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Abstract
Dietary manipulation can substantially lower ammonia (NH3) emissions from laying-hen houses or manure storage. Recent lab studies showed a reduction of 40–60% in ammonia emissions for an experimental (EcoCalTM) diet as compared the standard or control diet. However, adoption of a mitigation technology at commercial production level should be preceded by substantial field verification tests to document not only NH3 emission reduction, but also impact of the strategy on production performance of the hens and cash returns. A study to assess the effects of feeding diets containing EcoCal on NH3, hydrogen sulfide (H2S), and carbon dioxide (CO2) emissions, laying-hen production performance, and economic returns was conducted at a commercial laying-hen farm in central Iowa. Two houses (256,000 or 262,000 hens per house) were used for the study. Hens in one house were fed the EcoCal diet while hens in the other house were fed a standard or control diet containing no EcoCal. A state-of-the-art mobile air emissions monitoring unit (MAEMU) and the associated sampling system were used to continuously monitor the gaseous concentrations, ventilation rate and environmental conditions. Comparative data collected from December 2006 to May 2007 are presented in this paper. Data from this period showed that the EcoCal diet led to NH3 emission reduction by up to 23.2% (0.86±0.04 and 1.12±0.03 g/d·hen for EcoCal and Control diet, respectively), at the same time, H2S emission increased by up to 134% (4.38±0.20 and 1.82±0.07 mg/d·hen for EcoCal and Control diet, respectively), although the magnitude of H2S emission is rather small for both dietary regimens. Data on the hen production performance are reported in a companion paper (Roberts et al., 2008).

Keywords
Dietary modification, Ammonia, Hydrogen sulfide, Carbon dioxide, Laying hen, High-rise

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Abstract. Dietary manipulation can substantially lower ammonia (NH₃) emissions from laying-hen houses or manure storage. Recent lab studies showed a reduction of 40–60% in ammonia emissions for an experimental (EcoCal™) diet as compared the standard or control diet. However, adoption of a mitigation technology at commercial production level should be preceded by substantial field verification tests to document not only NH₃ emission reduction, but also impact of the strategy on production performance of the hens and cash returns. A study to assess the effects of feeding diets containing EcoCal on NH₃, hydrogen sulfide (H₂S), and carbon dioxide (CO₂) emissions, laying-hen production performance, and economic returns was conducted at a commercial laying-hen farm in central Iowa. Two houses (256,000 or 262,000 hens per house) were used for the study. Hens in one house were fed the EcoCal diet while hens in the other house were fed a standard or control diet containing no EcoCal. A state-of-the-art mobile air emissions monitoring unit (MAEMU) and the associated sampling system were used to continuously monitor the gaseous concentrations, ventilation rate and environmental conditions. Comparative data collected from December 2006 to May 2007 are presented in this paper. Data from this period showed that the EcoCal diet led to NH₃ emission reduction by up to 23.2% (0.86±0.04 and 1.12±0.03 g/d⋅hen for EcoCal and Control diet, respectively), at the same time, H₂S emission increased by up to 134% (4.38±0.20 and 1.82±0.07 mg/d⋅hen for EcoCal and Control diet, respectively), although the magnitude of H₂S emission is rather small for both dietary regimens. Data on the hen production performance are reported in a companion paper (Roberts et al., 2008).

Keywords. Dietary modification, Ammonia, Hydrogen sulfide, Carbon dioxide, Laying hen, High-rise

Introduction

Ammonia (NH₃) emissions from animal feeding operations (AFO) have been estimated to represent the largest portion of the national NH₃ emissions inventory in the United States (Battye et al. 1994). According to the most recent estimates by EPA (2005), NH₃ emissions from laying hens contribute 30.5% of the poultry emissions inventory and 8.3% of animal agriculture emissions. Ammonia emission is environmentally important because of its contribution to acidification of soil and water and increased nitrogen deposition in ecosystems. Excessive NH₃ in animal housing can also adversely affect bird health and production performance. The United Egg Producers 2006 Animal Husbandry Guidelines recommend that atmospheric concentrations of NH₃ should ideally be below 25 ppm and should not exceed 50 ppm (United Egg Producers, 2008). Maintaining atmospheric NH₃ concentrations below these maximum allowable amounts can be difficult in high-rise laying-hen houses, especially during winter when ventilation is low (Liang et al., 2005). To improve the environmental stewardship and indoor air quality, the egg industry has been progressively looking for practical means to reduce NH₃ generation and/or emissions from the production facilities.

Factors such as the protein content of the diet, pH value of the manure and feed additives, air temperature, air exchange rate affect the extent NH₃ emission from poultry housing. Ammonia is mainly released from uric acid of bird feces. Ammonia is highly water-soluble and can remain in the water in the dissociated form as ammonium (NH₄⁺). Reducing manure pH value can reduce or prevent NH₃ volatilization. Additives can be added to diet to sequester or trap NH₃. Among these dietary additives is zeolite—a mineral with a porous or lattice-like structure that binds NH₃ in the feces and prevents it from being emitted into the air. Another strategy is to acidify the diet through addition of gypsum (CaSO₄) or calcium benzoate, or by lowering the dietary electrolyte balance. The acidic diet will result in acidic manure, causing NH₃ to be converted to NH₄⁺.

The objectives of this field study were to evaluate the effects of feeding diets containing EcoCal on NH₃ and hydrogen sulfide (H₂S) emissions, laying-hen production performance. This paper describes the impact of the dietary manipulation on gaseous emissions, while a companion paper describes the hen production performance.
Materials and Methods

Housing Characteristics and Management Practices
This field monitoring study involved two commercial high-rise layer houses, each measuring 27.4 m × 180.4 m (90 × 592 ft) in Iowa. Each house was equipped with 72, 1.2 m (48 inch) diameter exhaust fans at the manure storage level, providing a negative-pressure cross ventilation (Figure 1). Manure first fell onto the dropping boards below the cages and was mechanically scraped into the lower-level storage four times a day at 6:30, 9:00, 12:00, and 15:00 hr. Photoperiod was 16L:8D throughout the monitoring period. One house with approximately 256,000 Hy-Line W-36 hens was assigned the EcoCal treatment diet (EcoCal) while the other house with approximately 262,000 Hy-Line W-36 hens was assigned a control diet (Control). Weekly bird performance data, including feed and water consumption, egg production, mortality, bird age, and body weight, were collected and provided by the cooperating producer. On November 23, 2006, hens (79 wk of age) in the EcoCal house began to receive a diet containing 1.75% EcoCal, while hens (87 wk of age) in the Control house continued to be fed the Control (EcoCal-free) diet. On November 30, 2006 addition of EcoCal was increased to 3.5%. All other ingredients were included in the proprietary commercial diet to supply nutrients to meet or exceed the NRC recommendations. On May 20, 2007, the Control hens were replaced with a new flock, which marked the end of the comparison between the two dietary regimens for this phase of the study.

Instrumentation and Measurement Protocol
A mobile air emissions monitoring unit (MAEMU) housing the measurement and data acquisition systems was used to continuously collect data on NH3, H2S and carbon dioxide (CO2) emissions from the two laying hen houses. A detailed description of the MAEMU and operation can be found in Burns et al. (2005). Briefly, a photoacoustic multi-gas analyzer (INNOVA model 1412, INNOVA AirTech Instruments A/S, Ballerup, Denmark) was used to measure NH3 and CO2 concentrations and dew-point temperature; whereas a UV Fluorescence H2S analyzer (Model 101E, Teledyne API, San Diego, CA) was used to measure H2S concentrations. It took approximately 30 s to complete one sampling cycle for NH3, CO2 and dew-point temperature measurements; and four measurement cycles (120 s) to reach 98% of the expected NH3 value (i.e., T98). The 95% response time for the API 101E H2S analyzer was less than 100 s. Hence, the fourth reading of each sampling cycle was used as the measured concentration value and used in the emission calculation. The gas analyzers were checked with calibration gases weekly, and recalibrated as needed. Calibration gases were certified with concentration of 25 ppm (for spring and summer) and 75 ppm (for winter) NH3 (balanced in air, certified grade with 2% accuracy, Matheson Tri-gas, Parsippany, NJ) and 10 ppm H2S (balanced in air, EPA Protocol, Matheson Tri-gas, Parsippany, NJ). The 10 ppm H2S calibration gas was diluted to 150 ppb with a digital dilutor (Model 701, Teledyne API, San Diego, CA) for the API 101E H2S analyzer weekly check and recalibration.
Figure 2. Schematic layout of laying-hen houses used in the study and air sampling locations.

Air samples were drawn from three composite locations (east, middle, and west parts) in each house as well as from an outside location to provide ambient background data (Figure 2). Each composite air sample was drawn from two sampling ports (north and south side) near the minimum ventilation fans in the manure storage level. Placement of the air sampling ports and the air temperature sensors were as follows: 1.2 m (4.0 ft) away from the exhaust fan in the axial direction, 2.7 m (9 ft) from the center in the radial direction, and 4 m (1.2 ft) above the floor. Sampling locations and placement of the sampling ports were chosen to maximize representation of the air leaving the houses. Each sample inlet port was equipped with dust filters to keep large particulate matter from plugging or contaminating the sample line, the servo valves or the delicate measurement instruments. A positive pressure gas sampling system (PP-GSS) was used in the MAEMU to eliminate or minimize introduction of unwanted air into the sampling line. The PP-GSS continuously pumps sample air from every location using individual, designated pumps. The sample air was bypassed when not analyzed. Air samples from each location were collected sequentially over two-min period via the controlled operation of the servo valves of the PP-GSS. Every two hours, air samples from the ambient (background) location were collected and analyzed for 8 min.

Ventilation rates of the houses were measured using the following procedure. Due to the high number of fans (72 fans per house), 25% of all the fans were strategically selected and calibrated in situ, individually and in combined operational stages. The in-situ calibration of the exhaust fans was conducted with a fan assessment numeration system (FANS) (Gates et al., 2004), from which an overall ventilation curve for each house (airflow rate vs. static pressure) was established. Runtime of each fan was monitored continuously using an inductive current switch (with analog output) attached to the power supply cord of each fan motor (Mühlbauer et al., 2006). Analog output of the current switches was connected to the data acquisition system. Concurrent measurement of the house static pressure was made with two static pressure sensors, one for the north side and one for the south side of the house. While the pressure differential was not expected to differ, two sensors were used to provide redundancy in this critical measurement. Summation of airflows from the individual fans during each monitoring cycle or sampling interval produced the overall house ventilation rate.

Determination of Emission Rates

The NH₃ or H₂S emission rate (ER) was calculated as the mass of the gas emitted from the layer houses per unit time and expressed using the following form:

\[
ER = Q \times \left( [G]_i - [G] \right) \times 10^{-6} \times \frac{w_{\text{a}}}{T_{\text{a}}} \times \frac{T_{\text{ref}}}{T_{\text{a}}} \times \frac{P_{\text{a}}}{P_{\text{ref}}}
\]

where

- \( ER \) = gaseous emission rate for the house (g/house-h)
- \( Q \) = ventilation rate at field temperature and barometric pressure (m³/house-h)
- \([G]_i\) = gaseous concentration of incoming ventilation air (ppm)
\[ G_e = \text{gaseous concentration of exhaust ventilation air (ppm)} \]
\[ T_{std} = \text{standard temperature, 273.15 K} \]
\[ T_a = \text{absolute house temperature, \(^\circ\)C+273.15 K} \]
\[ P_{std} = \text{standard barometric pressure, 101.325 kPa} \]
\[ P_a = \text{atmospheric barometric pressure for the site elevation, kPa} \]
\[ w_m = \text{molar weight of NH}_3 (17.031 \text{ g/mole}) \text{ or H}_2\text{S (34.082 g/mole)} \]
\[ V_m = \text{molar volume of gas at standard temperature (0 \(^\circ\)C) and pressure (101.325 kPa), or STP (0.022414 m}^3\text{/mole)} \]

The data were collected for 175 d from December 1, 2006 to May 20, 2007. Due to instrumentation problems and routine calibration and power outage, 11 days data were missing and a total of 164-d data were available and used for the data analysis. Statistical analysis was performed using JMP (version 6.0, SAS Institute, Inc., Cary, NC). Data were analyzed using ANOVA and considering each week as a repeated measure during the period. The dietary effect was considered significant at \( P \)-values \( \leq 0.05 \).

**Results and Discussion**

**Effects of Dietary Regimens on Gaseous Concentrations**

Figure 3 shows that the daily mean ventilation rates (VR) followed the same trend of the outside temperature over the 175-d period. The gaseous concentrations had a negative correlation with outside temperature and VR. The daily mean concentrations of NH\(_3\), H\(_2\)S, and CO\(_2\) from the two houses were compared (Table 1). The EcoCal house had lower NH\(_3\) concentration but higher H\(_2\)S concentration than the Control house (\( P < 0.001 \)). There was no difference in CO\(_2\) concentration between the two houses (Figure 4). Overall, NH\(_3\) concentration in the EcoCal house averaged 79\% of that in the Control house while H\(_2\)S concentration of the EcoCal house averaged 230\% of that in the Control house (Figure 4).

![Figure 3. Daily mean building ventilation rate (1 m\(^3\)/hr-hen = 0.59 cfm/hen) and outside temperature.](image-url)

**Table 1. Summary of gaseous concentration (mean ± standard error) for the two houses over 175-d testing period (December 2006 – May 2007).**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>( T_{out}, ^\circ)C</th>
<th>VR, m(^3)/hr-hen</th>
<th>NH(_3), ppm</th>
<th>H(_2)S, ppb</th>
<th>CO(_2), ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EcoCal</td>
<td>3.6±1.6</td>
<td>1.61±0.20</td>
<td>45.5±2.8</td>
<td>110.7±7.6</td>
<td>2,464±130</td>
</tr>
<tr>
<td>Control</td>
<td>3.6±1.6</td>
<td>1.64±0.19</td>
<td>57.8±3.6</td>
<td>47.8±3.9</td>
<td>2,450±132</td>
</tr>
</tbody>
</table>

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Effects of Dietary Regimens on Gaseous Emissions

The NH₃, H₂S, and CO₂ ER for the EcoCal and Control houses were plotted in Figure 5. The daily mean (± standard error) NH₃ ER from the EcoCal and Control houses over the 175-d continuous monitoring was 0.86±0.04 and 1.12±0.03 g/d-hen, respectively (P<0.001; Table 2). The overall NH₃ ER reduction by the EcoCal diet over the 175-d period was 23.2%. The daily NH₃ ER of the current study compared quite well with the annual mean NH₃ ER of 0.90±0.03 g/d-hen for high-rise houses in Iowa fed a standard diet, as reported by Liang et al. (2005). The daily mean CO₂ ER for the EcoCal and Control houses during the same period was 95.0±1.7 and 99.1±2.1 g/d-hen, respectively (P=0.017), although the difference was only 4%. The concomitant daily mean H₂S ER for the EcoCal and Control regimens was 4.38±0.20 and 1.82±0.07 mg/d-hen, respectively (P<0.001).

Table 2. Summary of gaseous emission rate (mean ± standard error) for the two houses over 175-d testing period (December 2006 – May 2007).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>T, °C</th>
<th>VR, m³/hr-hen</th>
<th>NH₃, g/d-hen</th>
<th>H₂S, mg/d-hen</th>
<th>CO₂, g/d-hen</th>
</tr>
</thead>
<tbody>
<tr>
<td>EcoCal</td>
<td>3.6±1.6</td>
<td>1.61±0.20</td>
<td>0.86±0.04</td>
<td>4.38±0.20</td>
<td>95.0±1.7</td>
</tr>
<tr>
<td>Control</td>
<td>1.64±0.19</td>
<td>1.12±0.03</td>
<td>1.82±0.07</td>
<td>99.1±2.1</td>
<td></td>
</tr>
</tbody>
</table>
Figure 5. NH₃, H₂S and CO₂ daily emission rates and outside temperature.

The weekly H₂S ER increase varied from 96.5% up to 231% and the monthly H₂S emission increase was in the range of 105% to 176% (Figure 6). In general, the H₂S increase rate increased with increasing outside temperature (P=0.005).

The efficacy of NH₃ emission reduction by the EcoCal diet tended to diminish over time during the 175-d experimental period. The efficacy decreased with increasing outside temperature (P<0.001). The weekly and monthly NH₃ ER reduction was shown in Figure 7. The weekly NH₃ ER reduction varied from 3.3% up to 48.2% and the monthly NH₃ emission reduction was in the range of 7.7% for May 2007 to 39.2% for February 2007. The outcome of seasonal variation in the dietary efficacy could have stemmed from changes in manure properties, especially moisture content, as the weather condition and VR varies across the season. We hope to address this aspect with ongoing research.
Figure 6. Weekly and monthly H$_2$S reduction from the EcoCal house and outside temperature.

Figure 7. Weekly and monthly NH$_3$ reductions from the EcoCal house and outside temperature.
Conclusions

Feeding EcoCal diet at 3.5% inclusion rate to laying hens in high-rise house showed the following impacts on gaseous emissions, based a 175-d continuous test period (December to May) in Iowa:

- 23.2% overall reduction in NH₃ emissions, with a mean daily NH₃ emission of 0.86±0.04 vs. 1.12±0.03 g/d-hen for the EcoCal and control diet, respectively.
- 134% overall increase in H₂S emissions, with a mean daily H₂S emission of 4.38±0.20 and 1.82±0.07 mg/d-hen for the EcoCal and control diet, respectively.
- 4% overall decrease in CO₂ emissions, with a mean daily CO₂ emission of 95.0±1.7 and 99.1±2.1 g/d-hen for the EcoCal and control diet, respectively.
- The efficacy of NH₃ emission reduction by the EcoCal diet decreased with increasing outside temperature, varying from 39.2% in February 2007 to 7.7% in May 2007.

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References


