et al., 2007b). The average daily $CO_2$ ER for the two houses during downtime was 0.19 ± 0.18 ton/d-house (0.21 ± 0.20 US ton/d-house).

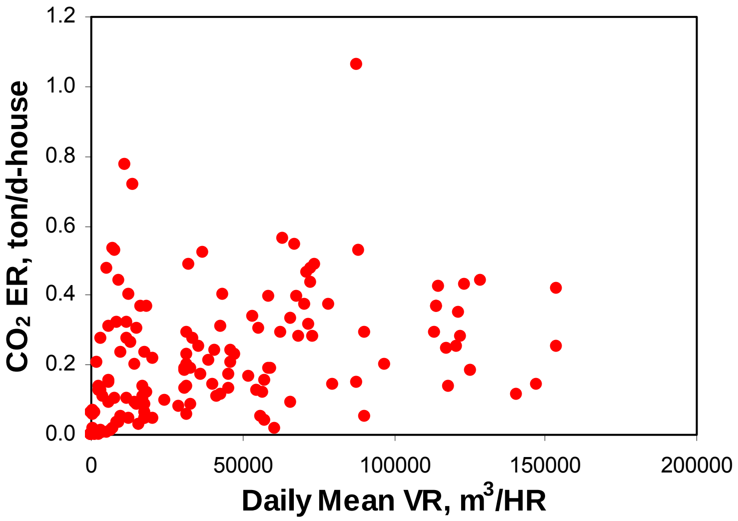

**Figure 4. $CO_2$ emission rate (ER) vs. ventilation rate (VR) during downtime.**

Figures 5 and 6 present $CO_2$ ER per 500 kg animal unit (g/AU-d) for all 12 flocks from the two houses. The ER per AU *vs.* bird age shows that the ER decreased with bird age and tended to be stable after 30 days. The ER was higher in winter than in summer due to $CO_2$ contribution from brooder and space heaters, and possibly greater metabolism from higher feed intake. There was no significant difference in ER per AU between T-1 and T-2 (P=0.96), 58.9 ± 37.1 and 63.3 ± 41.2 kg/d-AU for T-1 and T-2, respectively, yielding an overall daily ER of 61.9 ± 40.1 kg/d-AU.

Annual $CO_2$ emission from each house is the accumulation of daily ER over 365 days. Based on the regression of ER *vs.* bird age from Equation [1], the average flock ER was 120.5 tons per house per flock (132.8 US tons per house per flock). The annual $CO_2$ emission was 606 tons per house (668 US tons per house). In terms of $CO_2$ emissions per marketed bird, the annual mean value was 4.64 kg/bird-marketed (5.11 US tons per 1,000 birds marketed), including downtime emissions.

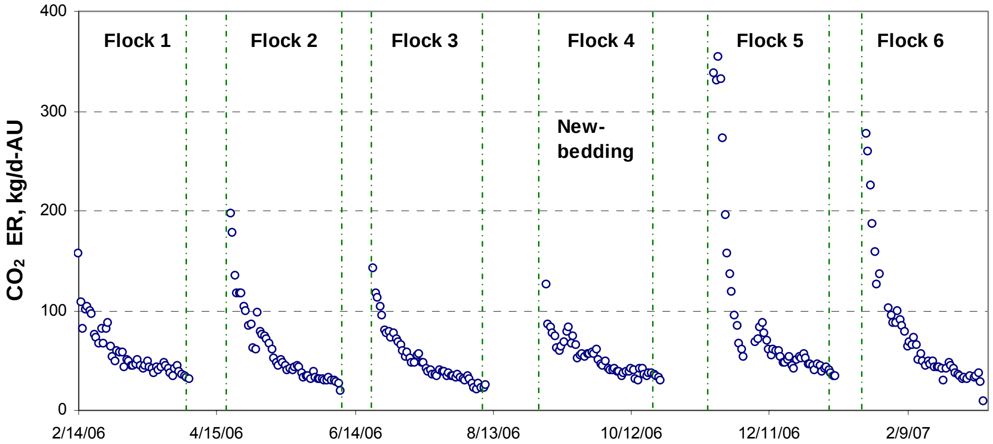

**Figure 5. Carbon dioxide ($CO_2$) emission rate (ER) per animal unit (AU=500 kg) vs. bird age for broiler house T-1.**

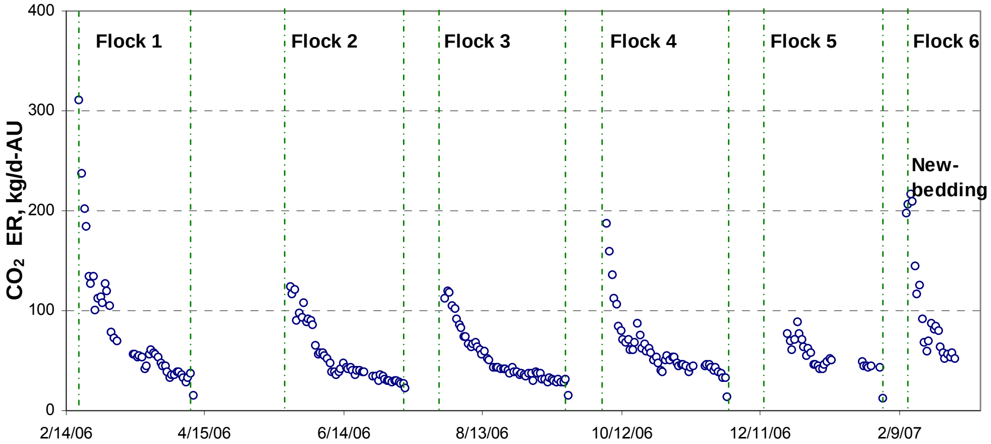

**Figure 6. Carbon dioxide ($CO_2$) emission rate (ER) per animal unit (AU=500 kg) vs. bird age for broiler house T-2.**

## Effects of Environmental Variables on $CO_2$ Emission

To assess the impact of environment on $CO_2$ emission from the broiler houses during growout, a multiple regression analysis was performed that related $CO_2$ ER (ton/d-house) to bird age (d), outside temperature (°C), RH (%), ventilation rate (VR, $m^3$/HR-bird) and bedding status (0 for new bedding; 1 for built-up litter). The results of the regression analysis are shown in Table 2. The outside temperature and VR had significant effect on $CO_2$ ER ($P< 0.01$). As VR increased, $CO_2$ ER decreased. This is because the lower VR was associated with the colder periods of the year when brooders and space heater were used more often, leading to higher $CO_2$ emissions. The cooler temperature in winter could also stimulate bird feed intake, which in turn led to greater metabolism and thus $CO_2$ production.

**Table 2. Multi-variable regression analysis of $CO_2$ for bird age (d), temperature ($^oC$), ventilation rate ($m^3$/HR-bird), and bedding statues ($R^2$=0.93) for the model:**

$$\boldsymbol{CO_2\ ER\ ton\ d^{-1}\ house^{-1}} = \beta_0 + \beta_1 \text{x Age} + \beta_2 \text{ x } T_o + \beta_3 \text{ x } RH_i + \beta_4 \text{ x VR} + \beta_5 \text{ x Bedding}$$

| Term | Estimate | S.E | t Ratio | Prob>$\lvert t \rvert$ |
|---|---|---|---|---|
| $\beta_0$= Intercept | 0.82 | 0.09 | 7.41 | <.0001 |
| $\beta_1$= Bird age, d | 0.09 | 0.00 | 51.3 | <.0001 |
| $\beta_2$= Outside Temp, $^oC$ | -0.0044 | 0.0009 | -5.21 | <.0001 |
| $\beta_3$= Inside RH, % | N/A | N/A | N/A | N/A |
| $B_4$= VR, $m^3$/HR-bird | -0.26 | 0.04 | -6.45 | <.0001 |
| $B_5$= Bedding | N/A | N/A | N/A | N/A |

## ***Methane ($CH_4$) Emissions***

### $CH_4$ Emission Rate Estimation/Prediction

Although other gaseous emissions monitored in the study (such as $NH_3$ and $CO_2$) were highly correlated to the bird age, there was no clear relationship between $CH_4$ ER and bird age, as shown in Figure 7.

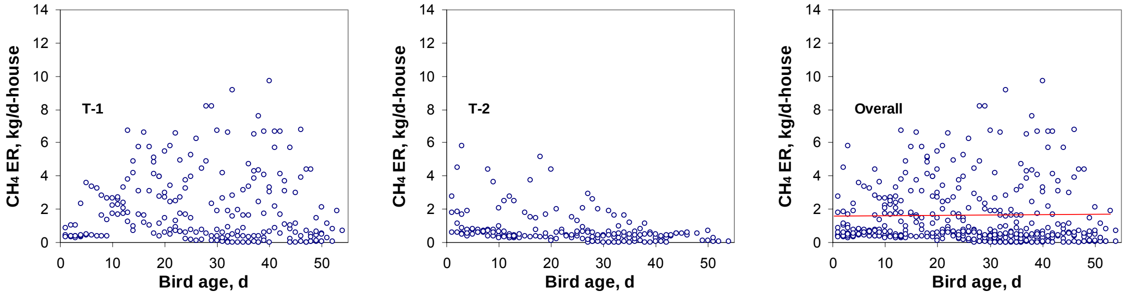

**Figure 7. Relationship between $CH_4$ ER and bird age for T-1 (a), T-2 (b), and Overall (c). The solid line is the average ER.**

Figure 8 provides the daily $CH_4$ ER of the two houses during the entire monitoring period with six flocks and downtime between flocks. The daily ER (kg/d-house) varied from 0 to 9.8 kg/d-house (21.5 lb/d-house). During grow-out period, the highest ER was 9.8 and 5.8 kg/d-house (21.5 and 12.8 lb/d-house) for T-1 and T-2, respectively. The average ER over the six flocks was 2.0 ± 2.1 kg/d-house (4.5 ± 4.7 lb/d-house) for T-1, which was higher than 0.8 ± 1.0 kg/d-house (1.8 ± 2.2 lb/d-house) for T-2 ($P<0.01$). The average ER over the 12 flocks was 1.5 ± 1.9 kg/d-house (3.3 ± 4.1 lb/d-house).

$CH_4$ emissions from the two houses were continuously monitored when the houses were empty between flocks or during downtime. There was no significant relationship between the ER and ventilation rate (fig. 9). The average daily $CH_4$ ER for the two houses during downtime was 0.3 ± 1.0 kg/d-house (0.66 ± 2.0 lb/d-house).

Figures 10 and 11 present $CH_4$ ER in terms of 500 kg animal unit (g/AU-d) for all 12 flocks from the two houses. The ER per AU *vs.* bird age show that ER decreased with bird age and was relatively stable after 30 days. The average daily ER per AU was 96.0 ± 149 and 82 ± 233 g/d-AU for T-1 and T-2, respectively; and the overall $CH_4$ ER was 89.9 ± 190 g/d-AU.

Annual $CH_4$ emission from each house is the accumulation of daily ER over 365 days. Based on average daily ER, the average flock ER was 77.8 kg (171.6 lbs) per house per flock. The annual $CH_4$ emission rate was 445 kg (982 lbs) per house per year.  In terms of $CH_4$ emissions per marketed bird, the annual mean value was 3.41 g/bird-marketed (7.52 lb per 1,000 birds marketed), including downtime emissions. Because $CH_4$ has a global warming potential of 25 $CO_2$ equivalent (100- year time horizon) (IPCC, 2007), the $CH_4$ emission of 3.41 g/bird-marketed was equivalent to 85 g $CO_2$/bird-marketed.

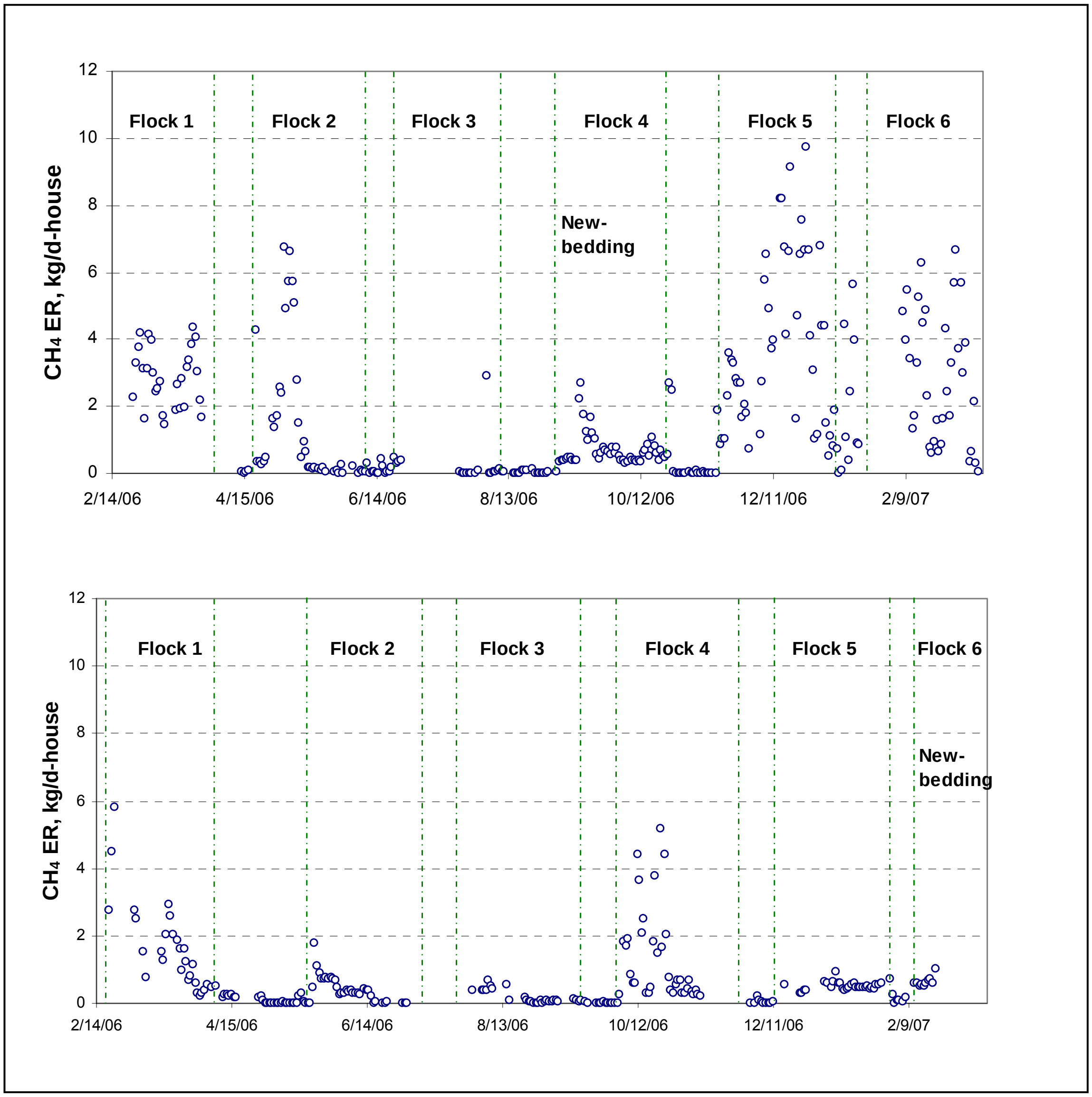

**Figure 8. Daily methane ($CH_4$) emissions during six flocks of growout and downtime for the two broiler houses (T-1 and T-2).**

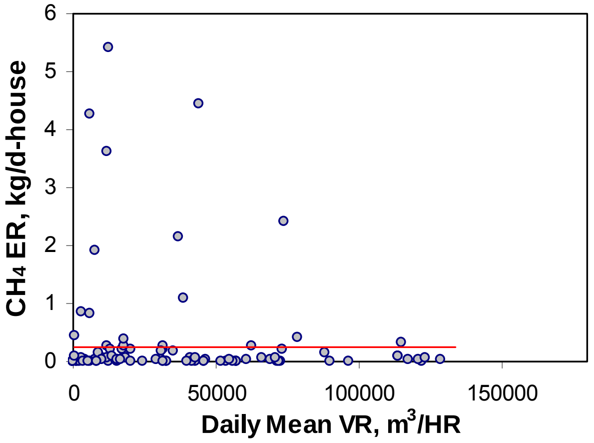

Figure 9. Methane ($CH_4$) emission rate (ER) vs. ventilation rate (VR) during downtime of broiler houses.

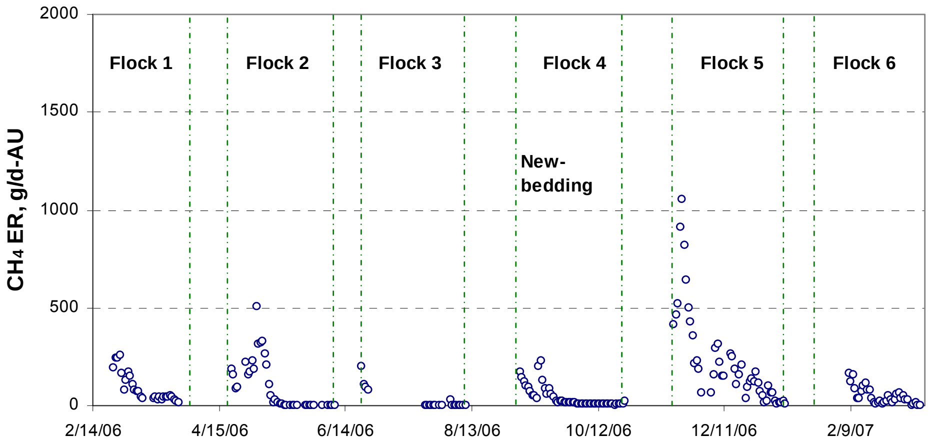

Figure 10. Methane ($CH_4$) emission rate (ER) per animal unit (AU=500 kg) vs. bird age for broiler house T-1.

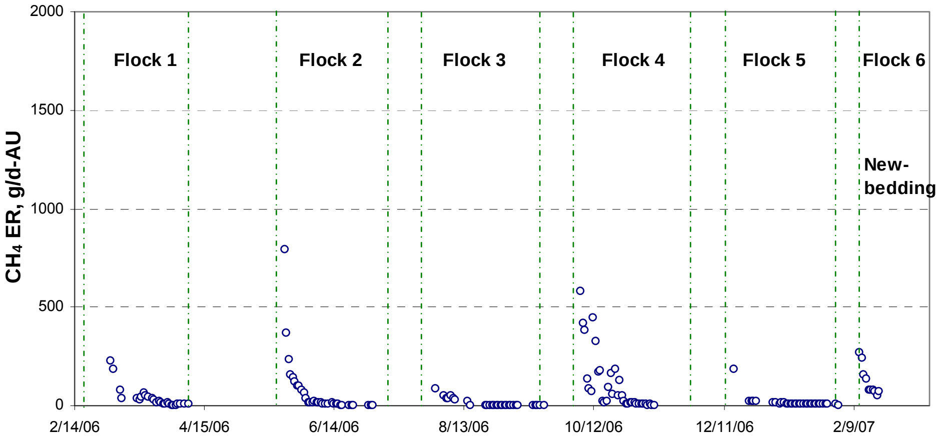

Figure 11. Methane ($CH_4$) emission rate (ER) per animal unit (AU=500 kg) vs. bird age for broiler house T-2.

## *Nitrous Oxide ($N_2O$) Emissions*

### $N_2O$ Emission Rate Estimation/Prediction

Similar to $CH_4$ emissions, there was no clear relationship between $N_2O$ ER and bird age (fig. 12).

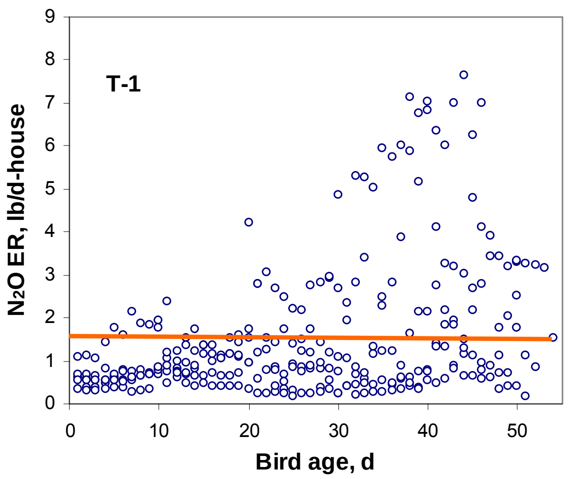

**Figure 12. Relationship between $N_2O$ ER per house vs. bird age for T-1. The solid line is the average ER.**

Figure 13 provides the daily $N_2O$ ER of T-1 house for the entire monitoring period with six full flocks and downtime between flocks. The daily ER varied from 0.1 to 3.4 kg/d-house (0.18 to 7.6 lb/d-house). The average ER for T-1 over the six flocks was 0.68 ± 0.7 kg/d-house (1.51 ± 1.54 lb/d-house).

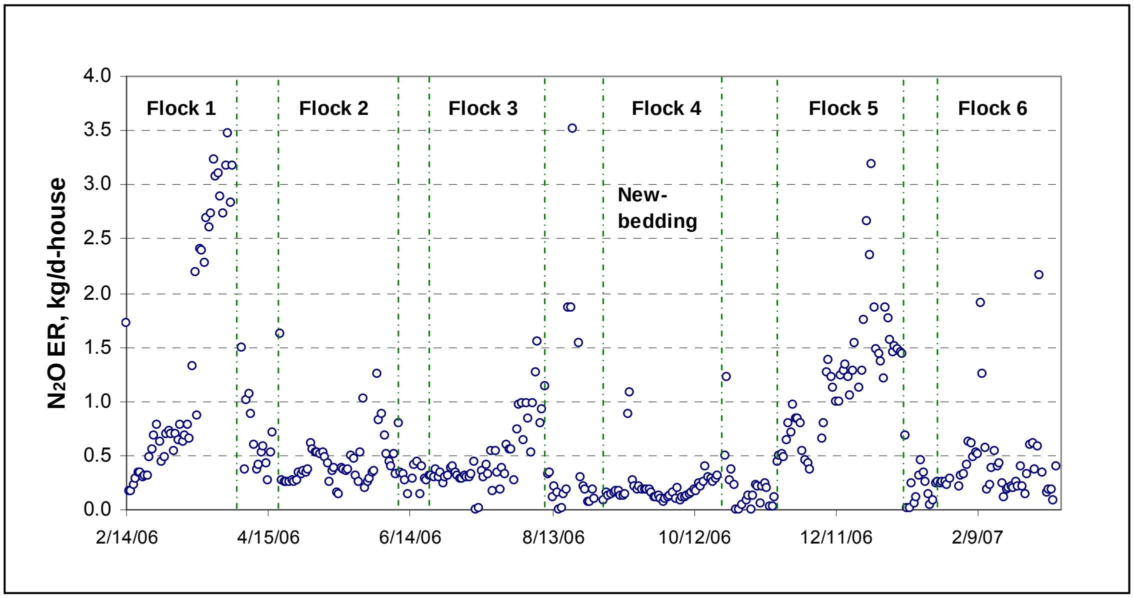

Figure 13. Daily $N_2O$ emission over the six flocks for T-1.

Downtime $N_2O$ emissions from the T-1 were continuously monitored as well. As shown in Figure 14, there was no significant relationship between the ER and ventilation rate. The average daily ER for the two houses during downtime was 0.86 ± 1.19 lb/d-house.

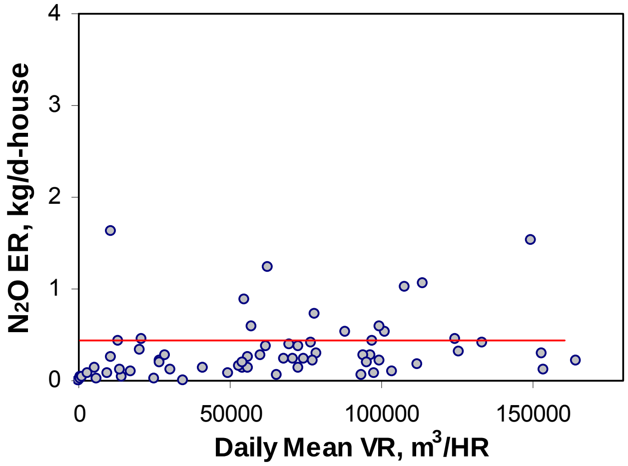

**Figure 14. $N_2O$ emission rate(ER) vs. ventilation rate (VR) during downtime of broiler house. The solid line is the average ER.**

Figure 15 presents $N_2O$ ER in g/AU-d for all 6 flocks for house T-1. The ER *vs.* bird age showed that ER decreased with bird age and was relatively after 30 days. The daily $N_2O$ ER was 28.8 ± 40.0 g/d-AU.

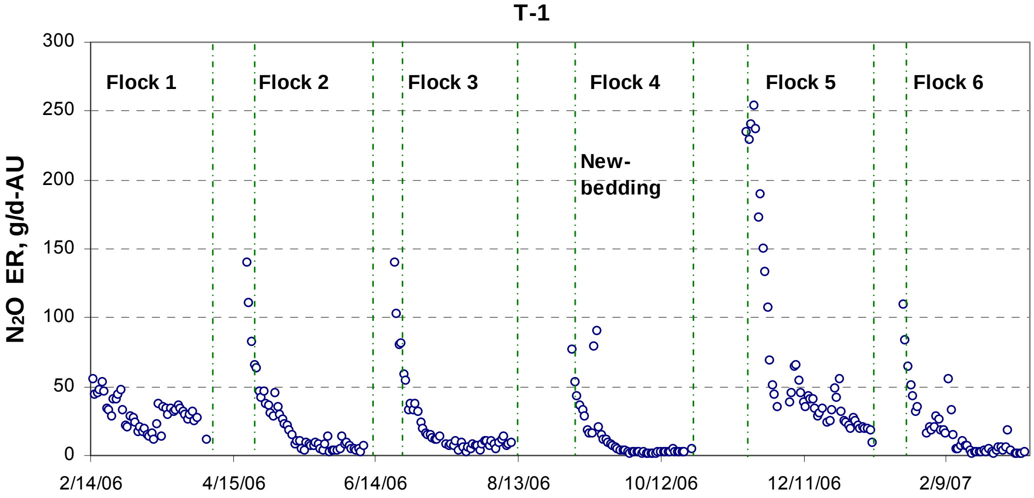

**Figure 15. $N_2O$ emission rate (ER) per animal unit (AU = 500 kg) vs. bird age in broiler house (T-1).**

Annual $N_2O$ emission from each house is the accumulation of daily ERs over 365 days. Based on average daily ER, the average flock ER was 35.6 kg (78.5 lbs) per house per flock. The annual $N_2O$ emission rate was 225 kg (496 lbs) per house per year. In terms of $N_2O$ emissions per marketed bird, the annual mean value was 1.72 g/bird-marketed (3.8 lb per 1,000 birds marketed), including downtime emissions. Because $N_2O$ has a global warming potential of 298 $CO_2$ equivalent (100-year time horizon) (IPCC, 2007), the $N_2O$ emission of 1.72 g/bird-marketed was equivalent to 513 g $CO_2$/bird-marketed.

## Conclusions

Greenhouse gas (GHG) emissions from representative broiler houses in southeastern United States were quantified during a one-year monitoring period. The broilers were grown to 52 days of age on new bedding or built-up litter at a stocking density of 11.8 birds/$m^2$ (0.9 $ft^2$/bird). Expressed in terms of GHG emission per bird marketed, the broiler houses were found to emit 4.64 kg $CO_2$, 3.41 g $CH_4$ (or 85.3 g $CO_2$ equivalent), and 1.72 g $N_2O$ (or 513 g $CO_2$ equivalent) per bird marketed (including downtime emissions). Based on $CO_2$-equivalent global warming potential (GWP over 100-year horizon) of 25 for $CH_4$ and 298 for $N_2O$, the combined GHG emission for the broiler operation monitored in this study was 5.238 kg $CO_2$ equivalent per bird marketed, comprised of 88.6%, 1.6% and 9.8% for $CO_2$, $CH_4$ and $N_2O$, respectively.

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