# EFFECT OF AMINO ACID FORMULATION AND SUPPLEMENTATION ON AIR EMISSIONS FROM TOM TURKEYS

Z. Liu, W. Powers, D. Karcher, R. Angel, T. J. Applegate

**ABSTRACT.** *Air emissions were determined for turkeys fed four diets in a 2×2 factorial design to determine the effects of diets with 100% or 110% of NRC-recommended amino acid (AA) formulation when the diets contained either two (lysine and methionine) or three (lysine, methionine, and threonine) supplemental AA. Hybrid tom turkeys were raised and monitored in 12 rooms (3 reps per diet; 20 toms per room at hatch, culled to 16 toms per room at 21 days, and then 12 toms per room at 28 days of age). Air emissions were measured throughout the 140-day study. Data were analyzed statistically using the Mixed model procedure of SAS. The 100% NRC diets contained less N compared to the 110% NRC diets. Diets containing three supplemental AA had less N content compared to diets containing two supplemental AA. Cumulative feed intake (55.7 kg bird$^{-1}$) and bird weight (BW; 19.8 kg bird$^{-1}$) were not affected by diet. Feeding the 100% NRC diets resulted in 9% less cumulative N intakes and 12% less cumulative $NH_3$ emissions as compared with feeding the 110% NRC diets. Formulation with three supplemental AA did not affect N intake but resulted in 25% less cumulative $NH_3$ emissions, as compared with formulation with two supplemental AA, because it significantly reduced the $NH_3$ emission rate (ER) on a per kg N consumption basis (88 vs. 109 g d$^{-1}$ kg$^{-1}$ N consumed) . The toms fed the 100% NRC diets generated lower ER of $NH_3$ (1.5 vs. 1.8 g d$^{-1}$ bird$^{-1}$), $H_2S$ (3.4 vs. 4.4 mg d$^{-1}$ bird$^{-1}$), and non-methane total hydrocarbons (NMTHC; 0.08 vs. 0.10 g d$^{-1}$ bird$^{-1}$) than the 110% NRC diets ($p < 0.05$). Results of stepwise regression analysis confirmed the positive influence of N/S intake, room air RH, ventilation rate, and room air temperature on ER of $NH_3$ and $H_2S$. The study demonstrated the potential of reducing $NH_3$ and $H_2S$ emissions from turkeys through diet modification of AA while maintaining acceptable production performance. No diet effect was observed on greenhouse gas emissions ($N_2O$ and $CH_4$).*

***Keywords.*** *Ammonia, Crude protein, Diet, GHG, Poultry.*

Air emissions from animal feeding operations continue to be of great concern due to human health and environmental implications. Regional and national governments are beginning to address air quality concerns through policy development and implementation of regulations (Powers et al., 2005). Dietary strategies have been studied to reduce air emissions while maintaining animal performance (Powers et al., 2007). Since many of the nitrogenous air emissions from animal manure come from the degradation of amino acids, most of the work on reducing nitrogen (N) through dietary means has focused on reducing dietary crude protein (CP) and supplementing amino acids that are most limiting in the diet to match bird dietary requirements, thereby improving conversion efficiency. Diets used by the poultry industry are currently formulated with crystalline L-lysine (Lys), DL-methionine (Met), and in some cases L-threonine (Thr). Several studies have indicated that 100% to 107% of NRC (1994) recommendations for essential amino acid (AA) were needed to maximize growth and breast meat yield of turkeys (Sell et al., 1994; Waibel et al., 1995; Boling and Firman, 1997; Kidd et al., 1997; Waldroup et al., 1997). Applegate et al. (2008) fed turkeys either 100% or 110% of NRC (1994) recommendations for amino acid (AA) in four-week phases and reported that diet formulation had no effect on bird weight (BW) or breast meat yields, but toms fed the 100% NRC diets had lower N intake (7%) and excretion (7%) compared to toms fed the 110% NRC diets. In addition, formulation with three supplemental AA resulted in a sizeable reduction in N intake (8%) and excretion (11%) as compared to formulation with two supplemental AA. Little work has been reported on how diet affects subsequent air emissions from a turkey operation.

This research considers air emissions from turkey operations when the diets contained different CP concentrations and AA supplementation. The objective was to determine if lowering dietary crude protein and formulating with three instead of two supplemental AA in diets would produce measurable differences in air emissions from tom turkey operations.

## MATERIALS AND METHODS

### FACILITIES

Hybrid (Ontario, Canada) tom turkeys were raised and monitored on pens in 12 environmentally controlled rooms

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(H 2.14 m × W 3.97 m × L 2.59 m) at the Animal Air Quality Research Facility at Michigan State University for 140 days (18 June to 4 November 2008). Numbers of toms per room were 20 at hatch and were culled to 16 at 21 days then 12 at 28 days of age in order to reinforce proper size and stocking density. Mortalities or culled toms were recorded, and the actual number of toms in each room was used when calculating air emission rate in g bird$^{-1}$ so that the culling and mortalities did not have much impact on the data. Toms in each room were weighted weekly before 56 days of age and then on days 96, 112, and 140. Tom BW was calculated by dividing the total weight by the actual number of toms in room. All animal procedures were approved by the Michigan State University Institutional Animal Care and Use Committee.

Each room was individually ventilated using 100% ambient air and exhausting all of the air to the outside (no recycling). Temperature within the environmental rooms was managed to optimize bird health and productivity. Air temperature in each room was programmed independently and dictated the ventilation rates. Ventilation rates of each room were recorded every 30 s using 15.24 cm orifice plates in the incoming ductwork of each room and a differential pressure transducer (model 239, Setra Systems, Inc., Boxborough, Mass.). Air temperature and relative humidity in each room and for the incoming air were measured using a temperature and relative humidity probe (CS500, Campbell Scientific, Inc., Logan, Utah) and recorded every 2 s.

The bedding/litter material was wood shavings. Fresh litter and end litter in pens in each of the rooms was weighed before the beginning of the experiment and at the end of the experiment, respectively. Litter was not removed throughout the 140-day experiment. More wood shavings were added once during the experiments as needed in rooms 2, 5, and 10, and the weights were recorded. At the end of the experiment, the litter weight in the pens ranged from 257.3 to 428.1 kg per room, and the litter dry matter ranged from 59.7% to 77.0% in the 12 rooms.

### AIR TEMPERATURE, RELATIVE HUMIDITY, AND VENTILATION RATE

The average air temperature and relative humidity (RH) in the 12 rooms and in the incoming air during the growth period are presented in figure 1. Air temperature in the rooms was regulated with an initial temperature of 33°C. In the first 56 days, air temperature was lowered approximately 1.4°C every week to 21.5°C. During the same period, the RH in the rooms increased from 23% to as high as 78%. After the first 56 days, room air temperature was maintained at 21.5°C while RH decreased to as low as 23%. The declining RH toward the end of the study could be mainly due to the weather in late October to November. Litter caking and humidity adsorption on litter could have been other reasons.

The rooms were ventilated according to temperature requirements. As shown in figure 2, in the first 56 days, the dai–

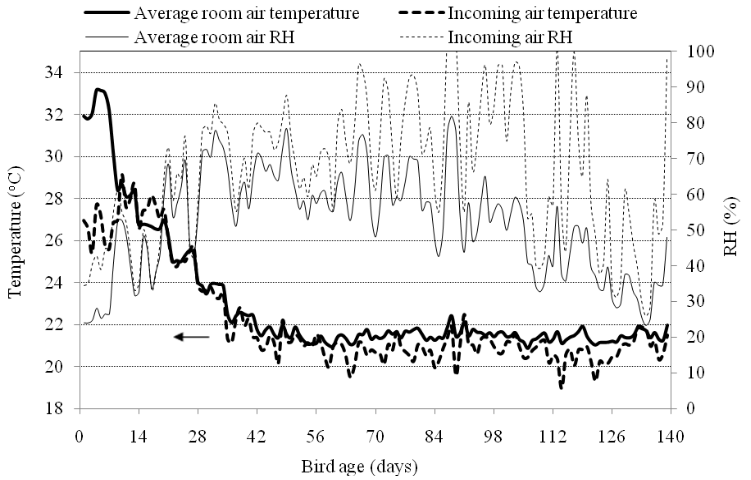

**Figure 1. Average air temperature and RH in the 12 rooms and temperature and RH of the incoming air.**

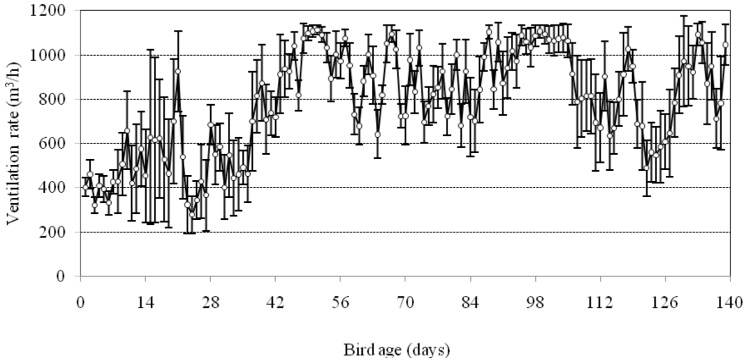

**Figure 2. Average ventilation rates of the 12 rooms (error bar represent standard deviation).**

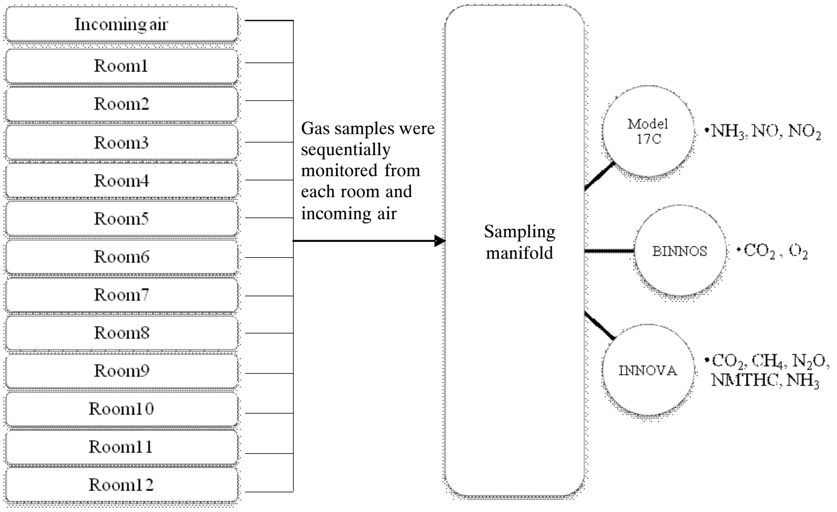

Figure 3. Diagram of the sampling and measurement system.

ly average air ventilation rates had an increasing trend. After the first 56 days, average ventilation rates stopped increasing and were varying over a wide range, from 490 to 1110 $m^3\ h^{-1}$ (41 to 92 $m^3\ h^{-1}\ bird^{-1}$).

### Air Emission Measurements

Through software control (LabView, version 8.2, National Instruments Corp., Austin, Tex.), gas concentrations were measured in a sequential manner, first with incoming air for 15 min and then through each of the 12 rooms' exhaust air for 15 min throughout the 140-day experiment. This allowed seven to eight daily observations per room (as described by Powers et al., 2007). The incoming air line and the rooms' exhaust sample lines were allowed to purge for 9.5 min before the start of data collection. Following purging, data were collected for 5.5 min. All gases were measured simultaneously within a sample stream. The gas sample was pulled to a sampling manifold using a vacuum pump (Cole-Parmer Instrument Co., Vernon Hills, Ill.) at a rate of 30 L $min^{-1}$ and was then diverted into three gas analyzers: a chemiluminescence analyzer (TEI model 17C, Thermo Fisher, Franklin, Mass.) that determines $NH_3$, NO, and $NO_2$ concentrations; a pulsed fluorescence $SO_2$-$H_2S$ analyzer (TEI model 450i, Thermo Fisher, Franklin, Mass.); and an Innova 1412 photoacoustic analyzer (Lumasense Technologies, Ballerup, Denmark) that determines $CO_2$, $CH_4$, non-methane total hydrocarbons (NMTHC), $NH_3$, and $N_2O$ concentrations. A diagram of the sampling and measurement system is shown in figure 3.

Weekly zero and span calibration were performed on all analyzers except the Innova analyzer, which was calibrated at the beginning and end of the study. Weekly span checks were performed on the Innova analyzer between calibrations. If the analyzer did not zero and/or the span concentration drifted more than 1 ppm in the weekly calibration, then the data for that week would be invalidated, which did not happen in this experiment. The calibration results did not necessitate any correction of the data. The detection limits, measurement ranges, and calibration gas concentrations of the gas analyzers are presented in table 1. The TEI model 17C and the Innova analyzer both have $NH_3$ readings, and the results showed they agree with each other. The correlation coefficient of $NH_3$ measured by the two instruments was 0.95. The $NH_3$ measurements from the TEI model 17C analyzer were used in the study. For statistical analysis, measurement data below the detection limits were replaced by half of the detection limits.

Gas emission rates were calculated as the product of ventilation rates and concentration differences between the exhaust and incoming air using the following equation:

$$\text{ER} = Q\frac{273}{T}\times(C_o - C_i)\times 10^{-6}\times\frac{MW}{V_m} \quad (1)$$

where ER is emission rate (g $min^{-1}$), $Q$ is ventilation rate at room temperature and pressure (L $min^{-1}$), $T$ is air temperature in room exhaust (K), $C_o$ is gas concentration in room exhaust (ppm), $C_i$ is gas concentration in the incoming air (ppm), $MW$ is molecular weight of the gas (g $mol^{-1}$), and $V_m$ is molar volume of gas at standard condition (22.414 L $mol^{-1}$). Emissions in one full measurement cycle were estimated by multiplying the ER (g $min^{-1}$) with 195 min. Daily emissions were calculated as sum of the emissions in the seven or eight measurement cycles.

### Experimental Design and Data Analysis

Turkeys were fed four diets in a 2×2 factorial experiment to determine the effects of diets formulated to 100% or 110% of NRC (1994) AA recommendations when using two (Lys

Table 1. Detection limits, measurement ranges, and the calibration gas concentrations of the gas analyzers.

| Analyzer | Gas | Detection Limit (ppm) | Measurement Range (ppm) | Calibration Gas Conc. (ppm) |
|---|---|---|---|---|
| TEI model 17C | $NH_3$ | 0.001 | 100 | 44.73 |
| | $NO_2$ | 0.001 | 10 | 3.33 |
| | NO | 0.001 | 10 | 4.01 |
| TEI model 450i | $SO_2$ | 0.003 | 1 | 0.911 |
| | $H_2S$ | 0.003 | 1 | 1.01 |
| Innova 1412 | $NH_3$ | 0.2 | 10,000 | 48.6 |
| | $N_2O$ | 0.03 | 50,000 | 5 |
| | $CH_4$ | 0.1 | 1,000 | 100 |
| | NMTHC | 0.02 | 10,000 | 19.08 |
| | $CO_2$ | 5.1 | 1,000 | 1,000 |

Table 2. Analyzed nutrient contents (%) for diets formulated to 100% or 110% of NRC (1994) recommendations with two or three supplemental AA during the five feeding phases.[a]

| Nutrient | Phase 1 (0-28 d) | Phase 2 (29-56 d) | | | | Phase 3 (57-84 d) | | | | Phase 4 (85-112 d) | | | | Phase 5 (113-140 d) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Common | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA |
| Threonine | 1.02 | 0.86 | 0.91 | 1.00 | 1.00 | 0.77 | 0.78 | 0.83 | 0.86 | 0.70 | 0.73 | 0.70 | 0.79 | 0.59 | 0.56 | 0.61 | 0.61 |
| Methionine | 0.63 | 0.50 | 0.56 | 0.61 | 0.61 | 0.44 | 0.46 | 0.46 | 0.52 | 0.30 | 0.34 | 0.34 | 0.40 | 0.26 | 0.28 | 0.30 | 0.31 |
| Lysine | 1.75 | 1.48 | 1.62 | 1.71 | 1.70 | 1.42 | 1.40 | 1.46 | 1.53 | 1.08 | 1.11 | 1.11 | 1.30 | 0.85 | 0.97 | 0.89 | 0.89 |
| Available lysine | 1.66 | 1.38 | 1.55 | 1.61 | 1.63 | 1.34 | 1.31 | 1.38 | 1.44 | 1.01 | 1.05 | 1.04 | 1.22 | 0.80 | 0.93 | 0.84 | 0.82 |
| CP | 28.20 | 26.02 | 24.88 | 28.34 | 26.24 | 21.95 | 20.27 | 24.72 | 22.53 | 19.98 | 18.99 | 21.10 | 21.04 | 17.00 | 15.99 | 17.51 | 16.64 |
| N content[b] | 4.51 | 4.16 | 3.98 | 4.53 | 4.20 | 3.51 | 3.24 | 3.96 | 3.60 | 3.20 | 3.04 | 3.38 | 3.37 | 2.72 | 2.56 | 2.80 | 2.66 |
| S content | 0.296 | 0.269 | 0.266 | 0.322 | 0.296 | 0.235 | 0.218 | 0.242 | 0.248 | 0.195 | 0.186 | 0.196 | 0.199 | 0.158 | 0.156 | 0.172 | 0.162 |

[a] 100%+2AA = 100% of NRC with two supplemental AA; 100%+3AA = 100% of NRC with three supplemental AA; 110%+2AA = 110% of NRC with two supplemental AA; and 110%+3AA = 110% of NRC with three supplemental AA. Nutrient percentages are based on mass (grams per 100 grams of sample). Results are expressed on an “as is” basis.

[b] N content = CP/6.25.

and Met) or three (Lys, Met, and Thr) supplemental AA. Each of the four diets was fed to three rooms as replicates. Data were analyzed statistically by ANOVA using the Mixed model procedure of SAS (version 9.1.3, SAS Institute, Inc., Cary, N.C.). Day was a random variable, and room was treated as a repeated term within diet. The level of AA formulation relative to NRC, the number of supplemental AA, and the feeding phase were treated as three covariates. Tukey’s test was applied in comparing diet and phase effects, and Bonferroni adjustment was used for multiple comparisons for phase × diet interaction. Statistical significance between means was accepted at $p < 0.05$. A stepwise regression analysis was conducted on emissions of $NH_3$ and $H_2S$.

### DIETS

Diets for tom turkeys were formulated with corn, soybean meal, and 6% meat and bone meal were fed in mash form. Toms were fed in four-week phases. A common diet was fed during phase 1 (0 to 28 days of age) and feeding of experimental diets began in phase 2. Diets were formulated to contain 100% or 110% of NRC (1994) amino acid recommendations using either two or three supplemental amino acids. Diet formulations were the same as that reported by Applegate et al. (2008). Feed was weighed and recorded weekly, and feed consumption was recorded. Diets were sampled and analyzed at each feeding phase. Feed amino acid content was analyzed using AOAC Official Methods 975.44 and 982.30 (AOAC, 2006). Crude protein (CP) or N content was determined using AOAC Official Method 984.13 (AOAC, 2006). Diet samples were analyzed by the University of Missouri Agriculture Experiment Station Laboratory. Analyzed nutrient contents for the four diets during the five feeding phases are reported in table 2. The 100% NRC diets had lower N content as compared to the 110% NRC diets. Diets containing three supplemental AA had reduced soybean meal inclusion, which therefore resulted in a reduction in N content as compared to diets containing two supplemental AA.

### UNCERTAINTY ANALYSIS

Assuming independent input measures, the uncertainties of ER were evaluated using component error analysis, coupled with estimates of uncertainties for measurements of gas concentration, room ventilation rate, air temperature, and air pressure, using the following equation (Gates et al., 2009).

$$\Delta \mathrm{ER}^2 = \left(\frac{\partial \mathrm{ER}}{\partial C}\Delta C\right)^2 + \left(\frac{\partial \mathrm{ER}}{\partial Q}\Delta Q\right)^2 + \left(\frac{\partial \mathrm{ER}}{\partial T}\Delta T\right)^2 + \left(\frac{\partial \mathrm{ER}}{\partial P}\Delta P\right)^2 \qquad (2)$$

where $\Delta$ER is uncertainty in emission rates, $\Delta C$ is uncertainty in gas concentration measurements, $\Delta Q$ is uncertainty in room ventilation rate, $\Delta T$ is uncertainty in room air temperature, and $\Delta P$ is uncertainty in room air pressure. Since calculation of ER was corrected for gas concentrations in the incoming air, the corresponding uncertainty was also considered. The uncertainties of ER on a per kg BW, per kg feed intake, or per kg N/S consumption basis were estimated through further introduction and propagation of uncertainties for measurements of BW, feed intake, and N/S content in diets.

## RESULTS AND DISCUSSION

### TURKEY PERFORMANCE

Diets had no significant effect on bird weight. The results are in agreement with Applegate et al. (2008), who reported that feeding 110% vs. 100% NRC did not change tom performance or breast meat yield. At 140 days of age, the bird weight averaged 19.8 kg bird$^{-1}$, the cumulative feed intake averaged 55.7 kg bird$^{-1}$, and the cumulative gain-to-feed ratio was 0.356. The average bird weight, cumulative feed intake, and gain-to-feed ratio are presented in figure 4.

### EMISSION OF $NH_3$

Significant diet effects were observed on $NH_3$ emissions from tom turkeys. The main effect means and least squares means of $NH_3$ emissions are presented in table 3. The 100% NRC diets resulted in lower $NH_3$ emissions as compared to the 110% NRC diets, and the three supplemental AA diets resulted in lower $NH_3$ emissions as compared to the two supplemental AA diets when expressing the daily average ER on a per room or per bird base. Feeding 110% NRC with two supplemental AA resulted in the highest daily average ER (averaged 1.9 g bird$^{-1}$). Feeding 100% NRC with three supplemental AA reduced it by 32% to 1.3g bird$^{-1}$. The number of supplemental AA had a significant main effect in all methods of $NH_3$ emission calculation (daily average ER on a per room, per bird, per kg BW, per kg feed intake, or per kg

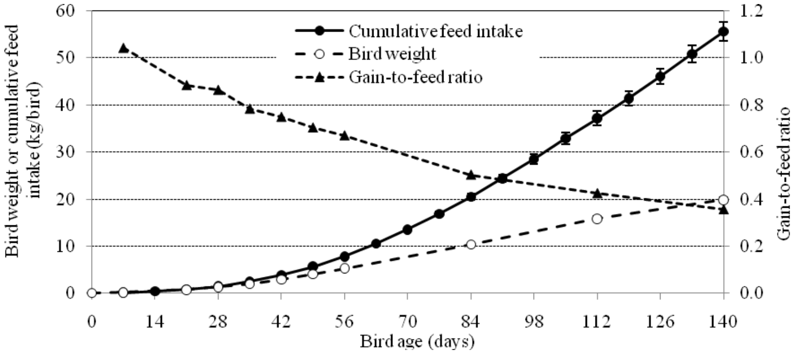

**Figure 4. Average bird weight, cumulative feed intake, and gain-to-feed ratio vs. bird age (error bars represent standard deviations for the 12 rooms).**

N consumption basis), while the effect of level of AA formulation relative to NRC was not significant when expressing the daily average ER of $NH_3$ on per kg BW, per kg feed intake, or per kg N consumption basis. This indicated that the reduced $NH_3$ emission from toms fed the 100% NRC diets instead of the 110% NRC diets mainly resulted from the reduced N intake only, while feeding the three supplemental AA diets instead of the two supplemental AA diets was more effective in reducing $NH_3$ emission from toms. Diet effects on cumulative N intake and $NH_3$ emissions are presented in table 4. The 100% NRC diets resulted in 9% less cumulative N intake as compared to the 110% NRC diets, and accordingly it resulted in 12% less cumulative $NH_3$ emissions. The number of supplemental AA did not have significant effect on cumulative N intake. However, when feeding the two supplemental AA diets, 12% of N intake was emitted as $NH_3$, and when feeding the three supplemental AA diets, N loss as $NH_3$ was only 10% of total N intake. Consequently, the three supplemental AA diets resulted in 25% less cumulative $NH_3$ emissions as compared to the two supplemental AA diets.

The feeding phase had significant effects on $NH_3$ emissions. There were also interactions between the effects of phase and diet. Daily average $NH_3$ ER reached the highest value in phase 3 on a per room, per bird, per kg BW, per kg feed intake, or per kg N consumption basis. Of the total cumulative emissions of $NH_3$, 82% was emitted in phases 3 and 4. Only 6% was emitted in phases 1 and 2, and 12% was emitted in phase 5. Diet effects on $NH_3$ emissions were not significant in phases 1, 2, and 5. They were most pronounced in phase 3, where the 100% NRC with three supplemental AA diets resulted in 53% lower $NH_3$ emissions (25.9 vs. 54.6 g bird$^{-1}$) than the 110% NRC with two supplemental AA diets. This suggests that if diet management of turkey toms was used to reduce $NH_3$ emission, then attention should be given to feeding phase 3. In phase 3, the 100% NRC with three supplemental AA diets had 4.45% unit reduction (20.27% vs. 24.72%) in dietary CP as compared with the 110% NRC with two supplemental AA diets. This indicated that for each 1% unit reduction in dietary CP, the $NH_3$ emission was reduced by 12%. The result is comparable with the report that, for each percentage unit reduction in dietary CP, estimated $NH_3$ losses are reduced by 8% to 10% in swine and poultry (Aarnink et al., 1993; Sutton et al., 1997; Kay and Lee, 1997).

The $NH_3$ daily average emissions and cumulative emissions from toms fed each of the four diets are presented in figure 5. For all four diets across the 12 rooms, the $NH_3$ daily emissions were negligible from day 0 to 28 and then increased exponentially from day 29 to 80. At around day 80, the $NH_3$ daily emissions reached the highest value measured during the study and then started to decrease until day 140. The decreasing $NH_3$ emissions in phases 4 and 5 could have been related to the decreasing diet N content (see table 2) and decreasing RH in phases 4 and 5. In figure 5, the daily average ER of $NH_3$ had local high values at days 67, 73, 80, 88, and 96 and had local low values at days 70, 87, and 91, which corresponded to the local high and low RH values of the room air. This indicated that the daily average ER of $NH_3$ was positively correlated with RH. Another reason for the lower $NH_3$ emissions at later stages of housing could have been litter caking, as suggested by Brewer and Costello (1999).

A stepwise regression analysis was conducted, and the results showed that N intake, RH, bird age, ventilation rate, and air temperature significantly influenced the daily $NH_3$ ER, which can be estimated by the following regression equation:

$$\begin{aligned} ER_{NH3} &= -14.7\,(\pm 1.0) + 0.33\,(\pm 0.01) \times NI \\ &\quad + 0.039\,(\pm 0.003) \times RH - 0.013\,(\pm 0.002) \times Age \\ &\quad + 0.0004\,(\pm 0.0001) \times Q + 0.14\,(\pm 0.01) \times T \end{aligned} \tag{3}$$

where $ER_{NH3}$ is daily $NH_3$ ER (g d$^{-1}$ bird$^{-1}$), *NI* is daily N intake (g d$^{-1}$ bird$^{-1}$), *Age* is bird age (d), *Q* is ventilation rate (m$^3$ h$^{-1}$), and *T* is room air temperature (°F). All variables left in the model are significant at the 0.05 level. The regression equation had adjusted $r^2 = 0.57$. The equation confirmed the positive influence of N intake ($p < 0.001$), room air RH ($p < 0.001$), ventilation rate ($p = 0.002$), and room air temperature ($p < 0.001$) on $NH_3$ ER.

The daily $NH_3$ ER from toms across all diets averaged 1.65 g d$^{-1}$ bird$^{-1}$, which is comparable with that reported by other researchers, e.g., 1.38 g d$^{-1}$ bird$^{-1}$ (Li et al., 2009), 2.3 g d$^{-1}$ bird$^{-1}$ (with used litter) and 0.98(with new litter) g d$^{-1}$ bird$^{-1}$ (Gay et al., 2005), 2.4 g d$^{-1}$ bird$^{-1}$ (Battye et al., 1994), and 1.22 g d$^{-1}$ bird$^{-1}$ (Asman, 1992).

### Emission of Nitrogen Oxides

Concentrations of NO and $NO_2$ in the 12 environmental rooms were all under the detection limit of measurements. Their emissions were negligible. The main effect means of $N_2O$ emissions are presented in table 5. The $N_2O$ ER was not affected by diets, but phase effects were observed. The $N_2O$ daily average ER on a per bird basis increased from phase 1 to phase 5. The $N_2O$ daily average ER on per kg BW or per kg feed intake basis peaked in phase 1 and did not vary significantly from phase 2 to phase 5, which indicated that the $N_2O$ daily average ER was proportional to BW or feed intake except in the first four weeks. The $N_2O$ daily average ER from

**Table 3. Effect of diet fed to turkey toms on $NH_3$ emissions.[a]**

| | | Main Effect Means of Diets | | | | | | p-Value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 100% NRC | 110% NRC | SEM | 2AA | 3AA | SEM | NRC | AA | NRC × AA |
| Daily average concentration (ppm) | | 1.3 | 1.6 | 0.11 | 1.7 b | 1.2 a | 0.11 | 0.10 | <0.01 | 0.10 |
| Daily ER | $g\ d^{-1}\ room^{-1}$ | 17.1 a | 20.3 b | 1.0 | 21.0 b | 16.4 a | 1.0 | 0.05 | 0.01 | 0.3 |
| | $g\ d^{-1}\ bird^{-1}$ | 1.5 a | 1.8 b | 0.07 | 1.8 b | 1.4 a | 0.07 | 0.03 | <0.01 | 0.3 |
| | $g\ d^{-1}\ kg^{-1}$ BW | 0.18 | 0.19 | 0.01 | 0.21b | 0.16 a | 0.01 | 0.47 | 0.05 | 0.44 |
| | $g\ d^{-1}\ kg^{-1}$ feed intake | 3.2 | 3.6 | 0.17 | 3.9b | 2.9 a | 0.17 | 0.17 | <0.01 | 0.26 |
| | $g\ d^{-1}\ kg^{-1}$ N consumed | 97 | 100 | 4.5 | 109b | 88 a | 4.5 | 0.69 | 0.01 | 0.18 |
| | | Main Effect Means of Phases | | | | | | p-Value | | |
| | | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | SEM | Phase | Phase × NRC | Phase × AA |
| Daily average concentration (ppm) | | 0.1 a | 0.5 b | 3.4 e | 2.3 d | 1.0 c | 0.09 | <0.01 | <0.01 | <0.01 |
| Daily ER | $g\ d^{-1}\ room^{-1}$ | 0.3 a | 6.5 b | 41.0 e | 35.1 d | 10.5 c | 0.9 | <0.01 | <0.01 | <0.01 |
| | $g\ d^{-1}\ bird^{-1}$ | 0.0 a | 0.5 b | 3.5 e | 3.2 d | 1.0 c | 0.07 | <0.01 | <0.01 | <0.01 |
| | $g\ d^{-1}\ kg^{-1}$ BW | 0.04 a | 0.16 c | 0.43 e | 0.25 d | 0.06 b | 0.01 | <0.01 | <0.01 | <0.01 |
| | $g\ d^{-1}\ kg^{-1}$ feed intake | 0.3 a | 2.2 c | 7.6 e | 5.3 d | 1.5 b | 0.16 | <0.01 | <0.01 | <0.01 |
| | $g\ d^{-1}\ kg^{-1}$ N consumed | 7 a | 53 b | 212 d | 165 c | 55 b | 4.4 | <0.01 | 0.19 | <0.01 |

| | | Treatment Means of Diets | | | | Least Square Means, Phase 1 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA |
| Daily average concentration (ppm) | | 1.7 b | 0.9 a | 1.7 b | 1.5 ab | 0.1 | 0.1 | 0.1 | 0.1 |
| Daily ER | $g\ d^{-1}\ room^{-1}$ | 20.1 b | 14.1 a | 21.8 b | 18.7 ab | 0.4 | 0.2 | 0.2 | 0.3 |
| | $g\ d^{-1}\ bird^{-1}$ | 1.8 b | 1.3 a | 1.9 b | 1.6 ab | 0.0 | 0.0 | 0.0 | 0.0 |
| | $g\ d^{-1}\ kg^{-1}$ BW | 0.021 | 0.15 | 0.21 | 0.18 | 0.06 | 0.04 | 0.03 | 0.04 |
| | $g\ d^{-1}\ kg^{-1}$ feed intake | 3.8 b | 2.6 a | 3.9 b | 3.3 ab | 0.4 | 0.2 | 0.2 | 0.3 |
| | $g\ d^{-1}\ kg^{-1}$ N consumed | 112 b | 82 a | 106 ab | 94 ab | 10 | 5 | 4 | 7 |
| | | Least Square Means, Phase 2 | | | | Least Square Means, Phase 3 | | | |
| | | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA |
| Daily average concentration (ppm) | | 0.6 | 0.4 | 0.5 | 0.5 | 4.1 c | 1.9 a | 4.4 c | 3.3 b |
| Daily ER | $g\ d^{-1}\ room^{-1}$ | 7.3 | 5.2 | 7.4 | 6.0 | 45.9 bc | 25.9 a | 54.6 c | 37.6 b |
| | $g\ d^{-1}\ bird^{-1}$ | 0.6 | 05 | 0.6 | 0.5 | 3.9 c | 2.3 a | 4.6 c | 3.2 b |
| | $g\ d^{-1}\ kg^{-1}$ BW | 0.17 | 0.15 | 0.16 | 0.14 | 0.50 bc | 0.28 a | 0.55 c | 0.39 b |
| | $g\ d^{-1}\ kg^{-1}$ feed intake | 2.5 | 2.0 | 2.5 | 2.0 | 8.9 c | 5.0 a | 9.8 c | 6.9 b |
| | $g\ d^{-1}\ kg^{-1}$ N consumed | 60 | 49 | 55 | 49 | 253 c | 155 a | 249 c | 192 b |
| | | Least Square Means, Phase 4 | | | | Least Square Means, Phase 5 | | | |
| | | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA |
| Daily average concentration (ppm) | | 2.5 ab | 1.7 a | 2.2 ab | 2.7 b | 1.1 | 0.6 | 1.1 | 1.0 |
| Daily ER | $g\ d^{-1}\ room^{-1}$ | 35.9 ab | 30.2 a | 33.9 ab | 40.3 b | 11.0 | 8.8 | 12.9 | 9.5 |
| | $g\ d^{-1}\ bird^{-1}$ | 3.3 ab | 2.7 a | 3.2 ab | 3.5 b | 1.0 | 0.8 | 1.2 | 0.9 |
| | $g\ d^{-1}\ kg^{-1}$ BW | 0.26 | 0.22 | 0.24 | 0.28 | 0.06 | 0.05 | 0.07 | 0.05 |
| | $g\ d^{-1}\ kg^{-1}$ feed intake | 5.8 | 4.5 | 5.2 | 5.8 | 1.6 | 1.2 | 1.9 | 1.3 |
| | $g\ d^{-1}\ kg^{-1}$ N consumed | 181 | 150 | 154 | 173 | 58 | 49 | 67 | 48 |

[a] Within the same section, values followed by different letters are significantly different ($p < 0.05$). SEM = standard error of the mean.

**Table 4. Effect of diet on cumulative N intakes and $NH_3$ emissions at 140 days of age.[a]**

| | Treatment Means ($kg\ bird^{-1}$) | | | | | Main Effect Means ($kg\ bird^{-1}$) | | | | | p-Value | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diet | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA | SEM | 100% | 110% | +2AA | +3AA | SEM | % of NRC | No. of AA | Inter-action |
| N intake | 1.76 a | 1.72 a | 1.95 b | 1.87 b | 0.04 | 1.74 a | 1.91 b | 1.86 | 1.79 | 0.03 | <0.01 | 0.13 | 0.64 |
| $NH_3$ | 0.26 bc | 0.19 a | 0.30 c | 0.24 b | 0.011 | 0.23 a | 0.26 b | 0.28 b | 0.21 a | 0.007 | <0.01 | <0.01 | 0.47 |

[a] Within the same section, values followed by different letters are significantly different ($p < 0.05$). SEM = standard error of the mean.

toms fed each of the four diets are presented in figure 6. The $N_2O$ ER from toms fed all diets averaged 0.15 g $d^{-1}$ $bird^{-1}$. The total N emission was 1.46 g $d^{-1}$ $bird^{-1}$, in which 93% was in the form of $NH_3$ and 7% was in the form of $N_2O$. As a comparison, Wu-Haan et al. (2007) noted that in measuring emissions from poultry, 99.7% of $NH_3$, NO, and $NO_2$ emissions were as $NH_3$.

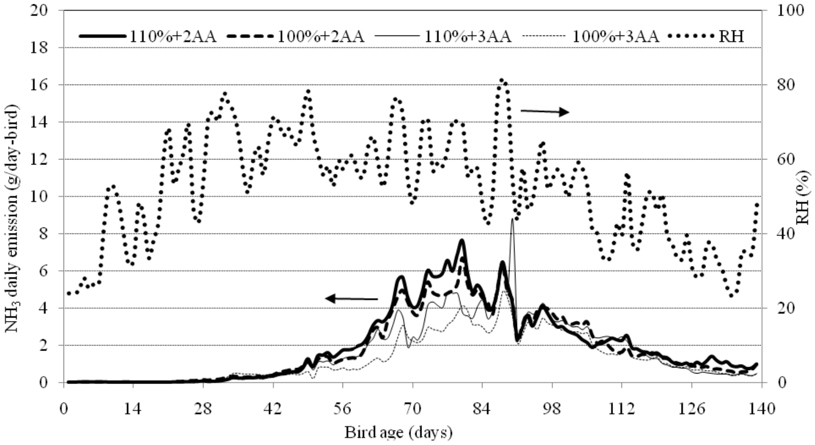

**Figure 5. Daily average ER of $NH_3$ for each of the four diets and the average RH in the 12 rooms.**

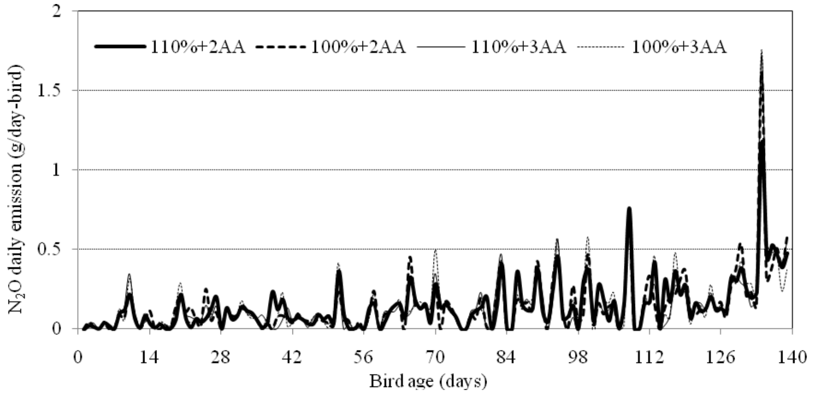

**Figure 6. Daily average ER of $N_2O$ for each of the four diets.**

**Table 5. Effect of diet fed to turkey toms on $N_2O$ emissions.[a]**

| | | Main Effect Means of Diets | | | | | | p-Value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 100% NRC | 110% NRC | SEM | 2AA | 3AA | SEM | NRC | AA | NRC × AA |
| Daily average concentration (ppm) | | 0.9 | 0.9 | 0.02 | 0.9 | 0.9 | 0.02 | 0.83 | 0.55 | 0.72 |
| Daily ER | g $d^{-1}$ $room^{-1}$ | 1.8 | 1.7 | 0.1 | 1.7 | 1.8 | 0.1 | 0.78 | 0.85 | 0.89 |
| | g $d^{-1}$ $bird^{-1}$ | 0.15 | 0.15 | 0.01 | 0.15 | 0.15 | 0.01 | 0.63 | 1.00 | 0.52 |
| | g $d^{-1}$ $kg^{-1}$ BW | 0.05 | 0.04 | 0.00 | 0.04 | 0.05 | 0.00 | 0.80 | 0.52 | 0.81 |
| | g $d^{-1}$ $kg^{-1}$ feed intake | 0.52 | 0.49 | 0.03 | 0.50 | 0.51 | 0.03 | 0.48 | 0.86 | 0.99 |
| | g $d^{-1}$ $kg^{-1}$ N consumed | 14 | 13 | 0.8 | 13 | 14 | 0.8 | 0.23 | 0.59 | 0.93 |
| | | Main Effect Means of Phases | | | | | | p-Value | | |
| | | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | SEM | Phase | Phase × NRC | Phase × AA |
| Daily average concentration (ppm) | | 1.2 c | 0.8 b | 0.6 a | 0.8 b | 1.1 c | 0.02 | <0.01 | 1.00 | 1.00 |
| Daily ER | g $d^{-1}$ $room^{-1}$ | 1.0 a | 0.9 a | 1.6 b | 2.1 c | 3.2 d | 0.1 | <0.01 | 0.98 | 0.98 |
| | g $d^{-1}$ $bird^{-1}$ | 0.06 a | 0.07 a | 0.13 b | 0.19 c | 0.30 d | 0.01 | <0.01 | 0.99 | 1.00 |
| | g $d^{-1}$ $kg^{-1}$ BW | 0.15 b | 0.03 a | 0.02 a | 0.01 a | 0.02 a | 0.01 | <0.01 | 0.99 | 0.59 |
| | g $d^{-1}$ $kg^{-1}$ feed intake | 1.16 b | 0.31 a | 0.30 a | 0.32 a | 0.45 a | 0.05 | <0.01 | 0.88 | 0.94 |
| | g $d^{-1}$ $kg^{-1}$ N consumed | 26 c | 7 a | 8 a | 10 a | 17 b | 1.1 | <0.01 | 0.97 | 0.98 |

[a] Within the same section, values followed by different letters are significantly different ($p < 0.05$). SEM = standard error of the mean.

### EMISSION OF $H_2S$

The main effect means of $H_2S$ emissions are presented in table 6. Effect of number of supplemental AA in diets on $H_2S$ emissions was not observed. The percentage of NRC had a significant main effect on the daily average $H_2S$ ER on a per room, per bird, per kg feed intake, or per kg S consumption basis. When feeding the 100% NRC diets, the $H_2S$ ER on a per bird basis was 23% lower than that when feeding the 110% NRC diets. Phase effects were observed for $H_2S$ emissions. Daily average $H_2S$ ER reached the highest in phase 3

**Table 6. Effect of diet fed to turkey toms on $H_2S$ emissions.[a]**

| | | Main Effect Means of Diets | | | | | | p-Value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 100% NRC | 110% NRC | SEM | 2AA | 3AA | SEM | NRC | AA | NRC × AA |
| Daily average concentration (ppb) | | 3.8 a | 4.3 b | 0.2 | 4.0 | 4.0 | 0.2 | 0.04 | 0.94 | 0.20 |
| Daily ER | $mg\ d^{-1}\ room^{-1}$ | 39 a | 51 b | 2 | 44 | 46 | 2 | 0.01 | 0.48 | 1.00 |
| | $mg\ d^{-1}\ bird^{-1}$ | 3.4 a | 4.4 b | 0.2 | 3.8 | 4.0 | 0.2 | <0.01 | 0.42 | 0.65 |
| | $mg\ d^{-1}\ kg^{-1}$ BW | 0.7 | 0.8 | 0.04 | 0.7 | 0.8 | 0.04 | 0.25 | 0.20 | 0.80 |
| | $mg\ d^{-1}\ kg^{-1}$ feed intake | 9.7 a | 11.5 b | 0.4 | 10.2 | 11.0 | 0.4 | 0.01 | 0.21 | 0.59 |
| | $mg\ d^{-1}\ kg^{-1}$ N consumed | 4.2 a | 4.8 b | 0.1 | 4.3 | 4.7 | 0.1 | 0.02 | 0.07 | 0.84 |
| | | Main Effect Means of Phases | | | | | | p-Value | | |
| | | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | SEM | Phase | Phase × NRC | Phase × AA |
| Daily average concentration (ppb) | | 3.4 b | 3.0 a | 4.9 d | 4.4 c | 4.5 c | 0.1 | <0.01 | <0.01 | 0.66 |
| Daily ER | $mg\ d^{-1}\ room^{-1}$ | 10 a | 37 b | 84 c | 56 d | 36 b | 2 | <0.01 | <0.01 | 0.50 |
| | $mg\ d^{-1}\ bird^{-1}$ | 0.7 a | 3.1 b | 7.2 d | 5.1 c | 3.3 b | 0.2 | <0.01 | <0.01 | 0.87 |
| | $mg\ d^{-1}\ kg^{-1}$ BW | 1.2 c | 1.1 c | 0.9 b | 0.4 a | 0.2 a | 0.07 | <0.01 | 0.80 | 0.80 |
| | $mg\ d^{-1}\ kg^{-1}$ feed intake | 10.8 c | 12.9 d | 15.8 e | 8.5 b | 5.0 a | 0.6 | <0.01 | 0.29 | 0.71 |
| | $mg\ d^{-1}\ kg^{-1}$ N consumed | 3.7 a | 4.6 b | 6.7 c | 4.4 b | 3.1 a | 0.2 | <0.01 | 0.07 | 0.80 |

[a] Within the same section, values followed by different letters are significantly different ($p < 0.05$). SEM = standard error of the mean.

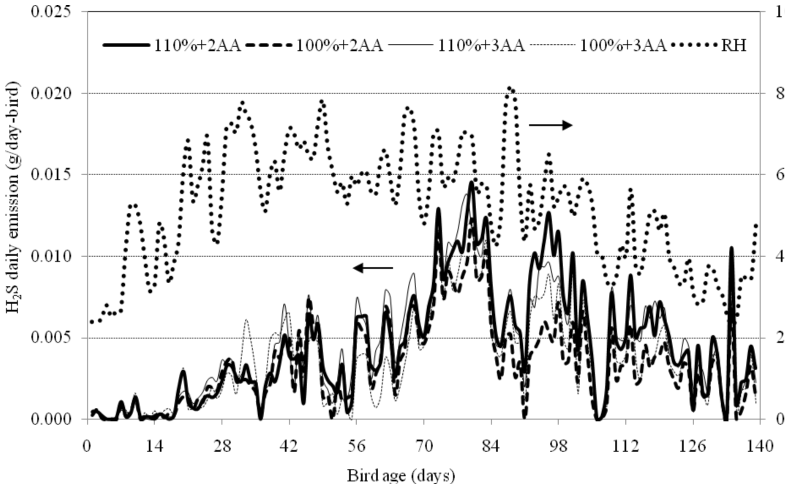

**Figure 7. Daily average ER of $H_2S$ for each of the four diets and the average RH in the 12 rooms.**

on a per room, per bird, per kg feed intake, or per kg S consumption basis. The $H_2S$ daily average emissions from toms fed each of the four diets are presented in figure 7. For all diets in the 12 rooms, the $H_2S$ daily emissions increased significantly from day 1 to 80. At around day 80, the $H_2S$ daily emissions reached the highest value during the study and then started to decrease until day 140. This trend was similar to the trend of $NH_3$ daily emissions. The decreasing $H_2S$ emissions in phases 4 and 5 could have been related to the decreasing diet S content (see table 2) and decreasing RH in phases 4 and 5. Li et al. (2008) reported that $H_2S$ emissions are weakly correlated with room air RH, which can also be observed in figure 7.

A stepwise regression analysis was conducted, and the results showed that RH, S intake, ventilation rate, and air temperature significantly influenced the daily $H_2S$ ER, which can be estimated by the following regression equation:

$$\begin{aligned} ER_{H2S} &= -22.9\,(\pm 2.1) + 0.090\,(\pm 0.005) \times RH \\ &+ 6.8\,(\pm 0.3) \times SI + 0.0007\,(\pm 0.0003) \times Q \\ &+ 0.22\,(\pm 0.02) \times T \end{aligned} \tag{4}$$

where $ER_{H2S}$ is daily $H_2S$ ER ($mg\ d^{-1}\ bird^{-1}$), *SI* is daily S intake ($g\ d^{-1}\ bird^{-1}$), *Q* is ventilation rate ($m^3\ h^{-1}$), and *T* is room air temperature (°F). All variables left in the model are significant at the 0.05 level. The regression equation had adjusted $r^2 = 0.45$. The equation confirmed the positive influence of room air RH ($p < 0.001$), S intake ($p < 0.001$), ventilation rate ($p = 0.016$), and room air temperature ($p < 0.001$) on $H_2S$ ER.

The ER of $H_2S$ from toms fed all diets averaged 3.9 $mg\ d^{-1}\ bird^{-1}$. Very limited $H_2S$ emission data for turkeys are available in the literature. As a reference, Xin et al. (2009) reported that $H_2S$ ER averaged 2.83 $mg\ d^{-1}\ bird^{-1}$ for a broiler operation and 2.16 $mg\ d^{-1}\ bird^{-1}$ for a laying hen operation. Wu-Haan et al. (2007) reported that $H_2S$ ER ranged from 0.45 to 1.93 $mg\ d^{-1}\ bird^{-1}$ for a laying hen operation fed a commercial diet.

## EMISSION OF $CH_4$ AND NMTHC

The main effect means of emissions of $CH_4$ and NMTHC are presented in tables 7 and 8. The $CH_4$ emissions were not affected by diets, while the NMTHC emissions were affected by the level of AA formulation relative to NRC. Toms fed the

Table 7. Effect of diet fed to turkey toms on $CH_4$ emissions.[a]

| | | Main Effect Means of Diets | | | | | | p-Value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 100% NRC | 110% NRC | SEM | 2AA | 3AA | SEM | NRC | AA | NRC × AA |
| Daily average concentration (ppm) | | 2.9 | 2.9 | 0.07 | 2.9 | 2.9 | 0.07 | 0.54 | 0.72 | 0.59 |
| Daily ER | $g\ d^{-1}$ room$^{-1}$ | 2.8 | 3.2 | 0.3 | 3.0 | 3.0 | 0.3 | 0.49 | 1.00 | 0.82 |
| | $g\ d^{-1}$ bird$^{-1}$ | 0.25 | 0.28 | 0.03 | 0.26 | 0.26 | 0.03 | 0.42 | 0.89 | 1.00 |
| | $g\ d^{-1}\ kg^{-1}$ BW | 0.08 | 0.08 | 0.01 | 0.08 | 0.08 | 0.01 | 0.99 | 0.97 | 0.77 |
| | $g\ d^{-1}\ kg^{-1}$ feed intake | 0.78 | 0.80 | 0.08 | 0.79 | 0.80 | 0.08 | 0.86 | 0.95 | 0.98 |
| | | Main Effect Means of Phases | | | | | | p-Value | | |
| | | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | SEM | Phase | Phase × NRC | Phase × AA |
| Daily average concentration (ppm) | | 1.0 a | 4.4 d | 4.5 d | 3.1 c | 1.6 b | 0.11 | <0.01 | 0.99 | 0.99 |
| Daily ER | $g\ d^{-1}$ room$^{-1}$ | 1.3 a | 1.8 b | 3.0 c | 4.9 e | 3.9 d | 0.3 | <0.01 | 0.58 | 0.21 |
| | $g\ d^{-1}$ bird$^{-1}$ | 0.08 a | 0.15 b | 0.25 c | 0.45 e | 0.36 d | 0.03 | <0.01 | 0.39 | 0.25 |
| | $g\ d^{-1}\ kg^{-1}$ BW | 0.27 b | 0.05 a | 0.04 a | 0.03 a | 0.02 a | 0.01 | <0.01 | 0.99 | 1.00 |
| | $g\ d^{-1}\ kg^{-1}$ feed intake | 1.47 b | 0.65 a | 0.57 a | 0.74 a | 0.54 a | 0.09 | <0.01 | 0.78 | 0.71 |

[a] Within the same section, values followed by different letters are significantly different ($p < 0.05$). SEM = standard error of the mean.

Table 8. Effect of diet fed to turkey toms on NMTHC emissions.[a]

| | | Main Effect Means of Diets | | | | | | p-Value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 100% NRC | 110% NRC | SEM | 2AA | 3AA | SEM | NRC | AA | NRC × AA |
| Daily average concentration (ppm) | | 0.33 | 0.34 | 0.004 | 0.33 | 0.34 | 0.004 | 0.08 | 0.80 | 0.78 |
| Daily ER | $g\ d^{-1}$ room$^{-1}$ | 1.0 | 1.2 | 0.07 | 1.0 | 1.1 | 0.07 | 0.08 | 0.35 | 0.22 |
| | $g\ d^{-1}$ bird$^{-1}$ | 0.08a | 0.10b | 0.005 | 0.09 | 0.09 | 0.005 | 0.04 | 0.42 | 0.09 |
| | $g\ d^{-1}\ kg^{-1}$ BW | 0.04 | 0.05 | 0.004 | 0.04 | 0.05 | 0.004 | 0.08 | 0.23 | 0.08 |
| | $g\ d^{-1}\ kg^{-1}$ feed intake | 0.33 | 0.36 | 0.01 | 0.33 | 0.37 | 0.01 | 0.09 | 0.08 | 0.02 |
| | | Main Effect Means of Phases | | | | | | p-Value | | |
| | | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | SEM | Phase | Phase × NRC | Phase × AA |
| Daily average concentration (ppm) | | 0.39 b | 0.29 a | 0.31 a | 0.30 a | 0.39 b | 0.01 | <0.01 | 0.91 | 0.98 |
| Daily ER | $g\ d^{-1}$ room$^{-1}$ | 0.8 b | 0.6 a | 0.9 b | 1.4 c | 1.7 d | 0.07 | <0.01 | 0.22 | 0.24 |
| | $g\ d^{-1}$ bird$^{-1}$ | 0.05 a | 0.05 a | 0.07 b | 0.13 c | 0.16 d | 0.06 | <0.01 | 0.11 | 0.19 |
| | $g\ d^{-1}\ kg^{-1}$ BW | 0.17 b | 0.02 a | 0.01 a | 0.01 a | 0.01 a | 0.006 | <0.01 | 0.10 | 0.45 |
| | $g\ d^{-1}\ kg^{-1}$ feed intake | 0.92 b | 0.21 a | 0.16 a | 0.21 a | 0.24 a | 0.02 | <0.01 | 0.99 | 0.23 |

[a] Within the same section, values followed by different letters are significantly different ($p < 0.05$). SEM = standard error of the mean.

Table 9. Effect of diet fed to turkey toms on cumulative GHG emissions in $CO_2$ equivalent units.[a]

| | Treatment Means (kg $CO_2e$ bird$^{-1}$) | | | | | Main Effect Means (kg $CO_2e$ bird$^{-1}$) | | | | | p-Value | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diet | 100% +2AA | 100% +3AA | 110% +2AA | 110% +3AA | SEM | 100% | 110% | +2AA | +3AA | SEM | NRC | AA | NRC × AA |
| $CH_4$ | 0.75 | 0.74 | 0.84 | 0.81 | 0.11 | 0.75 | 0.82 | 0.79 | 0.77 | 0.08 | 0.52 | 0.86 | 0.93 |
| $N_2O$ | 6.80 | 7.14 | 6.89 | 6.46 | 0.41 | 6.97 | 6.68 | 6.85 | 6.80 | 0.29 | 0.48 | 0.92 | 0.37 |
| $CO_2$ | 45.16 | 47.47 | 45.72 | 45.61 | 1.49 | 46.32 | 45.67 | 45.44 | 46.54 | 1.05 | 0.67 | 0.48 | 0.44 |
| Total GHG | 52.71 | 55.36 | 53.44 | 52.88 | 1.81 | 54.04 | 53.16 | 53.08 | 54.12 | 1.28 | 0.64 | 0.58 | 0.40 |

[a] SEM = standard error of the mean.

100% NRC diets resulted in 20% lower NMTHC ER on a per bird basis as compared to the 110% NRC diets. Both $CH_4$ and NMTHC emissions were affected by feeding phase. When expressing emissions on a per bird basis, the daily average ER of both $CH_4$ and NMTHC increased from phase 1 to 5, while the daily average ER on a BW and a feed intake basis all peaked during phase 1. This indicated that the daily average ER values of $CH_4$ and NMTHC were proportional to BW or feed intake except in the first four weeks. The daily average emissions of $CH_4$ and NMTHC from toms fed each of the four diets are presented in figures 8 and 9.

The ER of $CH_4$ and NMTHC from toms across diets averaged 0.26 and 0.09 g d$^{-1}$ bird$^{-1}$, respectively. Very limited $CH_4$ and NMTHC emission data for turkeys are available in the literature. An animal unit (AU) is a standardized measure of animals, with a 1000 lb (453.59 kg) beef cow as 1.0 AU and a turkey over 5 lb (2.27 kg) as 0.018 AU. The $CH_4$ ER in this study can be expressed as 14 g d$^{-1}$ AU$^{-1}$, which is comparable with 15 g d$^{-1}$ AU$^{-1}$ reported by Monteny et al. (2001) for a poultry operation.

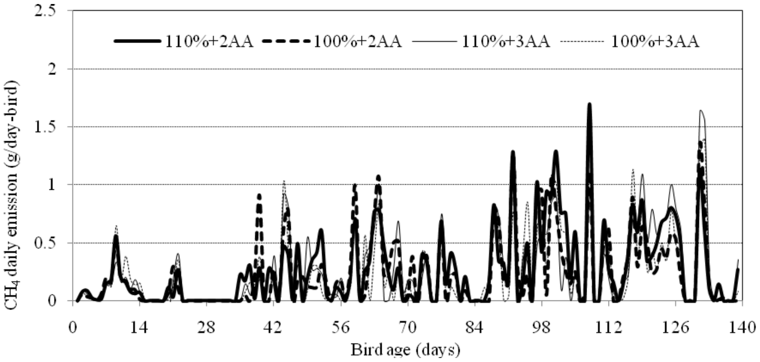

**Figure 8. Daily average ER of $CH_4$ for each of the four diets.**

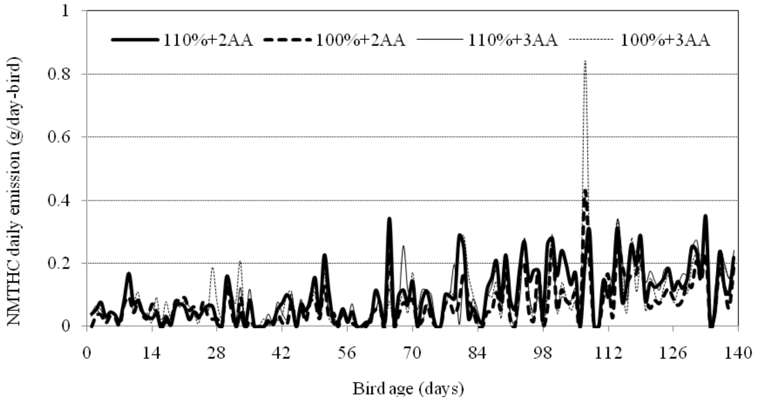

**Figure 9. Daily average ER of NMTHC for each of the four diets.**

## CUMULATIVE GHG EMISSIONS AND CARBON FOOTPRINT

Both $CH_4$ and $N_2O$ have been identified as important greenhouse gases (GHG). The 100-year global warming potential (GWP) of $CH_4$ is 21 times that of $CO_2$, and the GWP of $N_2O$ is 310 times that of $CO_2$ (Grubb et al., 1999). The main effect means and treatment means of cumulative GHG emissions at 140 days of age are presented in table 9. The $CO_2$ generated by animals is considered to be biogenic in nature or "carbon neutral" (in contrast to $CO_2$ from fossil-fuel combustion, which adds new carbon to the atmospheric-biospheric circulation system) and therefore is often not considered in estimates of impact on climate change. In this study, the $CO_2$ from the animals was not distinguished from that from the litter/manure and is listed in the table for comparison purposes. Cumulative emissions of $CH_4$ and $N_2O$ are expressed in $CO_2$ equivalent units. Diet effect was found to be not significant on cumulative GHG emissions.

Effects of diets with reduced CP or modified fibrous components have been investigated on GHG emissions from grow/finish pigs and dairy cows. Li et al. (2010) reported that feeding 20% DDGS to grow/finish pigs with inorganic or organic trace mineral sources resulted in increased $CH_4$ emissions by 64% and 92%, respectively, whereas the emission of $N_2O$ was not influenced. A dairy cow study (unpublished data) demonstrated that diets with reduced CP resulted in reduced $CH_4$ emission but did not affect $N_2O$ emission. More studies are needed to examine the impact of fiber sources and dietary CP on $CH_4$ emissions from manure as well as from enteric fermentation.

A carbon footprint was determined as the sum of the net emissions of the three important GHGs in $CO_2$ equivalent units divided by live weight produced in a room. The $CO_2$ equivalent emitted from turkeys from 0 to 140 days of age was estimated to be 2.7 kg $kg^{-1}$ BW, or 3000 kg $AU^{-1}$. The partition among $CO_2$, $CH_4$, and $N_2O$ was 85.8%, 1.5%, and 12.7%, respectively.

## UNCERTAINTIES OF ER

The uncertainty in gas concentration measurements is comprised of the standard uncertainty in the concentration measurement, which is based on the linearity and precision of the measurement instrument, and the added uncertainty associated with the calibration gas (Gates et al., 2009). In the uncertainty analysis, 1% standard uncertainty in the concentration measurement and 3% standard uncertainty the calibration gas were used. A standard uncertainty of 1% was used in room air temperature measurement. The study assumed one atmospheric pressure, and a reasonable estimate for the daily variation of barometric pressure is 2%. For measurements of ventilation rates, BW, feed intake, and N/S content in diets, a range of random uncertainties from 1% to 20% was used to evaluate how the random uncertainties in these measurements affect the uncertainties of ER. The results are presented in table 10. The uncertainties of ER could be as high as 34.9% when the random uncertainties in measurements of ventilation rates, BW, feed intake, and N/S content in diets were 20%. When the random uncertainties in these measurements were controlled to be less than 5%, the resulting uncertainties of ER were less than 10%. Uncertainty in

**Table 10. Uncertainties of ER when given fixed random uncertainties (1% to 20%) in measurements of ventilation rates, BW, feed intake, and N/S content in diets.**

| Random Uncertainties (%) | Uncertainties of ER | | | |
|---|---|---|---|---|
| | Per bird (%) | Per kg BW (%) | Per kg feed intake (%) | Per kg N/S consumption (%) |
| 1 | 4.1 | 4.2 | 4.2 | 4.4 |
| 2 | 4.6 | 4.9 | 4.9 | 5.3 |
| 5 | 6.4 | 8.1 | 8.1 | 9.5 |
| 10 | 10.8 | 14.7 | 14.7 | 17.8 |
| 20 | 20.4 | 28.6 | 28.6 | 34.9 |

ventilation rate is often the main source of uncertainty in ER on a per bird basis, especially when it is higher than 5%. The ER on a per kg BW, per kg feed intake, or per N/S consumption basis had higher uncertainties than the ER on a per bird basis.

## CONCLUSIONS

In conclusion, this experiment demonstrated the potential of reducing $NH_3$ and $H_2S$ emissions from turkeys through diet modification of AA while maintaining acceptable production performance. Feeding the 100% NRC diets resulted in 9% less cumulative N intakes and 12% less cumulative $NH_3$ emissions as compared with feeding the 110% NRC diets. Formulation with three supplemental AA did not affect N intake but resulted in 25% less cumulative $NH_3$ emissions, as compared with formulation with two supplemental AA, because it significantly reduced $NH_3$ daily average ER on a per kg N consumption basis (88 vs. 109 g $d^{-1}$ $kg^{-1}$ N consumed). The toms fed the 100% NRC diets generated lower ER of $NH_3$ (1.5 vs. 1.8 g $d^{-1}$ $bird^{-1}$), $H_2S$ (3.4 vs. 4.4 mg $d^{-1}$ $bird^{-1}$), and NMTHC (0.08 vs. 0.10 g $d^{-1}$ $bird^{-1}$) than the 110% NRC diets ($p < 0.05$). No diet effect was observed on GHG emissions ($N_2O$ and $CH_4$).

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