Feeding DDGS to Laying Hens to Demonstrate Economically Viable Reductions in Ammonia Emissions

Final Report to USDA

NRCS Conservation Innovation Grant

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Executive Summary

A USDA Natural Resources Conservation Service, Conservation Innovation Grant project was coordinated by the United Egg Producers (UEP). Concurrent demonstrations in Iowa (IA) and Pennsylvania (PA) were conducted at commercial laying hen facilities. The project goal was to document manure nutrient and gas emission improvements through the use of diets with dried distiller's grain with solubles (DDGS) and/or other dietary modifications, while maintaining or improving hen productivity.

The IA study site: Three different diets were used in three commercial high-rise layer houses in central Iowa over the course of two full years (December 6, 2007- December 5, 2009). The three diets were a standard industry diet (control), a diet that contained 7% by weight of a commercial dietary acidifying supplement (EcoCal), and a diet that contained 10% DDGS. Each high-rise house had 260,000 laying hens on the upper story with long-term manure storage on the lower level. Daily and weekly production data were supplied to the project team by farm staff at the monitored site. Continuous, real-time recording of gas emissions was performed.

Over the 24-month project, feeding EcoCal at 7% inclusion rate and DDGS at 10% inclusion rate to laying hens in the high-rise house was shown to have the following impact on gaseous emissions and production performance, compared with the control diet:

a) 39% and 14%, respectively, overall reduction in ammonia emissions: Efficacy of the DDGS treatment ranged from a 32% increase to a 46% decrease.

b) 202% and 7%, respectively, overall increase in hydrogen sulfide emission.

c) Minimal differences in egg production, egg weight, or egg mass (output) were observed for hens fed EcoCal or DDGS as compared to hens fed the control diet. Egg production of the DDGS-fed hens was somewhat lower than that of the control or EcoCal-fed hens.

d) Hens on the EcoCal diet showed higher feed consumption and a lower mortality rate and tended to have a heavier body weight.

The efficacy of ammonia emission reduction by the EcoCal diet decreased with increasing outside temperature, varying from 72% in February 2009 to an increase emission of 7% in September 2008. Manure of the EcoCal diet contained 68% higher ammonium nitrogen (NH_3-N) and 4.7 times higher sulfur content than the Control diet manure (1.5% on dry matter base) but lower phosphorous and potassium.

An extensive economic analysis was performed, and showed that cash return per hen over the 91-wk period averaged $11.88, $11.18, and $12.35 for Control, DDGS and EcoCal diets, respectively.

The PA site: Diets containing 10% corn DDGS with or without the probiotic Provalen™ were compared to a corn-soybean based Control diet. The isocaloric, amino acid balanced diets were fed to three groups of 39,800 Lohmann hens in one house. Hens were 20-65 wk of age with each diet provided to 2 of 6 rows of stacked cages with manure belts (six decks high). Bird and egg production data were obtained weekly and ammonia flux measurements collected every four weeks. Replicated monthly samples of hen manure (fresh on manure belt, and from storage) were analyzed for moisture and major nutrients. Ammonia gas measurements utilized replicated recordings from a non-steady state flux chamber method.

Results of this trial:

a) There was no clear trend in the magnitude of ammonia flux relative to the diets within the hen house as measured on the manure belt. At 32 and 36 wks of age, ammonia flux was significantly ($P < 0.10$) higher in the DDGS diet, with the other two diets being lower and similar. At 48 and 52 wks, ammonia flux from both DDGS and DDGS+ Probiotic fed birds was significantly lower than the Control diet.

b) There was no significant impact of diet on most bird production data; however, hens fed the Control diet had reduced egg production, albumen height, and yolk color compared to the DDGS and DDGS+ Probiotic diets, indicating that DDGS diets can improve egg quality and production.

c) Fresh manure total phosphorus (P_2O_5) was significantly lower in the DDGS and DDGS+ Probiotic manure samples, while other major agronomic nutrients and moisture were not significantly different. Stored manure samples from the Control diet had increased moisture and NH_4-N compared to those of DDGS and DDGS+ Probiotic diets, indicating conditions suitable for greater ammonia emissions from the Control manure.

An economic analysis of the three diets was conducted. Weekly Egg Income minus Feed Cost averaged $6,144, $6,216, and $6,204 for the Control, DDGS, and DDGS+ Probiotic diets, respectively, showing improved income from both DDGS based diets.

Recommendation: The use of diets with 10% DDGS or 7% Eco-Cal (a commercial product) has potential to reduce ammonia emission of laying hens compared with control diets. The use of 10% DDGS and 10% DDGS with a commercial probiotic was found to reduce ammonia flux from manure belts during some weeks of testing compared with the control diet. Bird production parameters using the test diets were generally equivalent to, or better than, control diets. Manure from the Eco-Cal diets fed in high-rise housing had higher ammonia-nitrogen; whereas manure from a DDGS diet fed to birds on manure belts had lower moisture and phosphorous. Economic analysis of the results suggest that these diets are economically attractive compared to the control diets. Thus, inclusion of 10% DDGS or 10% DDGS+ probiotic are economically viable alternative feeding strategies with potential for reducing ammonia emissions from egg production facilities. Diets with 7% Eco-Cal as a dietary acidifier more consistently reduced ammonia emissions.

FINAL PROJECT REPORT

Mitigating Ammonia Emissions from High-rise Hen Houses through Dietary Manipulation

NRCS CIG Project- Iowa Site

Submitted to

United Egg Producers

by

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Executive Summary

This report describes comparison of gaseous emissions (ammonia – NH_3 and hydrogen sulfide - H_2S) and production performance of three high-rise layer houses in central Iowa that received standard industry diet (Control), a diet that contained 7% EcoCal™ (EcoCal) and a diet that contained 10% dried distillers grain with solubles (DDGS). The high-rise houses each had 260,000 laying hens and were ventilated using a negative-pressure system with a total of 72 exhaust fans located along the walls in the manure storage level. Prior to feeding the respective diet and onset of the monitoring, manure in all houses was removed. The gaseous concentrations, ventilation rate, and the environmental conditions were recorded continuously using a state-of-the-art, environmentally-controlled mobile air emissions monitoring unit (MAEMU) installed on-site. Operation and maintenance of the MAEMU followed the previously developed EPA Category I type of quality assurance project plan (QAPP) for monitoring of air emissions from animal feeding operations. Daily and weekly production data were supplied to the project team by Rose Acre Farms staff at the monitored site. The comparison was made during the period of December 6, 2007 to December 5, 2009 when flock change started occurring.

Feeding EcoCal diet at 7% inclusion rate and DDGS diet at 10% inclusion rate to laying hens in the high-rise house was shown to have the following impact on gaseous emissions and production performance: a) 39% and 14% overall reduction in NH_3 emissions during the 24-month testing period, with a mean daily NH_3 emission rate of 0.58 ± 0.05, 0.82 ± 0.04, and 0.96 ± 0.05 g d^{-1} hen^{-1} for the EcoCal, DDGS, and control diet, respectively; b) 202% and 7% overall concomitant increase in H_2S emissions, with a mean daily H_2S emission of 5.39 ± 0.46, 1.91 ± 0.13 and 1.79 ± 0.16 mg d^{-1} hen^{-1} for the EcoCal, DDGS and control diet, respectively. The efficacy of NH_3 emission reduction by the EcoCal diet decreased with increasing outside temperature, varying from 72.2% in February 2009 to 4.0% in September 2008. Manure of the EcoCal diet contained 68% higher ammonium nitrogen (NH_3-N) and 4.7 times higher sulfur content than the Control diet manure (1.46% on dry matter base). Manure pH values of the three diets were 9.3, 8.9 and 8.0 for Control, DDGS and EcoCal, respectively. Few differences in egg production, egg weight, or egg mass (output) were observed for hens fed EcoCal, DDGS as compared to hens fed the control diet. Hens on the EcoCal diet showed higher feed consumption and a lower mortality rate than hens on the control or DDGS diet. The EcoCal hens tended to have a heavier body weight. Egg production of the DDGS-fed hens was somewhat lower than that of the control or EcoCal-fed hens, which could have been due to a new strain of hens. Finally, cash return per hen over the 91-wk period averaged $11.88, $11.18, and $12.35 for Control, DDGS and EcoCal regimens, respectively.

Introduction

Ammonia (NH_3) emissions from animal feeding operations (AFOs) have been estimated to represent the largest portion of the national N_3 emissions inventory in the United States (Battye et al., 1994). According to the most recent estimates by EPA (2005), NH_3 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 NH_3 in animal housing also adversely affect bird health and production performance. Atmospheric ammonia concentration in poultry houses is generally recommended to be lower than 25 ppm to ensure bird health (e.g., UEP 2006 Animal Husbandry Guidelines).

Understanding and mitigating air emissions from production facilities is an important issue for the U.S. livestock and poultry industries. Although baseline emission data are important, devising practical solutions to mitigate air emissions remains the ultimate goal for the animal industry to address air quality-related environmental issues. The U.S. egg industry has been proactively looking for practical means to reduce NH_3 generation and/or emissions from egg production facilities. One of the promising NH_3-lowering methods is dietary manipulation. For instance, lowering dietary protein content, including high-fiber ingredients (dried distillers grain with solubles-DDGS) or acidifier ingredient (e.g., EcoCal) in the diet have been shown to lower NH_3 emission from laying-hen manure. Although lab-scale tests involving small number of birds had shown considerable reduction of manure NH_3 emissions from laying hens fed EcoCal or DDGS diet, field verification and demonstration of the promising dietary strategies are needed before consideration of their wider adoption by the egg industry.

The objective of this field project was to demonstrate, over an extended (2-year) period, the effects of feeding diets containing EcoCal or DDGS on NH_3 and hydrogen sulfide (H_2S) emissions, hen performance, and production economics for commercial high-rise layer facilities.

Materials and Methods

Housing Characteristics and Management Practices

This demonstration project was conducted with three commercial high-rise laying-hen houses located in central Iowa, each measuring 90 x 592 ft with a housing capacity of approximately 260,000 W-36 hens. Each house has 72, 4-ft diameter exhaust fans along the sidewalls of the manure storage level, providing negative-pressure cross ventilation (fig. 1). Manure first fell onto the dropping boards below the cages and was then mechanically scraped into the storage 4 times a day (06:30, 09:00, 12:00, 15:00h). Photoperiod of 16L:8D was generally used except for during the molting period which followed a different lighting program. The three houses received three respective diets, namely, diet containing 7% (by weight) EcoCal (EcoCal), diet containing 10% (by weight) DDGS, and control diet (Control). Weekly bird performance data, including feed and water consumption, egg production, mortality, bird age, and body weight, were collected and provided to the project team by the farm staff. At the onset of the demonstration monitoring on December 6, 2007, hens for the dietary regimens had the following ages: 41 wk for EcoCal, 30 wk for Control, and 19 wk for DDGS. Monitoring of all the houses started free of manure accumulation (i.e., after a complete removal of manure in the storage). Molting started on June 30, 2008 in the EcoCal house and September 14, 2008 in the Control house (at age 72 to 75 wk). Molting diet was used during molting period. The EcoCal house was depopulated during the period of May 13-21, 2009 and restocked by June 9, 2009; the new flock in this house was fed DDGS diet. The Control house was depopulated during the period of July 16-24, 2009 and restocked by August 6, 2009; the new flock was fed EcoCal diet. Finally, the DDGS house was depopulated during the period of November 6-18, 2009 and restocked by December 17, 2009; and the new flock was fed Control diet.

Total egg production was provided daily by the producer and divided by the hen population, adjusted for daily mortality, to calculate the hen-day egg production, then averaged by week. Each week, a representative case (30 dozens) of eggs were collected from each house and weighed. Individual egg weight (g egg^{-1}) was subsequently calculated, and egg mass was calculated as egg production multiplied by egg weight to determine daily egg output of the hen. Feed consumption (g $hen^{-1}d^{-1}$) was measured as feed disappearance from the two bins per house. Hen body weight was determined monthly by weighing the same 100 hens in each house. Hen-level air temperature was recorded at the 3rd and 5th tiers and averaged by week.

A state-of-art mobile air emissions monitoring unit (MAEMU) housing the measurement and data acquisition systems was used to continuously collect data on NH_3, H_2S, and carbon dioxide (CO_2) emissions from the three laying hen houses (fig. 2). A detailed description of the MAEMU and its standard operational procedure (SOP) can be found in Burns et al. (2006). Briefly, a photoacoustic multi-gas analyzer (INNOVA model1412, INNOVA AirTech Instruments A/S, Ballerup, Denmark) was used to measure NH_3 and CO_2 concentrations and dew-point temperature; whereas a UV fluorescence H_2S analyzer (Model 101E, Teledyne API, San Diego, CA) was used to measure H_2S concentrations (fig. 3). It took approximately 30 s per sampling cycle for NH_3, CO_2 and dew-point temperature measurements; and four measurement cycles (~120 s) to reach 98% of the expected NH_3 value (i.e., T98). The 95% response time for the API 101E H_2S 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 at concentration of 25 ppm (for spring and summer) and 100 ppm (for fall and winter) NH_3 (balanced in air, certified grade with 2% accuracy, Matheson Tri-gas, Parsippany, NJ) and 10 ppm H_2S (balanced in air, EPA Protocol, Matheson Tri-gas, Parsippany, NJ). The 10 ppm H_2S calibration gas was diluted to 200 ppb with a digital dilutor (Model 701, Teledyne API, San Diego, CA) for the weekly check and recalibration, as needed, of the H_2S analyzer.

Air samples were drawn from two composite locations (east and west sections) in each house as well as from an inlet location in the ceiling of one house to provide ambient background data. Each composite air sample was drawn from two sampling ports (north and south side) near the minimum ventilation fans (130ft from end wall) in the manure storage level. Placement of the air sampling ports and the air temperature sensors were as follows: 4.0 ft away from the exhaust fan in the axial direction, 9ft from the center in the radial direction, and 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 point 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 pumped 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 2-min period via the controlled operation of the servo values of the PP-GSS. Every 2 hours, air samples from the ambient (background) location were collected and analyzed for 8 min.

Ventilation rates (VR) of the houses were measured using the following procedure. Due to the high number of fans (72 fans per house), 15 fans during each fall and 26 fans during each spring were strategically selected and calibrated *in situ,* individually and in combined operational stages. The *in-situ* calibration of the exhaust fans was conducted with fan assessment numeration system (FANS) unit, from which an overall ventilation curve (airflow rate *vs.* static pressure) for each house was established (fig 4.). Summation of airflow from all the running fans during each monitoring cycle produced the overall house VR. In addition to the direct VR measurement, CO_2 mass balance method was used to serve as a backup or check of directly measured VR.

The manure storage of each house was cleaned in November 2007 prior to the study. After one year accumulation the manure were hauled out and weighed separately for each individual house during the period of November 2008 to January 2009. Nine manure samples from each house were collected from nine selected representative locations and analyzed for nutrient, pH, and moisture content by a certified commercial lab (Midwest Lab Inc, Omaha, NE).

Determination of Emission Rates

The NH_3 or H_2S emission rate (ER) was calculated as mass of the gas emitted from the layer houses per unit time, of the following form:

$$ER = Q \times ([G]_e - [G]_i) \times 10^{-6} \times \frac{w_m}{V_m} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}} \qquad [1]$$

where ER = gaseous emission rate for the house ($g \cdot house^{-1} \cdot h^{-1}$)

Q = ventilation rate at field temperature and barometric pressure ($m^3 \cdot house^{-2} \cdot h^{-1}$)

$[G]_i$ = volumetric gaseous concentration of incoming ventilation air (ppm_v)

$[G]_e$ = volumetric gaseous concentration of exhaust ventilation air (ppm_v)

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

W_m = molar weight of NH_3 (17.031 g $mole^{-1}$) or H_2S (34.082 g $mole^{-1}$)

V_m = molar volume of gas at standard temperature (0°C) and pressure (101.325 kPa), or STP (0.022414 $m^3 \cdot mole^{-1}$)

The gaseous emission data were collected for 825 days from December 6, 2007 to March 9, 2010 and the first two full years of data were used for the final data analysis. Due to occasional instrumentation problems, routine calibration and unavoidable power outage, 26 days of emission data were missing and 731-d data were available and used in the analysis. Statistical analysis was performed using JMP (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 0.05.

Results and Discussion

Effects of Dietary Regimens on Gaseous Emissions

Daily and monthly mean NH_3 and H_2S ERs for the layer houses are shown in Figures 5 and 6. Monthly mean (±S.E.) NH_3 and H_2S ERs for the DDGS, EcoCal, and Control houses over the 731-d monitoring period are summarized in Tables 1 and 2.

The monthly mean (±S.E.) NH_3 ER was the lowest for the EcoCal diet (0.58 ± 0.05 g d^{-1} hen^{-1}), followed by the DDGS diet (0.82 ± 0.04 g d^{-1} hen^{-1}), and highest for the Control (0.96 ± 0.05 g d^{-1} hen^{-1}) (P<0.01) (Table 3). The efficacy of NH_3 emission reduction by the DDGS or EcoCal diet tends to be season-dependent during the 2-yr monitoring period (P<0.01). As shown in Figure 7, the efficacy of NH_3 emission reduction by the EcoCal diet decreased with increasing outside temperature, varying from 72.2% in February 2009 to -7.1% in September 2008. In comparison, NH_3 ER reduction varied from -31.8% from January 2009 to 51.0% from October 2009 for the DDGS diet. The NH_3 emission reduction rates over the 2-yr period were 13.8% and 39.2% for DDGS and EcoCal diets, respectively. The outcome of seasonal variations in the dietary efficacy could have stemmed from changes in manure properties, especially moisture content, as the weather and VR varied considerably with the season.

The monthly mean H_2S ER for the EcoCal diet (5.39 ± 0.46 mg d^{-1} hen^{-1}) is significantly higher than that of the DDGS (1.91 ± 0.13 mg d^{-1} hen^{-1}) or Control (1.79 ± 0.16 mg d^{-1} hen^{-1}) (P<0.001). However, no difference in H_2S ER was observed between DDGS and Congrol (P=0.23). Monthly mean H_2S ER increase varied from -1.4% to 499% for the EcoCal diet (Table 1). The mean H_2S ER increased 6.7% and 202% for the DDGS and EcoCal diets, respectively.

Effects of Dietary Regimens on Manure Nutrients and pH

Compositions of the manure from the three diets are shown in Table 4. There was no significant difference among the three diets for TKN and organic nitrogen (org-N). The manure of EcoCal diet flock had higher ammonium nitrogen NH_3-N), and sulfur content, but lower P_2O_5 and K_2O than the Control and DDGS diet flocks. The NH_3-N contents (2.44% in dry matter base) in EcoCal diet manure was 68% higher than the Control diet manure (1.46% in dry matter base). The EcoCal diet manure contained 4.7 times higher sulfur content than Control diet manure (4.24 vs. 0.74% in dry matter base). The manure pH values of the three diets were 9.3, 8.9 and 8.0 for Control, DDGS and EcoCal, respectively. The acidifier ingredients in EcoCal and DDGS reduced the manure pH and less N was emitted as aerial NH_3 into the air and NH_3-N would be more easily retained in the manure. The moisture contents of the three diets were 46.1, 43.5, and 50.2 %for the Control, DDGS and EcoCal diets, respectively.

Effects of Dietary Regimens on Hen Production Performance

The feed consumption, egg production, and egg mass on the 1st cycle were estimated as the sum of the weekly feed consumption and egg production from weeks 20 to 69. The second cycle was defined as weeks 1-42 after molting.

Feed consumption data are shown in table 5. EcoCal-fed hens consumed 6.7 and 4.3 lb, respectively, more feed than Control and DDGS-fed hens for the periods of two production cycles of the first flock. The increased feed consumption might have led to the larger body weight (BW) for the EcoCal hens. The mean BW over this period was 3.54, 3.52, and 3.69 lb for the Control, DDGS, and EcoCal and diets, respectively. BW of the EcoCal-fed hens was higher than those of hens with DDGS and Control diets for both production periods. The greater BW would in turn require higher energy intake for metabolic maintenance. Furthermore, air temperature was somewhat cooler in the EcoCal house (73.5 °F) than in the Control (75.1 °F) and DDGS (75.3 °F) houses, which could contribute to the higher feed consumption. The overall feed conversions were 1.96, 2.02, and 1.98 for Control, DDGS, and EcoCal fed hens, respectively.

Egg production was slightly lower for the DDGS-fed hens (424 eggs hen^{-1} or 58.6 lb hen^{-1}) than for the Control (435 eggs hen^{-1} or 59.2 lb hen^{-1}) or EcoCal-fed (447 eggs hen^{-1} or 61.9 lb hen^{-1}) hens during the two production cycles. The peak of production of the 1st flock of DDGS-fed hens was lower than those of the other two regimens, although it was likely caused by a new bird strain that took some adjustment in production management (fig. 8). The 2nd DDGS flock peak was much higher than in the 1st flock and was similar to those for the Control and EcoCal flocks. Egg weights are shown in Table 5 and Figure 9. Mean egg weights were 61.7, 62.6, and 62.8 g for the Control, DDGS, and EcoCal-fed hens, respectively.

During the two-cycle production the EcoCal flock had a lower mortality than the Control and DDGS flocks (fig. 10). However, it is difficult to say with certainty if the differences in the observed flock mortality were linked to the dietary treatment.

Economics Analysis

The prices of feed ingredients (corn, soybean meal, DDGS, meat and bone meal, fat and salt) were the 2007-2009 average prices for Minneapolis, Chicago and Kansas City as published on the Feedstuffs newspaper. Ecocal was priced at 8 cents per cwt and micronutrients were priced at \$1,000 ton^{-1} (personal communication with industry nutritionist). The feed prices throughout the two-year period were estimated from the feed formulas provided by the producer and were \$184.3, \$182.2, and \$189 per US ton (2000 lbs) for Control, DDGS and EcoCal diets, respectively. The USDA NASS published prices for urea and 44-46% P_2O_5 were used to estimate the nutrient value of the manure. The manure was priced at 70% of its nutrient value. Ecocal diet manure had a lower percentage of phosphorus when expressed on "as-is" basis but the weight was greater because of its higher moisture content than manure from the other two diets. The manure values were \$5.87, \$7.35, and \$8.95 per 1000 hens per week for Control, DDGS and EcoCal diets, respectively. The egg price paid to producers was estimated using 2007-2009 Urner Barry prices minus a discount for washing, grading, packaging, etc. The pullet cost was assumed to be

$2.96 bird^{-1} and all the pullets were paid in the 1st cycle and the starting cost of the birds in the 2nd cycle was the cost of feeding them throughout the molting period. The other costs, including labor, utilities, depreciation, insurance, etc., were assumed to be 27.2 cents per month per hen housed. The returns (revenue - total cost) per hen were, respectively, $11.88, $11.18 and $12.35 for Control, DDGS and EcoCal dietary regimens over the 91-wk period (49 wks pre-molt and 42 wks post-molt).

Detailed description of the economic analysis is provided in Appendix A of the report (starting on page 18).

Summary and Conclusions

Feeding EcoCal diet at 7% inclusion rate and DDGS diet at 10% inclusion rate to laying hens in high-rise houses showed the following impact on gaseous emissions and production performance, based a two-year continual field test (December 2007 to December 2009) in Iowa:

- 39% and 14% overall reduction in NH_3 emissions for EcoCal and DDGS diet, respectively; with mean daily NH_3 emission of 0.58 ± 0.05, 0.82 ± 0.02, and 0.96 ± 0.05 g $d^{-1}hen^{-1}$ for the EcoCal, DDGS, and control diet, respectively.
- 202% and 7% overall concomitant increase in H_2S emissions, with mean daily H_2S emission of 5.39 ± 0.46, 1.91 ± 0.13 and 1.79 ± 0.16 mg $d^{-1}hen^{-1}$ for the EcoCal, DDGS, and control diet, respectively.
- The efficacy of NH_3 emission reduction by the EcoCal diet decreased with increasing outside temperature, varying from 72.2% in February 2009 to -7.1% in September 2008.
- The manure of EcoCal diet contained 68% higher NH_3-N and 4.7 times higher sulfur content than the Control diet manure (1.46% on dry matter base). Manure pH values of the three diets were 9.3, 8.9 and 8.0 for Control, DDGS and EcoCal, respectively.
- There were few differences in egg production, egg weight or egg mass (output) for hens fed 7.0% EcoCal, 10% DDGS as compared to hens fed the control diet.
- Compared with the control and DDGS hens, the EcoCal hens consumed more feed and had a lower mortality rate, and had a similar feed conversion. Additionally, the EcoCal hens tended to have a greater body weight.
- Egg production was slightly lower from the DDGS-fed hens (424 eggs hen-1 or 58.5 lb hen^{-1} than the Control (435 eggs hen^{-1} or 59.2 lb hen^{-1}) and EcoCal-fed (447 eggs hen^{-1} or 61.9 lb hen^{-1}) hens, which could have been caused by a new strain of DDGS-fed hens that needed some adjustment to the production management.
- The cash returns (revenue- total cost) of each hen were, respectively, $11.88, $11.18 and $12.35 for Control, DDGS and EcoCal dietary regimens over the 91-wk period.

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Table 1. NH_3 emission rates of three diets and emission reduction relative to Control diet

Month, Year	Mean T_{out} °F	Mean NH_3, g $hen^{-1}d^{-1}$			S.E. NH_3, g $hen^{-1}d^{-1}$			Reduction, %	
		Control	DDGS	EcoCal	Control	DDGS	EcoCal	DDGS	EcoCal
Dec, 07	28.4	1.11	0.6	0.48	0.04	0.05	0.04	45.9	56.7
Jan, 08	20.4	1.29	0.92	0.40	0.06	0.03	0.02	28.9	69.4
Feb, 08	20.8	0.99	0.72	0.35	0.04	0.02	0.01	27.6	65.2
Mar, 08	37.4	1.02	0.76	0.39	0.05	0.04	0.02	25.6	61.5
Apr, 08	47.5	1.32	1.19	0.62	0.04	0.07	0.02	9.7	52.8
May, 08	60.4	1.15	1.05	0.71	0.05	0.05	0.04	8.7	38.1
Jun, 08	72.3	1.25	1.07	0.92*	0.07	0.05	0.04	14.4	26.5
July, 08	75.9	1.38	1.18	0.9*	0.07	0.04	0.05	14.3	34.9
Aug, 08	71.2	1.12	1.16	1.06	0.04	0.04	0.03	-3.9	5.0
Sep, 08	64.6	0.94*	1.09	1.00	0.06	0.05	0.04	-16.3	-7.1
Oct, 08	53.2	0.81*	0.85	0.69	0.04	0.04	0.04	-5.1	14.0
Nov, 08	41.2	0.88	0.66	0.58	0.04	0.05	0.03	25.1	33.5
Dec, 08	21.8	0.91	0.73*	0.58	0.02	0.04	0.04	20.2	36.3
Jan, 09	19.6	0.6	0.80*	0.36	0.05	0.06	0.01	-31.8	39.6
Feb, 09	29.4	0.78	0.96	0.22	0.04	0.03	0.01	-23.4	72.2
Mar, 09	40.0	0.91	0.8	0.26	0.03	0.02	0.01	12.3	71.6
Apr, 09	48.4	0.58	0.6	0.46	0.04	0.04	0.02	-2.0	21.8
May, 09	61.9	0.7	0.76	0.68	0.04	0.02	0.06	-8.2	4.0
Jun, 09	69.8	1.01	0.94	-	0.06	0.06	-	6.8	-
July, 09	69.9	1.01	0.61	-	0.14	0.03	-	39.5	-
Aug, 09	69.9	0.53	0.72	-	0.03	0.03	-	24.7	-
Sep, 09	64.4	0.73	0.58	0.67	0.08	0.02	0.05	19.9	7.4
Oct, 09	46.0	-	0.47	0.47	-	0.02	0.02	51.0	50.7
Nov, 09	45.7	-	0.56	0.40	-	0.02	0.01	41.5	58.2

**Molting diet was used.*

- No meaningful comparison due to manure flock changing

Table 2. H_2S emission rates of three diets and emission increases relative to Control diet

Month, Year	Mean	Mean H_2S, g $hen^{-1}d^{-1}$			S.E. H_2S, g $hen^{-1}d^{-1}$			Increase, %	
	T_{out}, °F	Control	DDGS	EcoCal	Control	DDGS	EcoCal	DDGS	EcoCal
Dec, 07	28.4	1.66	1.46	2.23	0.06	0.13	0.14	-11.7	34.8
Jan, 08	20.4	2.43	1.89	4.25	0.14	0.11	0.14	-22.2	75.0
Feb, 08	20.8	2.03	1.80	6.99	0.10	0.04	0.33	-11.2	245
Mar, 08	37.4	2.4	1.81	8.97	0.09	0.07	0.28	-24.7	273
Apr, 08	47.5	2.89	1.99	7.59	0.07	0.07	0.21	-31.1	163
May, 08	60.4	2.39	1.9	5.8	0.08	0.09	0.40	-20.7	142
Jun. 08	72.3	3.17	2.12	7.36'	0.11	0.15	0.59	-33.0	132
July, 08	75.9	2.97	3.68	2.04'	0.13	0.24	0.11	23.7	-31.3
Aug, 08	71.2	2.27	3.44	2.24	0.10	0.19	0.07	51.3	-1.5
Sep, 08	64.6	1.45'	2.52	5.93	0.18	0.13	0.32	73.9	309
Oct, 08	53.2	0.76'	1.46	4.46	0.06	0.05	0.24	91.4	485
Nov, 08	41.2	0.85	1.50	4.11	0.10	0.18	0.45	76.8	385
Dec, 08	21.8	1.05	1.95	3.98	0.11	0.23	0.44	85.8	280
Jan, 09	19.6	1.78	0.97'	6.33	0.13	0.13	0.37	-45.7	256
Feb, 09	29.4	1.38	1.17'	7.45	0.05	0.05	0.29	-15.6	438
Mar, 09	40.0	0.93	1.34	7.10	0.04	0.06	0.46	44.5	665
Apr, 09	48.4	1.06	1.7	5.39	0.05	0.09	0.2	59.7	406
May, 09	61.9	0.80	1.57	4.79	0.08	0.08	0.2	95.9	499
Jun. 09	69.8	1.35	1.71	-	0.1	0.21	-	27.0	-
July, 09	69.9	1.85	1.59	-	0.47	0.07	-	-13.9	-
Aug, 09	69.9	2.03	2.47	-	0.1	0.11	-	21.4	-
Sep, 09	64.4	1.94	2.06	2.30	0.09	0.05	0.09	6.5	18.7
Oct, 09	46.0	-	1.31	2.59	-	0.08	0.26	-26.5	44.8
Nov, 09	45.7	-	1.48	3.57	-	0.07	0.1	-17.3	99.8

**Molting diet was used.*

- No meaningful comparison due to flock changing

Table 3. Summary of gaseous emission rate (mean ±standard error) for the three high-rise laying hen houses over 2-yr testing period (December 2007-December 2009)

Gases	Dietary Regimen		
	Control	DDGS	EcoCal
NH_3, g hen^{-1}d^{-1}	0.96±0.05	0.82±0.04	0.58±0.05
H_2S, mg hen^{-1}d^{-1}	1.79±0.16	1.91±0.13	5.39±0.46

Table 4. Manure compositions, productions, and values of three different diets

		Mean			S.E.		
		Control	DDGS	EcoCal	Control	DDGS	EcoCal
NH_3-N,%	As-is	0.8	0.9	1.2^a	0.1	0.0	0.0
	Dry	1.5	1.6	2.4^a	0.2	0.2	0.1
Org-N, %	As-is	1.4	1.4	0.8	0.2	0.5	0.1
	Dry	2.5	2.3	1.7	0.3	0.7	0.2
TKN, %	As-is	2.2	2.2	2.0	0.2	0.5	0.1
	Dry	4.0	3.9	4.1	0.2	0.7	0.2
P_2O_5, %	As-is	3.9	4.3	2.5^a	0.4	0.3	0.1
	Dry	7.1	7.7	4.9^a	0.4	0.3	0.1
K_20,%	As-is	3.0	3.0	1.9^a	0.3	0.1	0.1
	Dry	5.5	5.4	3.9^a	0.2	0.2	0.1
S, %	As-is	0.4^a	0.7^b	2.1^c	0.0	0.0	0.1
	Dry	0.7	1.2	4.2^a	0.0	0.2	0.2
pH		9.3^a	8.9^b	8.0^c	0.1	0.2	0.2
Moisture content, %		46.1	46.1	43.5	50.2	3.2	1.7
Manure production, lb hen^{-1} wk^{-1}		0.40	0.46	0.75			
N, $ ton^{-1}			1,013				
P_2O_5, $ ton^{-1}			1,228				
Manure value, $1000 hen^{-1} wk^{-1} *		5.87	7.35	8.95			

** Manure was priced at 70% of its nutrient value.*

Table 5. Summary of production data and economic analysis of three flocks* with two production cycles separated by molting (1st cycle: 21 to 69 wk of age; 2nd cycle: 1 to 42 wk of post-molting)

Parameters		Control	DDGS	EcoCal
Feed consumed, lb hen^{-1}	1st cycle	69.3	70.4	72.0
	2nd cycle	46.6	47.9	50.6
	Overall	115.9	118.3	122.6
Eggs produced, eggs hen^{-1}	1st cycle	283.1	270.1	278.6
	2nd cycle	151.5	154.3	167.8
	Overall	434.7	424.4	446.5
Egg mass, lb hen^{-1}	1st cycle	37.6	36.4	37.4
	2nd cycle	21.6	22.2	24.4
	Overall	59.2	58.6	61.9
Egg weight, g hen^{-1}	1st cycle	59.2	60.8	60.5
	2nd cycle	61.3	61.6	62.6
	Overall	60.6	61.3	61.7
Feed conversion, lb lb^{-1}	1st cycle	1.84	1.93	1.92
	2nd cycle	2.16	2.16	2.07
	Overall	1.96	2.02	1.98
Egg price, cents $dozen^{-1}$	1st cycle	84.25	84.23	84.89
	2nd cycle	84.74	84.52	85.54
	Overall	84.42	84.33	85.13
Manure Value, \$ hen^{-1}	1st cycle	0.29	0.36	0.44
	2nd cycle	0.25	0.31	0.38
	Overall	0.53	0.67	0.81
Egg Value, \$ hen^{-1}	1st cycle	19.94	19.03	19.77
	2nd cycle	10.74	10.91	12.00
	Overall	30.68	29.94	31.78
Feed Cost, \$ hen^{-1}	1st cycle	6.39	6.41	6.80
	2nd cycle	4.29	4.36	4.78
	Overall	10.68	10.78	11.59
Pullet cost, \$ hen^{-1}	1st cycle	2.96	2.96	2.96
	2nd cycle	-	-	-
	Overall	2.96	2.96	2.96
Other cost, \$ hen^{-1}	1st cycle	3.07	3.07	3.07
	2nd cycle	2.63	2.63	2.63
	Overall	5.70	5.70	5.70
Revenue- Feed Cost, \$ hen^{-1}	1st cycle	13.85	12.98	13.41
	2nd cycle	6.69	6.86	7.60
	Overall	20.54	19.84	21.01
Revenue- Total Cost, \$ hen^{-1}	1st cycle	7.82	6.95	7.38
	2nd cycle	4.06	4.23	4.97
	Overall	11.88	11.18	12.35

* *The number of hens per barn was estimated for each week if all started with 260,000 hens per barn using each week mortality rate.*

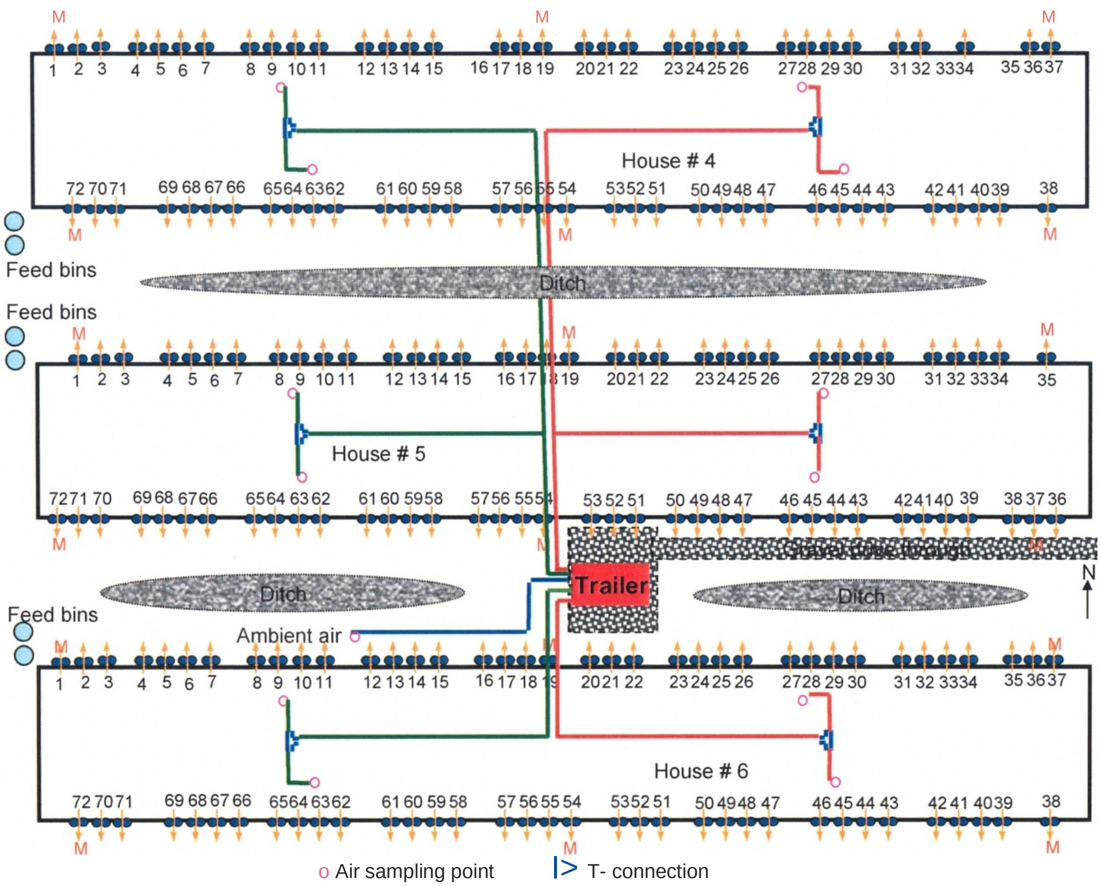


Figure 1. Schematic layout of air sampling ports in the high-rise laying hen houses monitored.

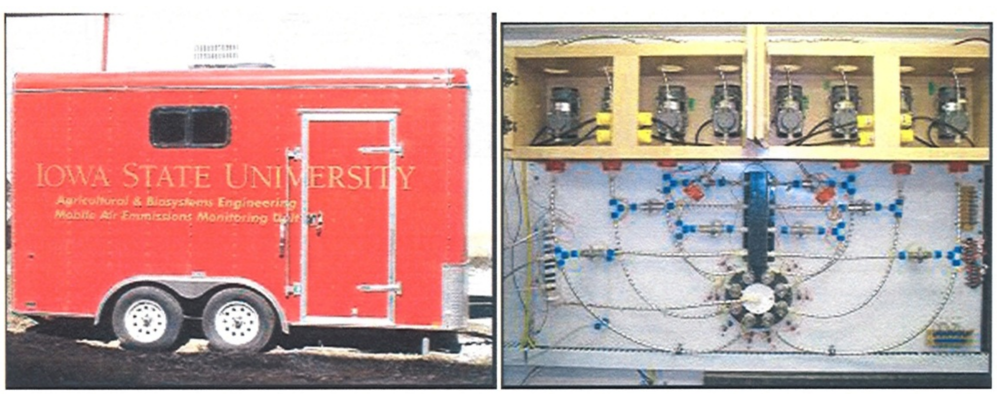


Figure 2. Mobile air emissions monitoring unit and positive-pressure gas sampling system.

Figure 3. Photoacoustic multi-gas (INNOVA 1412) and fluorescent (API101E) H2S analyzers.

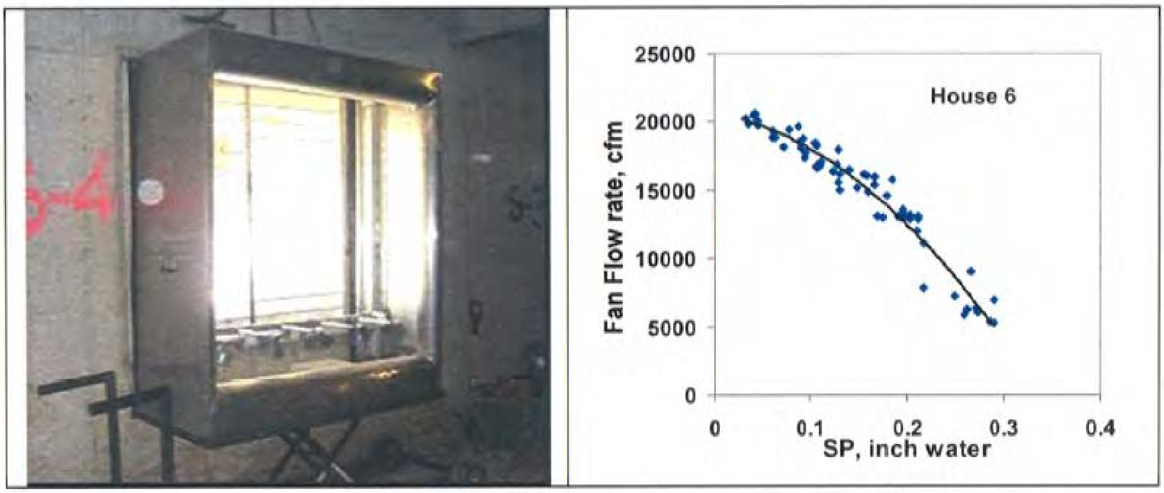
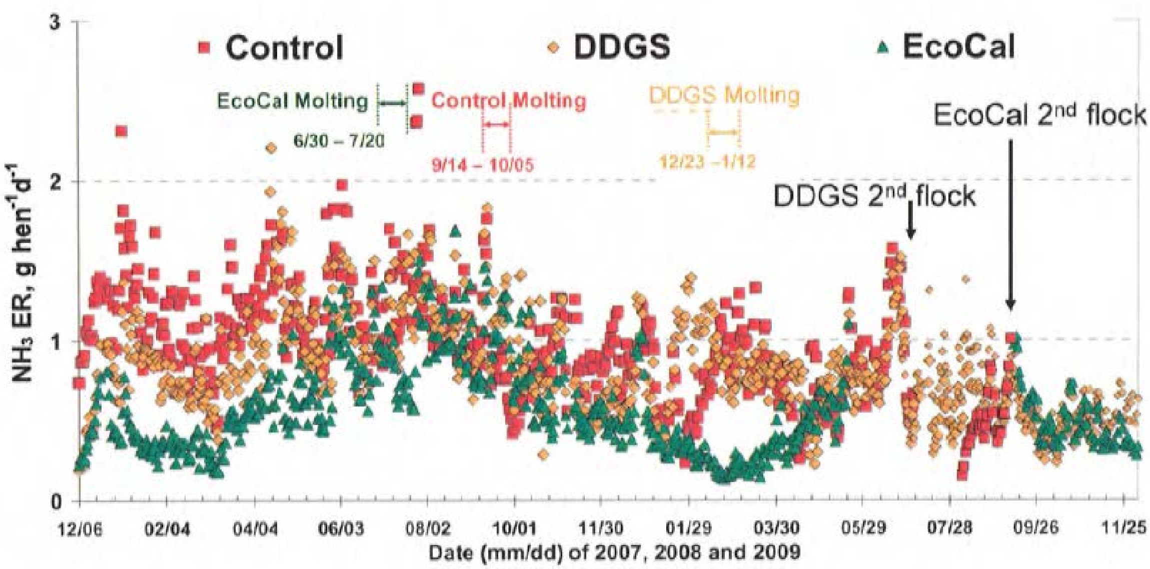
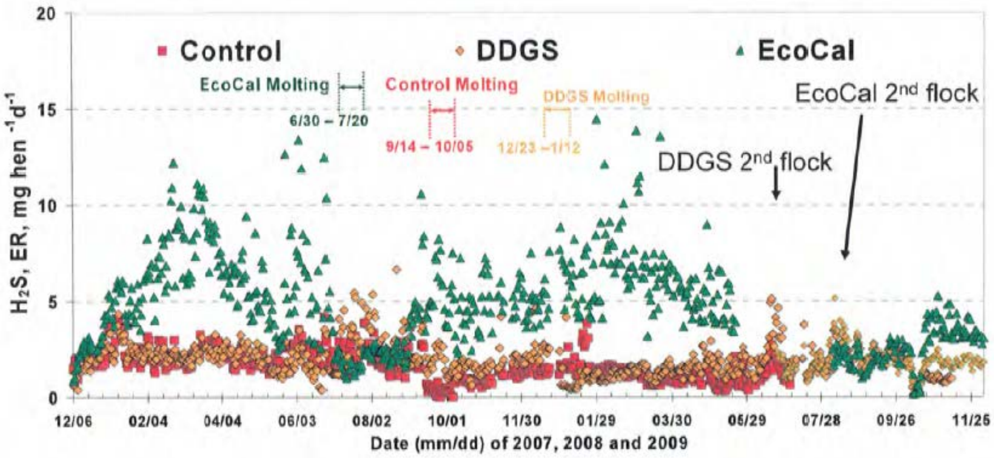


Figure 4. FANS unit and fan performance curve used to calculate the house ventilation rate.





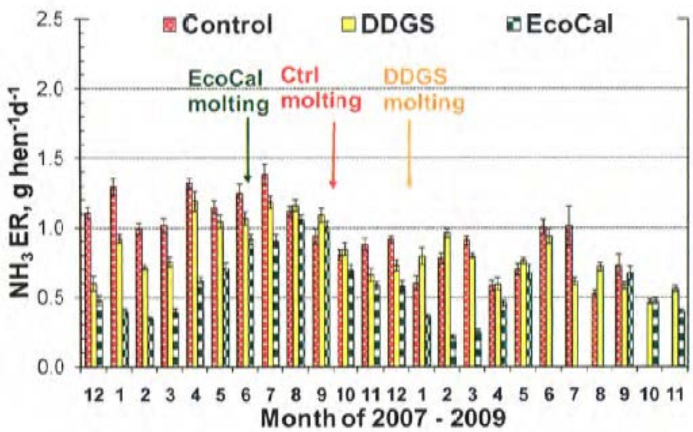


Figure 5. NH_3 and H_2S daily emission rates.

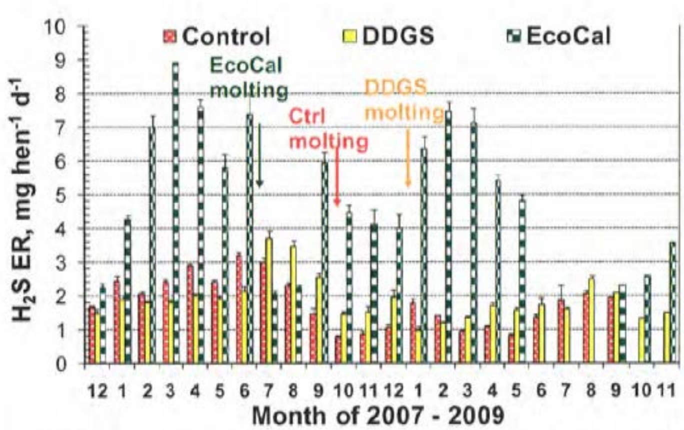


Figure 6. Monthly NH_3 and H_2S emission rate from the Control, DDGS and EcoCal house and outside temperature.

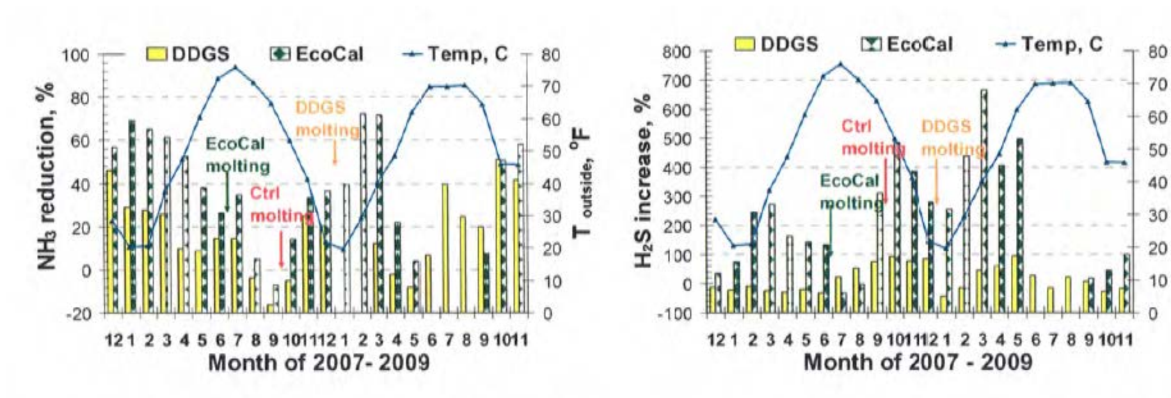


Figure 7. Monthly NH_3 and H_2S emission rate from the DDGS and EcoCal house and outside temperature.

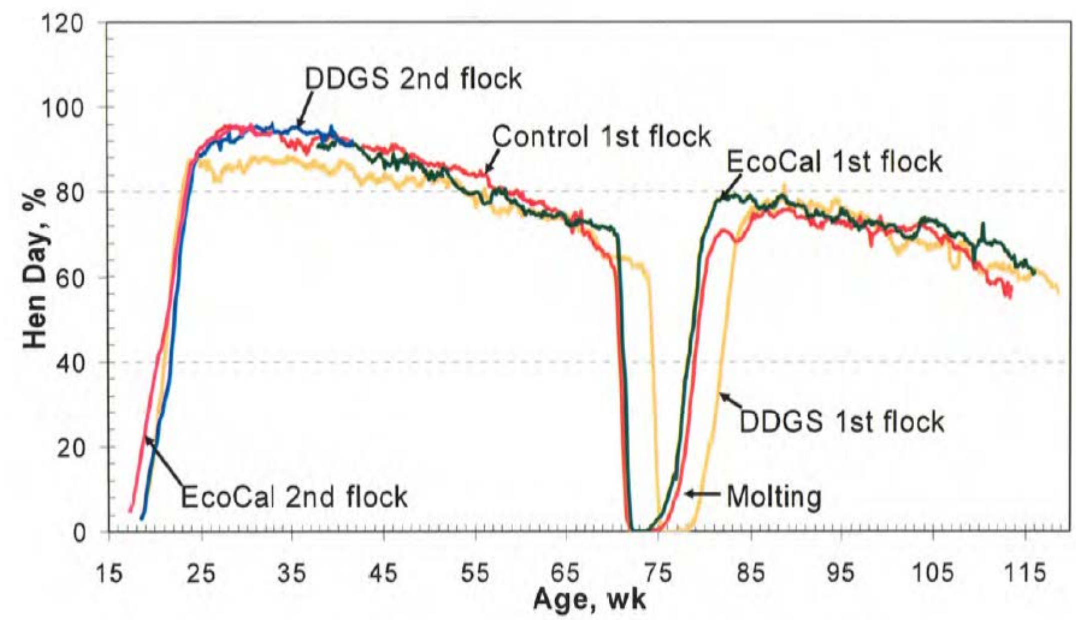


Figure 8. Egg production rates of the Control, DDGS and EcoCal fed hens.

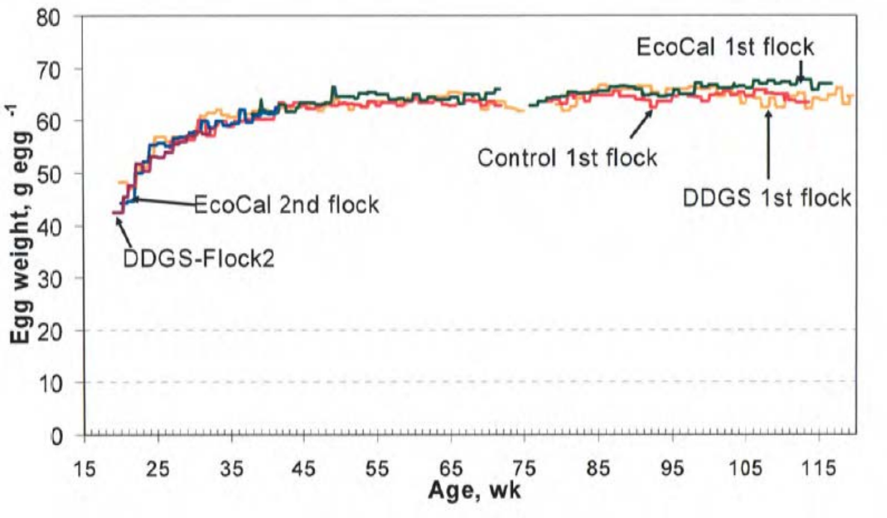


Figure 9. Egg mass of the Control DDGS and EcoCal fed hens.

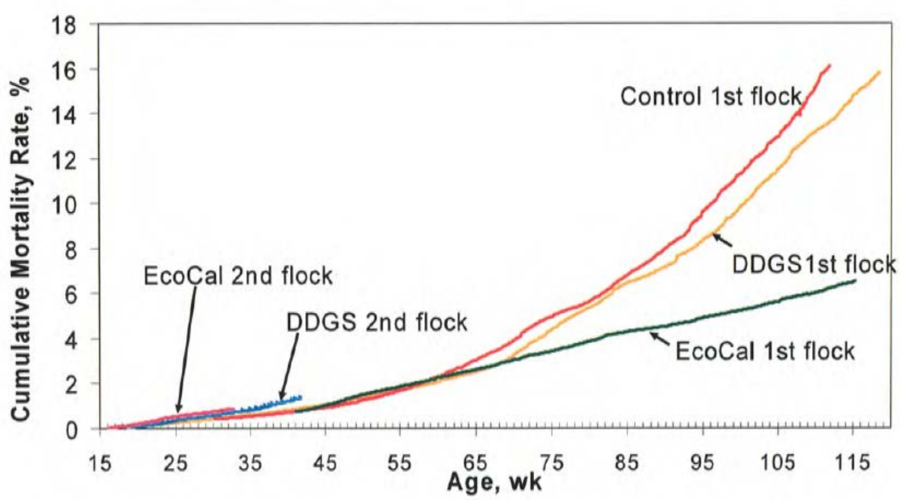


Figure 10. Cumulative mortality rates of the Control, DDGS and EcoCal fed hens.

Appendix A. ECONOMIC ANALYSIS

General Information

The economic analysis utilizes a budgeting approach to provide information on the revenues and production for the three diets considered. The control diet represents the diet typically utilized in the egg production unit. Results of the control diet are compared to results of the diet which included EcoCal and results of the diet which included DDGS. Information from the three different diets is used for the economic analysis.

Information in Table 1 shows the diet composition and ingredient prices for the three diets. Ingredient prices are standardized using the respective average ingredient prices over the 2007-2009 time period. Ingredient use is the actual amount utilized over the study period for the three respective diets. It is the actual amount consumed (disappearance) by the hens during the study period. The prices of corn, soybean meal, DDGS, meat and bone meal, fat and salt are the 2007-2009 average prices for Minneapolis, Chicago and Kansas City as published in the Feedstuffs newspaper. Dehydrated corn germ was priced at 112 percent of the DDGS price. EcoCal was priced at 8 cents/cwt and micronutrients were priced at $1,000 per ton. EcoCal and dehydrated corn germ prices were provided by industry personnel.

As shown in Table 1, the feed cost per metric ton is $203.19 for the control diet, $200.86 for the DDGS diet and $208.34 for the EcoCal diet. These diets were fed for a time period that allowed for completion of the full hen egg production cycle.

Table 1: Diet composition and prices for the three rations

	Percent of ingredients			2007-2009	Ingredient cost		
Ingredient	Control	DDGS	EcoCal	average price ($/metric ton)	Control	DDGS	EcoCal
Corn	63.57%	54.88%	58.23%	159.50	101.40	87.53	92.88
Soybean Meal	18.48%	15.94%	17.51%	335.11	61.93	53.40	58.69
Lime Blend	9.99%	9.95%	7.11%	26.73	2.67	2.66	1.90
DDGS	0.00%	10.00%	0.00%	142.52	0.00	14.25	0.00
EcoCal	0.00%	0.00%	6.16%	176.21	0.00	0.00	10.85
Corn Germ Dehy	2.77%	3.98%	5.69%	159.63	4.42	6.36	9.08
Meat & Bone 50 N	3.89%	3.04%	3.07%	336.90	13.12	10.25	10.33
Fat	0.63%	1.17%	1.57%	526.50	3.29	6.18	8.27
Salt	0.34%	0.32%	0.35%	43.71	0.15	0.14	0.15
Micro-ingredients	0.32%	0.71%	0.32%	1000.00	3.20	7.09	3.19
Transport and milling ($/ton)					13.00	13.00	13.00
Feed price ($/ton)					$203.19	$200.86	$208.34

Egg prices were also standardized using the 2007-2009 Urner Barry prices. These prices were utilized with the information on level of egg production for the three diets studied.

Manure Value Estimation

The amount of manure produced by the hens with each diet was measured. The manure was tested to determine the amount of nitrogen, phosphorus and potassium in the manure. The level of moisture in the manure was also determined. The level of dry manure was determined and then the amount of N and P_2O_5 was determined. Potassium was not considered as it was not utilized by the operation in determining the manure value. Nitrogen and P_2O_5 prices were obtained from USDA NASS published prices. The manure was then priced at 70 percent of its nutrient value as there would be field application costs. It was indicated that the manure pricing standard is to sell the manure at about 70 percent of its nitrogen and phosphorus value.

Information in Table 2 shows that the manure value per 100,000 hens housed was the highest with the EcoCal diet at $73,924 or $895 per week. It was the lowest with the control diet at $48,466 or $587 per week for the control diet. The DDGS diet had a manure value of $60,728 or $735 per week. The moisture content was the greatest for the EcoCal diet. The level of manure production was also the greatest for the EcoCal diet, 1,393 tons of dry manure. This compared to 803 tons of dry manure for the control diet.

Table 2: Manure production and value for every 100,000 hens housed

	Control	DDGS	EcoCal
Wet Manure Production (metric tons)	1,490	1,723	2,809
Moisture,%	46.1	43.5	50.4
Dry Manure Production (metric tons)	803	973	1,393
TKN,%	4.0	3.9	4.4
P_2O_5,%	7.1	7.7	4.6
Nitrogen (metric tons)	32.09	38.21	60.61
Phosphorus (metric tons)	24.68	32.58	28.03
Nitrogen price ($/metric ton)	1,117	1,117	1,117
Phosphorus price ($/metric ton)	1,353	1,353	1,353
Manure Nutrients Value	69,238	86,754	105,606
Manure Value at 70%	48,466	60,728	73,924
Manure Value per ton at 70%	60.34	62.40	53.07
Weeks of accumulated manure	82.57	82.57	82.57
Manure Value per week	587	735	895

Estimation of Returns and Costs

The economic projection of returns and costs will be based on an egg production barn of 100,000 hens. Information will be provided for the two production cycles of pre molt (first cycle) and post molt (second cycle). Information was available on hen mortality allowing for tracking the number of hens available weekly with each diet. Revenue and cost information is available per 100,000 hens housed and per 30 dozen case of eggs produced. Information on a per hen basis can be determined by dividing by 100,000.

Estimation of Returns and Costs Pre Molt (first cycle)

General productivity and egg price information is provided in Table 3. Birds fed the DDGS diet experienced the lowest mortality rate and birds fed the control diet experienced the highest mortality rate. Hen day production rate was 7% (3%) lower for the birds fed the DDGS diet (EcoCal diet) than for the birds fed the control diet. The egg weight was the lowest for the control diet. The egg price was slightly higher for the EcoCal diet. Feed conversion (kg. feed/kg. egg) was 7% (6%) higher for the birds fed the DDGS diet (EcoCal diet) than for the birds fed the control diet. Feed conversion (kg feed/dozen egg) was 9% (8%) higher for the birds fed the DDGS diet (EcoCal diet) than for the birds fed the control diet.

Table 3: Production information pre-molt (weeks 21 to 69 of age)

	Control diet	DDGS diet	Ecocal diet	DDGS-Control		Ecocal-Control	
Date	Mean	Mean	Mean	Dif	%	Dif	%
Mortality (#/100 hens/day)	0.0105	0.0086	0.0097	-0.0019	-18%	-0.0008	-7%
Eggs (#/100 hens)	85.36	79.61	82.45	-5.75	-7%	-2.91	-3%
Water (ml/bird)	169.97	169.70	177.69	-0.27	0%	7.72	5%
Feed cons (g/hen/day)	92.69	94.12	96.68	1.43	2%	3.99	4%
Water/Feed ratio	1.83	1.80	1.84	-0.03	-2%	0.00	0%
Body Weight (Kgs)	1.51	1.51	1.54	0.00	0%	0.03	2%
Temp, F	70.08	68.96	68.42	-1.12	-2%	-1.66	-2%
Egg weight (g/egg)	60.05	61.03	60.91	0.99	2%	0.87	1%
Egg Price (cents/dozen)	84.54	84.54	85.16	0.00	0%	0.62	1%
Egg Mass (g/hen/day)	51.26	48.59	50.22	-2.67	-5%	-1.03	-2%
Feed Conversion							
(kg feed/kg egg)	1.81	1.94	1.92	0.13	7%	0.12	6%
(kg feed/dozen)	1.30	1.42	1.41	0.12	9%	0.10	8%

The number of layers per barn was estimated for each week with the beginning inventory of laying hens at 100,000 per barn for each diet. The weekly mortality rate was used to determine the number of layers remaining each week. Hen-day production (eggs produced per 100 hens per day) was used to determine the eggs produced every week for the laying population. Weekly feed consumption per hen was used to determine the total feed consumed each week for the hen population determined above. The egg mass per week was determined by multiplying the total eggs per week by the egg weight.

The pre molt (first cycle) was during the time when the hens were 21-69 weeks of age: a 49 week period. Information is available for all three treatments for this time period. Thus, for example, total feed consumed during the pre molt cycle was determined as the sum of the weekly feed consumption over weeks 21 through 69. The similar procedure was used to determine the number of eggs produced and the egg mass.

The egg price utilized was determined using the 2007-2009 Urner Barry prices minus a discount for washing, grading, packaging, etc (32 cents for the period between January 2007 to March 2009, 35 cents for the period after April 2009). The pullet cost utilized was $2.96/pullet. The full pullet cost was considered as a cost for the pre molt time period analysis. The other costs (which include labor, utilities, depreciation, insurance, etc.) were estimated to be 27.2 cents/month per hen housed. The after molt (second cycle) was defined as weeks 1 through 42 after molting (second cycle). In total each diet comparison covers a 91 week period; 49 weeks pre molt and 42 weeks post molt.

Information is also available for this period for each of the three treatments. The calculations are similar to the pre molt (first cycle) with the exception that the pullets cost is $0 for this period. As indicated above, it is assumed that the full pullet cost is covered in the first cycle and the feed cost for the birds during the molting period is considered in the second cycle or post molt time period.

Information for return and cost for the 100,000 hen facility pre molt is provided in Table 4. This shows that the feed cost per dozen eggs was the lowest for the control diet at $.27 per dozen eggs. The feed cost per dozen eggs was $.28 for the DDGS diet and $.29 for the EcoCal diet. The total feed consumed, eggs produced, egg mass, manure value, egg value, feed cost, pullet cost and other cost is also provided. The revenue less the total cost is greatest for the control diet at $781,860. The revenue less total cost for the EcoCal diet is$ 738,269 while it was $695,107 for the DDGS diet.

Table 4: Return and cost information for every 100,000 hens housed. Pre-molt (weeks 21 to 69 of age).

	Units	Control	DDGS	Ecocal	DDGS-Control	Ecocal-Control
Feed consumed	tons	3,143	3,193	3,265	50	122
Eggs produced	eggs	28,311,09	27,014,41	27,863,59	-1,296,677	-447,501
Egg mass	tons	1,708	1,652	1,698	-55	-9
Manure Value	$	28,761	36,038	43,869	7,276	15,107
Egg Value	$	1,994,49	1,903,227	1,977,322	-91,264	-17,169
Feed Cost	$	638,615	641,381	680,145	2,766	41,530
Pullet cost	$	296,000	296,000	296,000	0	0
Other cost	$	306,777	306,777	306,777	0	0
Revenue - Feed Cost	$	1,384,63	1,297,884	1,341,046	-86,754	-43,592
Revenue - Total Cost	$	781,860	695,107	738,269	-86,754	-43,592
Feed Cost per Kg	$/kg	0.37	0.39	0.40	0.01	0.03
Feed Cost per dozen	$/dozen	0.27	0.28	0.29	0.01	0.02

The manure value was the greatest for the EcoCal diet ($43,869) and the lowest for the control diet ($28,761). Thus, the difference in revenue less total cost would be greater if a value was not placed on the manure.

Table 5 provides similar information per 30 dozen case of eggs produced. Return over total cost was $9.94 for the control diet, $9.54 for the EcoCal diet, and $9.26 for the DDGS diet.

Table 5: Return and cost information per 30 dozen case produced. Pre-molt (weeks 21to 69 of age).

	Units	Control	DDGS	Ecocal	DDGS-Control	Ecocal-Control
Feed consumed	Kgs	39.97	42.55	42.18	2.59	2.21
Eggs produced	eggs	360.00	360.00	360.00	0.00	0.00
Egg mass	Kgs	21.71	22.02	21.94	0.31	0.23
Manure Value	$	0.37	0.48	0.57	0.11	0.20
Egg Value	$	25.36	25.36	25.55	0.00	0.19
Feed Cost	$	8.12	8.55	8.79	0.43	0.67
Pullet cost	$	3.76	3.94	3.82	0.18	0.06
Other cost	$	3.90	4.09	3.96	0.19	0.06
Revenue - Feed Cost	$	17.61	17.30	17.33	-0.31	-0.28
Revenue - Total Cost	$	9.94	9.26	9.54	-0.68	-0.40

Evaluation of Return and Costs Post Molt (second cycle)

Information for the post molt time period (42 weeks) is provided in Tables 6, 7, and 8. Production information such as egg weight and mass, feed conversion, and egg price is in Table 6.

Birds fed the EcoCal diet experienced the lowest mortality rate and birds fed the control diet experienced the highest mortality rate in the post-molt period. This is similar to the pre molt period. Hen day production rate was 2% (7%) higher for the birds fed the DDGS diet (EcoCal diet) than for the birds fed the control diet. The egg weight was the lowest for the control diet. The egg price was almost 1 cent higher for the EcoCal diet. Feed conversion (kg. feed/kg. egg) was 7% lower for the birds fed the EcoCal diet than for the birds fed the control diet. Feed conversion (kg feed/dozen egg) was 5% lower for the birds fed the EcoCal diet than for the birds fed the control diet.

Table 6: Production information post-molt (weeks 1 to 42 post-molt)

SECOND CYCLE	Control diet	DDGS diet	Ecocal diet	DDGS-Control		Ecocal-Control	
Date	Mean	Mean	Mean	Dif	%	Dif	%
Mortality (#/100 hens/day)	0.0470	0.0411	0.0114	-0.0059	-13%	-0.0356	-76%
Eggs (#/100 hens)	57.47	58.44	61.77	0.97	2%	4.30	7%
Water (ml/bird)	155.54	158.48	172.20	2.94	2%	16.65	11%
Feed cons (g/hen/day)	91.58	93.77	93.65	2.19	2%	2.07	2%
Water/Feed ratio	1.70	1.69	1.84	-0.01	0%	0.14	8%
Body Weight (Kgs)	1.58	1.56	1.67	-0.01	-1%	0.09	6%
Temp,F	69.25	71.15	68.59	1.90	3%	-0.66	-1%
Egg weight (g/egg)	61.32	61.63	62.60	0.31	1%	1.28	2%
Egg Price (cents/dozen)	85.05	84.87	85.84	-0.18	0%	0.79	1%
Egg Mass (g/hen/day)	35.24	36.02	38.67	0.78	2%	3.43	10%
Feed Conversion							
(kg feed/kg egg)	2.60	2.60	2.42	0.00	0%	-0.18	-7%
(kg feed/dozen)	1.91	1.93	1.82	0.01	1%	-0.09	-5%

Information per 100,000 hens housed is provided in Table 7. This shows that during the post molt time period the feed cost per dozen eggs produced was essentially the same for all three diets: $.34 per dozen eggs. The hens on the EcoCal diet produced more eggs but also ate more feed in total. Revenue over total cost per hen housed was the highest for the EcoCal diet - $4.97 per hen housed. It was $4.23 per hen housed for the DDGS diet and $4.06 for the control diet.

Table 7: Return and cost information for every 100,000 hens housed. Post-molt (weeks 1 to 42 post-molt)

	Units	Control	DDGS	Ecocal	DDGS-Control	Ecocal-Control
Feed consumed	tons	2,113	2,172	2,297	60	184
Eggs produced	eggs	15,154,115	15,429,257	16,782,043	275,142	1,627,928
Egg mass	tons	978	1,005	1,108	27	130
Manure Value	$	24,652	30,889	37,602	6,237	12,949
Egg Value	$	1,074,005	1,091,183	1,200,460	17,178	126,455
Feed Cost	$	429,277	436,366	478,466	7,089	49,188
Pullet cost	$	0	0	0	0	0
Other cost	$	262,952	262,952	262,952	0	0
Revenue - Feed Cost	$	669,380	685,706	759,596	16,326	90,215
Revenue- Total Cost	$	406,428	422,754	496,644	16,326	90,215
Feed Cost per Kg	$/kg	0.44	0.43	0.43	0.00	-0.01
Feed Cost per dozen	$/dozen	0.34	0.34	0.34	0.00	0.00

Information per 30 dozen case of eggs is provided in Table 8. It is interesting to see how the lower mortality rate of the birds fed the EcoCal diet resulted in a lower non-feed, non-pullet cost per egg case produced. This lower cost and a slightly higher egg price resulted in almost $1.00/case advantage of the EcoCal over the control diet for the post-molt period.

Table 8: Return and cost information per 30 dozen case produced. Post-molt (weeks 1 to 42 post-molt)

	Units	Control	DDGS	Ecocal	DDGS-Control	Ecocal-Control
Feed consumed	Kgs	50.19	50.69	49.26	0.50	-0.93
Eggs produced	eggs	360.00	360.00	360.00	0.00	0.00
Egg mass	Kgs	23.24	23.46	23.77	0.22	0.53
Manure Value	$	0.59	0.72	0.81	0.14	0.22
Egg Value	$	25.51	25.46	25.75	-0.05	0.24
Feed Cost	$	10.20	10.18	10.26	-0.02	0.07
Pullet cost	$	0.00	0.00	0.00	0.00	0.00
Other cost	$	6.25	6.14	5.64	-0.11	-0.61
Revenue- Feed Cost	$	15.90	16.00	16.29	0.10	0.39
Revenue - Total Cost	$	9.66	9.86	10.65	0.21	1.00

Information on Returns and Costs Entire Production Period- Pre molt and Post Molt

Information for the entire 91 week egg production period, 49 weeks pre molt and 42 weeks post molt, are provided in Tables 9, 10, and 11. The biggest production differences are in the mortality rate and feed efficiency.

Table 9: Production information for both cycles combined

	Control diet	DDGS diet	Ecocal diet	DDGS-Control		Ecocal-Control	
Date	Mean	Mean	Mean	Dif	%	Dif	%
Mortality (#/housed)	0.1835	0.1566	0.0679	-0.0268	-15%	-0.1156	-63%
Eggs (#/hen housed)	434.65	424.44	446.46	-10.22	-2%	11.80	3%
Water (liters/bird)	104.03	104.80	111.57	0.77	1%	7.54	7%
Feed cons (Kg/hen housed)	52.56	53.66	55.61	1.10	2%	3.05	6%
Water/Feed ratio	1.98	1.95	2.01	-0.03	-1%	0.03	1%
Body Weight (Kgs)	1.54	1.53	1.60	-0.01	-1%	0.06	4%
Temp,F	69.70	69.97	68.50	0.27	0%	-1.20	-2%
Egg weight (g/egg)	60.64	61.31	61.69	0.67	1%	1.06	2%
Egg Price (cents/dozen)	84.72	84.66	85.41	-0.06	0%	0.70	1%
Egg Mass (Kg/hen)	26.36	26.02	27.54	-0.33	-1%	1.19	5%
Feed Conversion							
(kg feed/kg egg)	1.99	2.06	2.02	0.07	3%	0.02	1%
(kg feed/dozen)	1.45	1.52	1.49	0.07	5%	0.04	3%

Feed cost per dozen eggs was $.30 for the DDGS diet, $.31 for the EcoCal diet and $.29 for the control diet (Table 10). Egg mass was the greatest for the EcoCal diet (2,806 tons) and the lowest for the DDGS diet (2,658 tons). Feed cost per kg of eggs produced was $.41 for the EcoCal and DDGS diets and $.40 for the control diet. Revenue over total cost was $12.35 per hen for the EcoCal diet, $11.88 for the control diet and $11.18 for the DDGS diet.

Table 10:Return and cost information for every 100,000 hens housed (both cycles combined)

	Units	Control	DDGS	Ecocal	DDGS-Control	Ecocal-Control
Feed consumed	tons	5,256	5,366	5,561	110	305
Eggs produced	eggs	43,465,211	42,443,675	44,645,638	-1,021,536	1,180,427
Egg mass	tons	2,686	2,658	2,806	-28	121
Manure Value	$	53,414	66,927	81,470	13,513	28,057
Egg Value	$	3,068,496	2,994,410	3,177,782	-74,086	109,286
Feed Cost	$	1,067,892	1,077,746	1,158,611	9,854	90,718
Pullet cost	$	296,000	296,000	296,000	0	0
Other cost	$	569,729	569,729	569,729	0	0
Revenue - Feed Cost	$	2,054,018	1,983,590	2,100,642	-70,427	46,624
Revenue - Total Cost	$	1,188,289	1,117,861	1,234,912	-70,427	46,624
Feed Cost per Kg	$/kg	0.40	0.41	0.41	0.01	0.02
Feed Cost per dozen	$/doze	0.29	0.30	0.31	0.01	0.02

Information per 30 dozen case of eggs is provided in Table 11. Feed cost and manure value were the 2 most important traits affecting the economic result per 30 dozen case produced. EcoCal and the control diet resulted in similar economic results with a slight difference in favor of the EcoCal diet. The DDGS diet resulted in $0.36/case (1.20 cents/dozen) lower profit.

Table 11: Return and cost information per 30 dozen case produced (both cycles combined)

	Units	Control	DDGS	Ecocal	DDGS-Control	Ecocal-Control
Feed consumed	Kgs	43.53	45.51	44.84	1.98	1.31
Eggs produced	eggs	360.00	360.00	360.00	0.00	0.00
Egg mass	Kgs	22.24	22.54	22.63	0.30	0.38
Manure Value	$	0.44	0.57	0.66	0.13	0.21
Egg Value	$	25.41	25.40	25.62	-0.02	0.21
Feed Cost	$	8.84	9.14	9.34	0.30	0.50
Pullet cost	$	2.45	2.51	2.39	0.06	-0.06
Other cost	$	4.72	4.83	4.59	0.11	-0.12
Revenue - Feed Cost	$	17.01	16.82	16.94	-0.19	-0.07
Revenue- Total Cost	$	9.84	9.48	9.96	-0.36	0.12

A few points are in order that likely impact the productivity and economic results. It appears that the DDGS hens were a new genetic base for the operation. Some production requirements of the hens needed to be adjusted. In the process of determining these adjustments pre molt production was lower. Secondly, there was a slight gap in information for the EcoCal diet. Extrapolation was needed for week 34 through 39. Linear interpolation was used to approximate the results during this time. Different forms of interpolation and regression was evaluated but they did not prove to be any better than linear interpolation.

FINAL PROJECT REPORT

Egg Production, Ammonia Emission, Manure Nutrients, and Economics of Laying Hens Fed Distiller Dried Grain Diets

Natural Resources Conservation Service-Conservation Innovation Grant (NRCS-CIG) Demonstration Project-

Pennsylvania Site

Submitted to

United Egg Producers

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Egg Production, Ammonia Emission, Manure Nutrients,

and Economics of Laying Hens fed DDGS Diets

ABSTRACT

A USDA Natural Resources Conservation Service, Conservation Innovation Grant project coordinated by the United Egg Producers (UEP) conducted concurrent demonstrations in Iowa (IA) and Pennsylvania (PA) at commercial laying hen facilities. The goal was to document manure nutrient and gas emission improvements through the use of dried distiller's grain with solubles (DDGS) diets and/or other dietary modifications while maintaining or improving hen productivity. Results of the PA trial are presented here. Diets containing 10% corn DDGS with (D+P) or without (D) the probiotic Provalen™ were compared to a corn-soybean based control diet (CON). The isocaloric, amino acid balanced diets were fed to three groups of 39,800 Lohmann hens in one house. Hens were 20-65 wk of age with each diet provided to 2 of 6 rows of stacked cages with manure belts (six decks high). Feed intake, water consumption, hen body weight (BW), egg production (EP), egg case weight, mortality, feed cost (FC), and egg income (EI) were provided weekly by the cooperating egg company. Replicated monthly data, including egg weight (EW), albumen height (AH), Haugh units (HU), yolk color (YC), shell strength (SS) and shell thickness (ST), were determined from eggs collected from six 4-cage sections of hens on each diet. Replicated monthly samples of hen manure (fresh and from storage) were analyzed for moisture and major nutrients. Ammonia (NH_3) gas measurements utilized a non-steady state flux chamber method coupled with photoacoustic infrared gas analyzer. There was no clear trend in the magnitude of NH_3 emissions relative to the diets within the hen house as measured on the manure belt. At 32 and 36 wks of age, NH_3 emissions were significantly ($P < 0.10$) higher in D while D+P and CON were lower and similar. At 48 and 52 wks, NH_3 emissions from D were similar to D+P and significantly lower than CON. There was no significant impact of diet on BW, EW, HU, SS, or ST ($P = 0.10$ to 0.66), however, CON hens had lower EP, AH, and YC compared to D and D+P hens (PO.OS). Fresh manure total phosphorus (P_2O_5) was higher for CON samples ($P < 0.05$) while other major agronomic nutrients and moisture were not significantly different among treatments. Stored CON manure samples had increased moisture and NH_4-N compared to those of D and D+P treatments ($P < 0.10$). Weekly El minus FC averaged $6,144, $6,216, and $6,204 for the CON, D, and D+P diets, respectively.

INTRODUCTION

According to the U.S. Environmental Protection Agency (EPA), egg farming contributed about one quarter of ammonia gas (NH_3) emissions from the animal-agriculture sectors. Many management strategies are reported to mitigate NH_3 emission with reduced dietary protein becoming a strategy widely applied in the industry (Liang et al., 2005). Dried distiller's grain with solubles (DDGS) has become a feed alternative for poultry due to its greater availability from increased production of ethanol for fuel and its competitive price supplying protein and other important nutrients. Up to 32% inclusion of DDGS did not impact second-cycle hen performance (Loar II et al., 2010) while broiler growth and feed conversion was not impacted by up to 12% DDGS during the growing period (Dale and Batal, 2003). Lumpkins et al., 2005 suggested that the maximum DDGS inclusion level for commercial laying hen diets be 10 to 12% to avoid reduction in hen-day egg production, particularly on low density diets.

There have been reports from laboratory and field studies of DDGS-diets offering reduced NH_3 emissions (Roberts et al. 2006; Hale 2008). A diet containing 10% DDGS fed to laying hens in a commercial production environment reduced manure NH_3 emissions an average of 16.9% (Hale, 2008) with ranges from +6.3% to -33.3% compared to control groups. Wu-Haan et al. (2009) found a significant linear decrease in NH_3 emitted per kg nitrogen (N) intake during a laying hen laboratory study with 0, 10 and 20% DDGS diets. Our project goal was to document manure nutrient and gas emissions during the use of DDGS diets while maintaining or improving hen productivity and egg quality.

Materials and Methods

United Egg Producers (UEP) coordinated concurrent demonstrations of DDGS fed hens in Iowa and Pennsylvania (PA) at commercial facilities. Results of the PA trial presented here were conducted at a commercial hen farm set up for research trials (Picture 1) with laboratory evaluations at The Pennsylvania State University (Penn State). Lohmann LSL-Lite pullets (119,400) were placed into the house at 18 wk of age and distributed randomly into 13,104 cages with 9 to 10 birds per cage (61x66x46 cm; LxWxH) and fed a commercial diet based on corn and soybean meal. The cages were arranged in 6 rows of 6 tiers with 2-cages back-to-back. Each tier-row of cages was equipped with an egg belt in the front and a manure belt underneath. One-third of the manure was removed from the house each day by running all belts for 6 min. Therefore, each belt had 1, 2 and 3d manure accumulation depending on proximity to the belt scraper at the cross-conveyer. The feeding trial began when hens were 22 wk old. Environment and manure information was collected monthly during site visits to the facility starting with 23 week old hens in July 2008 and concluding when hens were 60 weeks of age in late April 2009. Hen, egg, economic and other farm data were collected weekly to 64 wks. Eggs were sold to the breaker market so size and grade data were not available.

Pictures 1. Top three tiers of stacked manure-belt cages on the Pennsylvania study farm, while three more tiers of cages are below the grated walkway. Exterior view of egg handling room at front end of commercial poultry house that is set up to feed three diets in one house.

Diets and hen performance

There were three diets used in this study: a control diet based on corn and soybean meal (CON), CON plus 10% corn DDGS (D) and CON plus 10% DDGS and 0.5g/kg probiotics (D+P). The probiotic used was Provalen™ (Agtech Product,Inc., Waukesha, WI),which contained dried *Bacillus subtilis* and *Bacillus licheniformis* fermentation product (1.5 x 108 CFU/g). Dietary treatments were formulated to contain approximately 1,300 kcal ME/kg and 16.9 to 19.0% crude protein (Table 1). All other nutrients satisfied the NRC nutrient recommendations (NRC,1994). Each of the diets was distributed automatically from one of three feed bins to two rows of cages per treatment (Figure 1). Feeding times were staggered throughout the 16 h light period each day and water was provided ad libitum with nipple drinkers in each cage.

Table 1. Mean formulated diet nutrient concentrations

	Dietary nutrient (%)[1,2]					
Diet	CP	ME	Lys	Met+Cys	Ca	AvP
Control	16.892	1298	0.876	0.706	4.308	0.426
DDGS	17.131	1297	0.886	0.709	4.304	0.425
DDGS+Provalen	17.159	1297	0.886	0.709	4.305	0.425

[1]CP =crude protein; Lys =lysine; Met+Cys =methionine+ cysteine; Ca = calcium; AvP = available phosphorus
[2] All nutrient values are reported on an "as is" basis

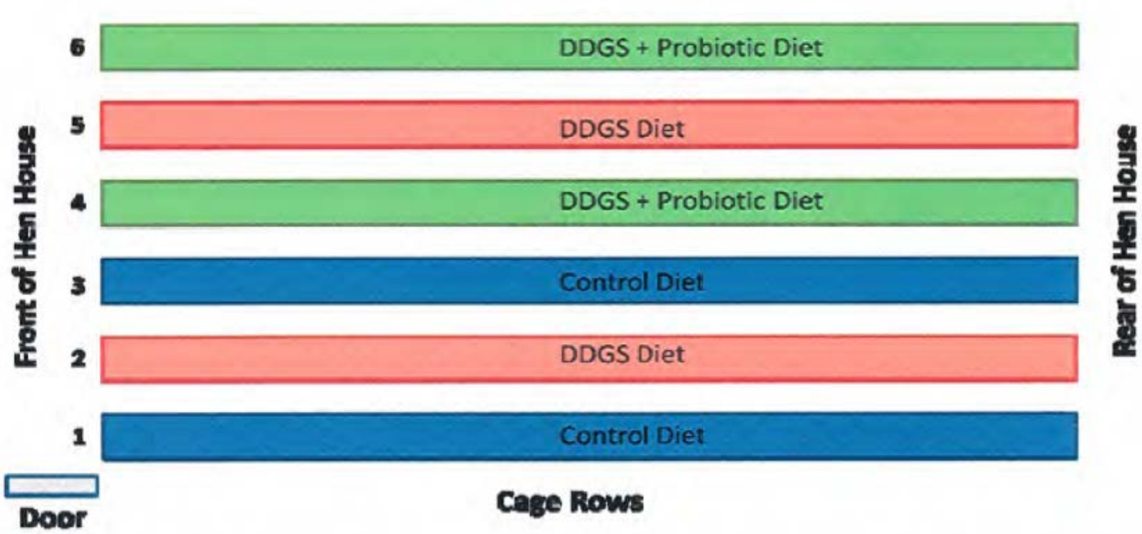

Figure 1. Plan view of layout of diets in six-row belt cage battery hen house with two rows dedicated to each diet with its own supply feed bin.

Replicated data were collected during monthly farm visits (see below) and weekly from company-supplied records [egg production (EP), egg weight (EW), feed consumption, water intake, hen body weight (BW), egg case weight, mortality, feed cost (FC), and egg income (EI)]. A second measure of BW was determined during monthly site visits using a portable scale on hens in designated sections of the building representing each diet (Picture 2). In these 4-cage designated sections (Figure 2), eggs were collected for 5 to 14 h from 3 locations per row (6 locations per treatment representing 558 hens total) and refrigerated at 5°C for maximum of 7 d before external (EW,shape, air cell, specific gravity) and internal quality of eggs [albumen height (AH), Haugh units (HU), yolk color (YC), shell strength (SS) and shell thickness (ST)] were determined at Penn State laboratories. Because feed consumption was monitored automatically per row basis, EP over FC was determined on an average basis for each treatment. Statistical differences among treatments for replicated monthly production (and manure agronomic nutrient data, described later) were detected using a one-way ANOVA. Data analysis was done using the PROC GLM procedure (SAS , 2003). Mean comparisons were made using Tukey's procedure and p-values P≤0.05 were deemed significant.

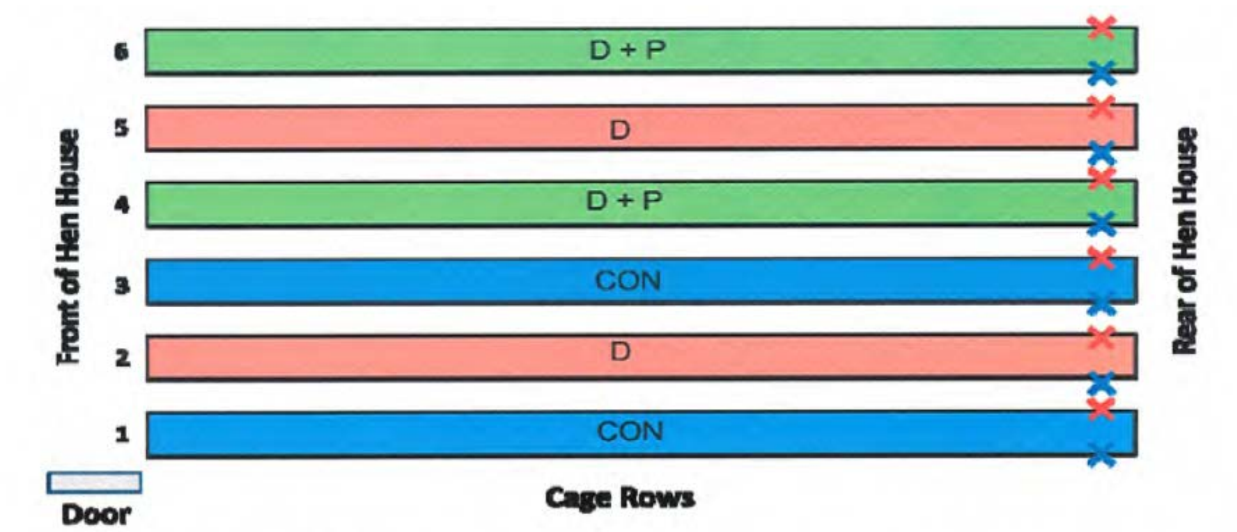

Figure 2. Hen body weight and population and eggs collected for quality characteristics were obtained from four- cage sections in same area where gas flux measurements were taken. At red X samples were from top and bottom tiers of upper deck of cages with three replications per row for six per diet treatment.

Pictures 2.Hen weight and egg samples were collected during monthly site visits.

Ammonia emissions

With three dietary treatments under study in one house it was necessary to sample NH_3 emission at its source. A flux chamber method was used for this purpose with the primary benefit being the ability to measure treatment effects among various surfaces. Fluxes measured were not designed to simulate actual emission,as measured from the building, but instead offered a relative comparison of ammonia flux from manure of each diet. Ammonia flux was determined using a non-steady-state flux chamber based on a design of Woodbury et al. 2006. A 29 cm diameter stainless-steel, bowl-topped,skirted (28 cm H), flux chamber (volume 0.027 m^3) was connected to a photoacoustic infrared analyzer (Model 1412,Innova Air Tech Instruments, Ballerup,Denmark). Detection limit for ammonia was 0.2 ppm; sensitivity to water vapor compensated. Detection limits for greenhouse gases evaluated were: CH_4 0.1ppm; CO_2 5.1ppm; N_2O 0.03 ppm. These three greenhouse gases were not the focus of the project, but all data are included in this report with some findings noted in results. The analyzer was calibrated annually by California Analytical Instruments (Orange, CA) at expected gas ranges and humidity level for manure measurements. The chamber sampling ports connected to the analyzer via 1m long Teflon™-lined tubing. The chamber had a small internal,12 V battery-operated circulation fan (Picture 3). Providing air velocity over the enclosed manure has been shown to result in more realistic ammonia flux measurements (Blanes-Vidal et al. 2006; Ni,1999). Deployment of the non-steady state flux chamber for a short time was desirable to minimize interference with accumulating gases and to monitor multiple locations to better capture variability in emissions from potentially non-uniform emission sources.

Picture 3.Interior of non-steady state flux chamber showing small air circulation fan and stainless steel construction.

Flux measurements were collected at the top tier-cages of each row on one-third of the belt that contained up to 3d manure accumulation (Picture 4). Three locations with two sub-samplings per location of this segment of the belt were selected for these measurements (n=6 for each cage row). Preliminary emission measurements determined that position along the manure belt did not affect NH_3 measurements (Appendix Table A2). When taking readings, a flat, 60 mm thick board, 0.25 m square was placed under the belt to provide a firm sealing surface. The chamber was forced downward through the manure until it seated firmly on the belt. The emission monitoring protocol included: 1) running the belt for 10 s to expose a section of belt that had been under cages to the location where the flux chamber could be placed for measurements (2.3 m from the scraped-end of the manure belt) and measuring two flux locations on the belt coinciding with manure accumulated under each of the 2 back-to-back cages 2) running the belt for 2 min and 30 s, thus removing manure from the house and obtaining a new belt location for dual flux readings and 3) running the belt again for 2 min and 30 s for the third pair of flux readings (Figure 3). The 1d and 2 d manure accumulations were not monitored to reduce the number of variables under study. All emission measurements of the three dietary treatments in the hen house were conducted within a 5.5 h timeframe during each site visit commencing, on average, at 10:30 (range 9:30-12:00) to minimize the impact of diurnal variation.

The length of time the flux chamber was deployed (total of 4 min) was minimized to reduce perturbations of conditions in the near-surface atmosphere that can modify gas flux rate. One reading of NH_3 concentration (C_x) was obtained during one concentration measurement cycle. A measurement cycle consisted of the analyzer sample pump running for 19 s, which flushed the tubing and sample chamber, then the sample pump stopped for 41s during which time the analyzer measured the gas concentration contained in the sample chamber. The flux chamber was placed on the manured surface as soon as the sample pump stopped running from drawing the background air (C_0) sample from 0.5 m above the manure belt. The chamber was left on the manure belt undisturbed for 4 min, taking a concentration measurement every 60s. This resulted in a total of 5 readings per measurement site. The first (C_0), third (C_1) and fifth (C_2) readings were used in the emission flux rate calculation (Eqn. 1).

Pictures 4.Flux chamber positioned to enclose manure on top-most manure belt that was deposited the past three days; gas monitor nearby on top of cages. Manure belt was moved to expose manure that had been below hen cages in six locations per cage row.

FIGURE NOT PROVIDED

Figure 3. Plan view of gas flux measurement locations (n=12 per diet; oval dots) on belts containing manure up to three-days' accumulation. Dots also indicate location of belt manure sample collections.

Ammonia flux rate from the manure covered by the chamber, f, was calculated as proposed by Livingston and Hutchinson (1995) for non-steady state flux chamber measurements. This equation calculates initial gas flux at the beginning ofthe sampling period:

$$f = \frac{V_c (C_1 - C_0)^2}{A_c t (2C_1 - C_2 - C_0)} \mathrm{Ln} \frac{C_1 - C_0}{C_2 - C_1} \qquad (1)$$

Where, f gas flux rate from the manure covered by the chamber, g $m^{-2}s^{-1}$

C_0 background gas concentration, g/m^3

C_1 gas concentration at a moment t after placing the chamber on the surface, g/m^3

C_2 gas concentration at a moment 2t after placing the chamber on the surface, g/m^3

V_c volume of the chamber, 0.0271m^3

A_c area covered by the chamber,0.0670 m^2

t time (s) between measuring C_0 and C_1; set at 120 s for this study

This model is non-linear, as it assumes that the rate of gas exchange is not uniform over the measurement period, but rather decreases as the gas accumulates inside of the chamber. It is essential to confirm for each flux measurement that this theoretical assumption is fulfilled by verifying Eqn. 2, otherwise a linear relationship is used. Flux from the surface was converted to per bird with an estimated 29 hens m^{-2} above the manure belt area.

$$\frac{C_1 - C_0}{C_2 - C_1} > 1 \qquad (2)$$

Manure sampling and storage emissions

Hen manure from the belt was collected from the entire area enclosed during ammonia flux chamber measurement with manure from the two spots at each belt location combined. This resulted in three manure samples per belt; six total for each diet at each data collection visit. Manure was placed in a plastic bag, transported on ice to campus for immediate storage at -20°C. Manure was homogenized before delivery to Penn State's Agricultural Analytical Services Laboratory [AASL] for nutrient analysis (moisture, total nitrogen (N), ammonium-N (NH_4-N), organic-N, total phosphorus (P_2O_5), and total potash (K_2O)). Storage and belt manure pH was measured on the last site visit samples (wk 60).

Ammonia flux measurements were taken from a manure storage building where treatment hen manure was segregated into subsamples (~1 m^3) of manure from each dietary treatment. This manure was stored in the building between farm visits with no addition of manure. Subsamples were required because farm manure management would normally co-mingle manure from all cage rows into the covered storage. During flux measurements in the hen house, the two cage rows with each diet were measured sequentially so that manure was removed from the belts below these cages (the one-third of each belt containing the 3d manure accumulation) and conveyed to storage. Manure from each diet treatment was placed into one of three open-front temporary bins (3x1.2x1.2 m; LxWxH: Picture 5). Manure from each month was added on top of manure accumulated from the previous month. Flux measurements were conducted immediately upon arrival at the farm site from all three storage bins before additional manure was added. A preliminary analysis evaluated calculated NH_3 emissions from 3 positions within each storage bin and determined that only 1 replicate was statistically similar to overall mean from 2 or 3 replicates; so 2 manure storage positions in each bin were measured for flux with 1 replicate each. Manure samples from the stored manure for each diet was collected from each flux measurement location (n=2) for analysis at AASL.

Pictures 5. Manure storage: Individual bins were temporarily constructed to segregate manure from each diet to conduct gas flux and manure nutrient analysis. Foreground pile is from one treatment diet collected for immediate movement to its respective storage bin during a data-collection farm visit. Background left shows main layer house manure stockpile of aggregated from all three diets.

Results and Discussion

Hen performance and egg quality

Dietary treatments had a significant impact on EP and two egg quality parameters (AH and YC) with the CON diet being significantly lower than D or D+P fed hens (P≤0.05: Table 2; Figure 4). Table 2 reflects findings of replicated monthly measurements on a sample of hens from each diet in the study house. There were no significant impacts on hen BW or egg parameters EW, HU, SS, or ST (P > 0.05) among the diets. Based on company-supplied weekly data for the whole flock for the CON, D, and D+P diets, respectively, hen-day EP averaged 85.8, 85.2, 85.7% over the study period and total eggs per hen housed were 271, 270 and 271 at 65 wks of age. Mean feed intake and feed conversion were similar among the diets for the CON, D, and D+P diets, respectively, at 100.0, 100.0,and 104.3 g $hen^{-1}d^{-1}$ and 1.91, 1.95,1.95 kg feed per dozen eggs.

Table 2.The effect of DDGS with (D+P) or without (D) probiotic supplementation on hen body weight, egg production and egg quality versus Control diet (CON) of monthly on-farm collected data. Egg production for the D + P diet was significantly greater than for the control diet. Albumen height and yolk color were significantly improved egg quality indicators for the diets containing DDGS.

Diet	Body Weight	Hen-Day Egg Prod.[1]	Egg Count[1]	Egg weight[3]	Shell[4] Strength	Shell Thick.	Albumen Height[4]	Haugh Unit	Yolk Color Score
	kg/hen	%	mean/trt	g/egg	g force	mm	mm		
CON	1.57	91.26b	33.83	58.74	4094	0.373	7.625	86.83	7.27^{b}
D	1.58	94.69ab	36.39	59.34	4180	0.376	7.86.	87.65	7.80^{b}
D+P	1.57	94.84.	36.69	59.12	4117	0.374	7.85.	88.01	7.83^{a}
SEM[2]	0.009	0.941	0.813	0.251	33.94	0.0013	0.051	0.392	0.039
P-value	0.662	0.027	0.049	0.244	0.180	0.302	0.001	0.099	< 0.0001

a-b Means within a column with different superscripts differ significantly (P < 0.05)

1 Hen-Day Egg Production calculated as the ratio of# eggs to# hens in six 4-cage sections per treatment from which eggs were sampled for quality measurements. Egg Count is number of eggs laid by these hens.

2 Standard error of the mean with 6 replicates per treatment per data collection date.

3 Recorded from the 15 selected eggs per sampling cage.

4 External egg quality (shell strength and thickness) was performed in alternate months with internal egg quality (albumen height, Haugh unit, and yolk color).

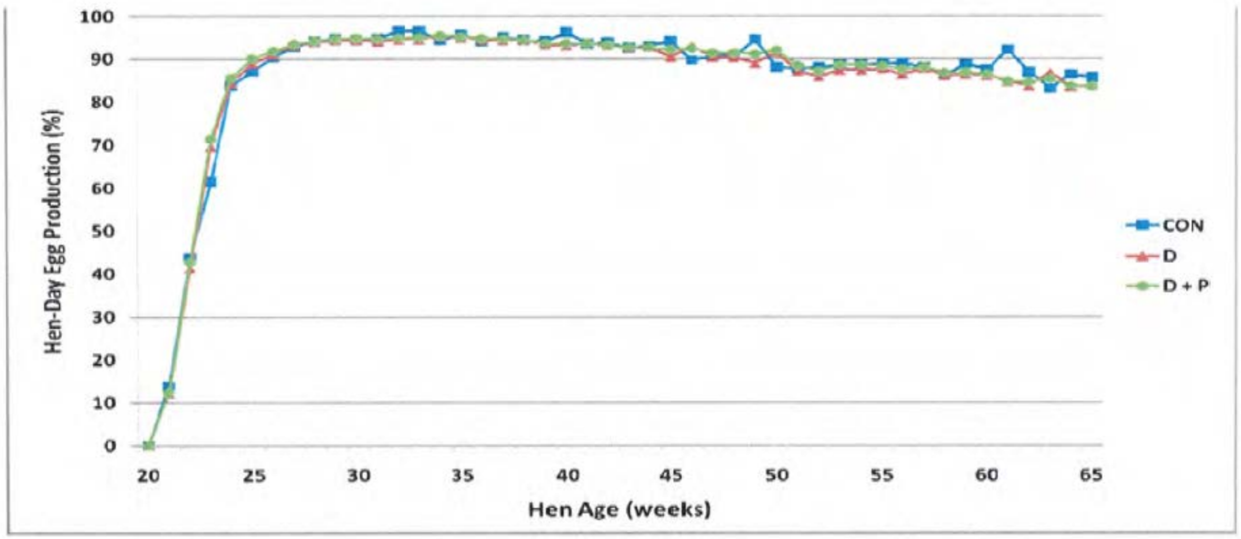

Figure 4. Hen day egg production of laying hens fed a typical commercial corn-soybean meal based-diet (Control: CON),a diet with DDGS (D),or with DDGS plus probiotics (D+P) based on monthly farm visit data.

Economics

Egg revenue was higher for the DDGS diets. Weekly average FC (Figure 5) and breaker-market El are shown in Table 3,which resulted in higher average weekly farm revenue (EI-FC) from the two DDGS diets ($6,216 (D) and $6,204 (D+P)) versus the CON diet ($6,144).

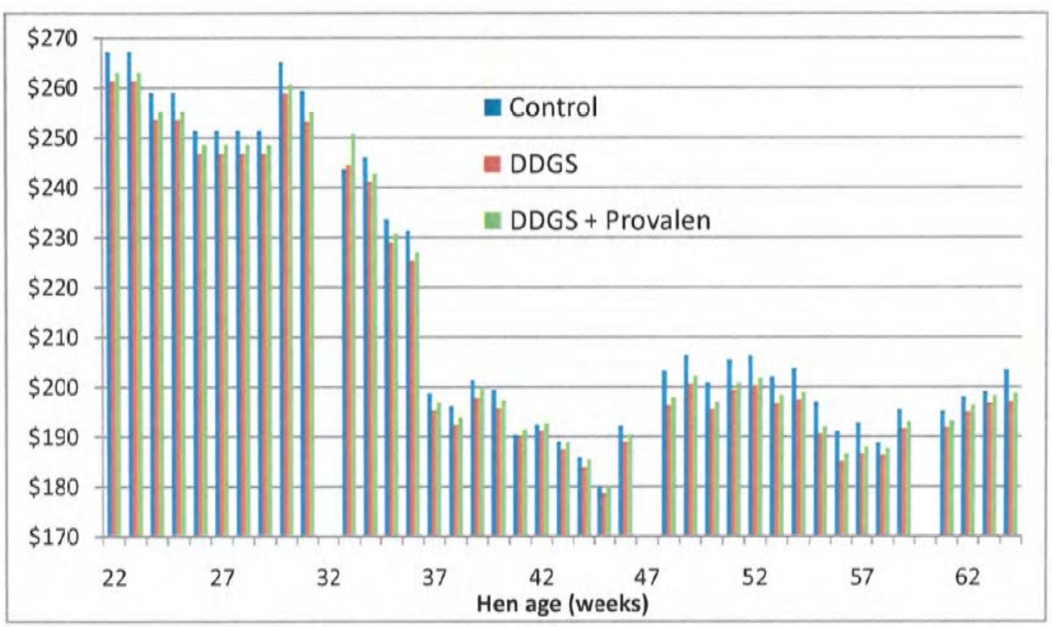

Figure 5.Feed cost from pullet placement in early summer 2008 through late spring 2009.

Table 3.Summary of economic analysis of three treatment diets in relation to income and feed cost.

Diet	Mean egg income ($/week)	Mean feed cost ($/week)	Mean egg income -feed cost ($/week)
CON	12,851	6,705	6,144
D	12,801	6,599	6,216
D+P	12, 864	6,671	6,204

Manure characteristics

Table 4 provides a summary of manure characteristics of samples collected from the hen house manure belt at locations where emissions were determined for each diet treatment. Only manure P_2O_5 was significantly different among the diets ($P < 0.05$), being higher in CON samples than the DDGS samples. The DDGS-based diets may offer advantage for crop management plans utilizing layer hen manure in PA where phosphorus-based nutrient management plans (rather than N-based) have been used when there is a high potential for phosphorus loss to waterways. Manure moisture, total N, NH_4-N, organic-N, and K_2O were not significantly different among the dietary treatments.

Table 4.Solids content and major nutrients in manure accumulated for 3d on belt under cages of laying hens fed Control diet (CON), DDGS (D), or a DDGS diet supplemented with probiotics (D+P). Manure total phosphorus was reduced 15% and statistically lower for diets containing DDGS.

Diet	Solids	Total-N	NH_4-N	Organic-N	Total P_2O_5	Total K_2O
	(%)	(g/kg of manure, DM basis)				
CON	39.93	49.26	9.47	39.79	45.73"	23.02
D	40.37	49.78	8.96	40.80	39.26b	23.60
D+P	39.71	50.1 2	8.55	41.57	39.39b	22.93
SEM[1]	1 .623	1 .641	0.462	1.685	1.1 27	0.310
P-value	0.9578	0.9332	0.3915	0.7591	0.0013	0.2873

[a-b] Means within a column without the same superscripts differ significantly ($P < 0.05$)

[1]Standard error of the mean of 6 samples per treatment per sampling date.

Results from the stored manure pile analyses are included in Table 5. After storage the only significantly different ($P < 0.10$) characteristics were CON manure having higher moisture and NH_4-N than D or D+P manures. A trend for reduced phosphorus in the DDGS treatment manures is observed but differences with the CON diet are no longer highly significant (P=0.13) for the stored manure. For manure stored in 34 high-rise commercial layer houses on three farms Behrends and Roberts (2009) found mixed results comparing 0, 8 and 12% DDGS diets' impact on P_2O_5 content of manure. One farm had a significant increase in high-rise manure P_2O_5 but no difference was observed at the other two farms. Behrends and Roberts (2009) DDGS diets did not affect N content of manure stored at any of the three farms. Figure 6 compares manure total P_2O_5 for belt and stored manure for all three diet treatments while Figure 7 offers a similar comparison for manure NH_4-N.

Table 5. Manure storage pile solids and major agronomic nutrients from laying hens fed corn-soybean- Control diet (CON), a similar diet containing DDGS (D), or a DDGS diet supplemented with probiotic (D+P). Moisture and ammonium-N contents were higher in the control diet versus DDGS diets ($P<0.10$).

Diet	Solids	Total-N	NH_4-N	Organic-N	Total P_2O_5	Total K_2O
	(%)	(g/kg of manure, DM basis)				
CON	56.78	50.69	10.66	40.02	55.05	26.89
D	64.98	44.89	7.51	37.38	49.45	26.38
D+P+Pro	62.65	41.18	6.89	34.29	49.17	26.65
SEM[1]	1.526	2.362	0.681	2.999	1.611	0.497
P-value	0.0662	0.1382	0.0556	0.4893	0.1339	0.7827

[1]Standard error of the mean of two samples per treatment per sampling date.

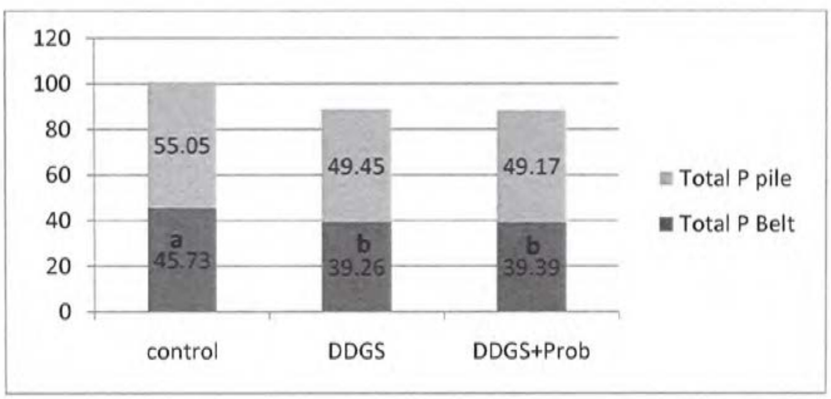

Figure 6. Comparison of total P_2O_5 (g kg^{-1} DM) for samples from manure belt under hens and storage pile manure.

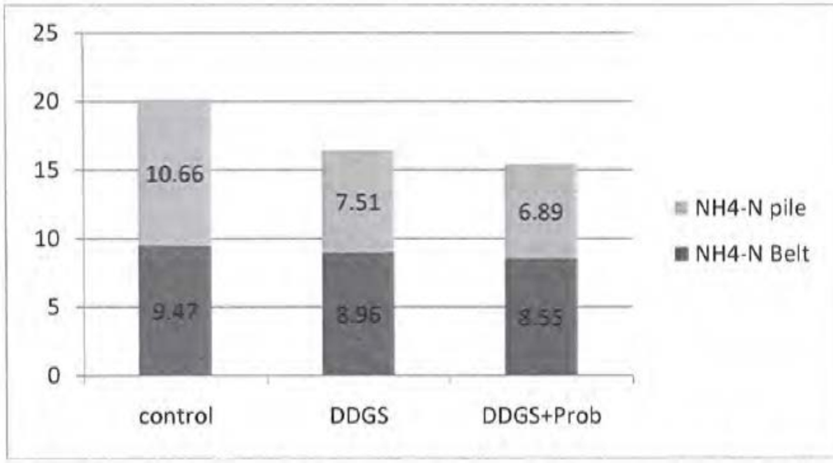

Figure 7. Manure NH_4-N (g kg^{-1} DM) for belt and pile manures (P=0.056 Pile).

Gas flux from hen house and storage

There was no clear trend in the magnitude of NH_3 flux within the hen house as measured at the manure belt between DDGS treatments and CON diet during the measurement periods (Figure 8). At 32 and 36 wk of hen age (P= 0.003; 0.064, respectively), NH_3 flux was significantly (P <0.10) higher in D than for the other two diets, while D+P flux was similar to CON. At 48 and 52 wk of age (P= 0.078; 0.084, respectively), NH_3 flux from D and D+P were similar and significantly lower than CON. Average ammonia flux rate for all diets was 0.419 ± 0.025 g $b^{-1}d^{-1}$ over the study period ranging from a high of 0.663 ± 0.11for CON at 44 wks to a low of 0.182 ± 0.02 for CON at 36 wks of hen age. Air temperature was not correlated with NH_3 emission within the laying hen house (P=0.984), likely due to the rather narrow temperature range (average 22°C; range 16.4-26.3°C) maintained during the study period. In contrast, air temperature in the storage building was significantly correlated with manure pile NH_3 flux.

Manure pH was not significantly different among the diet treatments (Table 6. P=0.54 belt; P= 0.66 pile), which can partially explain the similar ammonia emissions. During storage the manure pH increased 1unit for all diets resulting in a pH above 8 that would favor ammonia emission.

Greenhouse gas emissions as detected by the flux chamber instrumentation are presented in Appendix Tables A1 and A3 and Figures A2 to A4 for belt manure flux while Table A4 and Figures A6 to A8 show findings for stored manure greenhouse gas flux. Methane emissions from belt manure were generally higher in DDGS+Probiotics, however out of nine sampling dates only at 28 weeks of age was there a significant difference in methane emissions in the three diets. CO_2 emissions from DDGS and DDGS+Probiotics diets were generally higher than Control in all sampling dates. N_2O emissions remained below 2.0 mg N_2O $m^{-2}hr^{-1}$ regardless of diet treatment and increasing air temperature. N_2O emissions were not significantly different among diet treatments for all sampling dates. In the manure storage piles the background methane reading in the open-front naturally ventilated structure was often higher than methane flux from the manure piles resulting in the appearance of a "negative" flux rate (Table A4) shown as "zero" flux in Figure A6. For manure storage, the greenhouse gas emissions of the control manure tended to be greater than the two DDGS treatments reversing the minor trend documented from the belt manure.

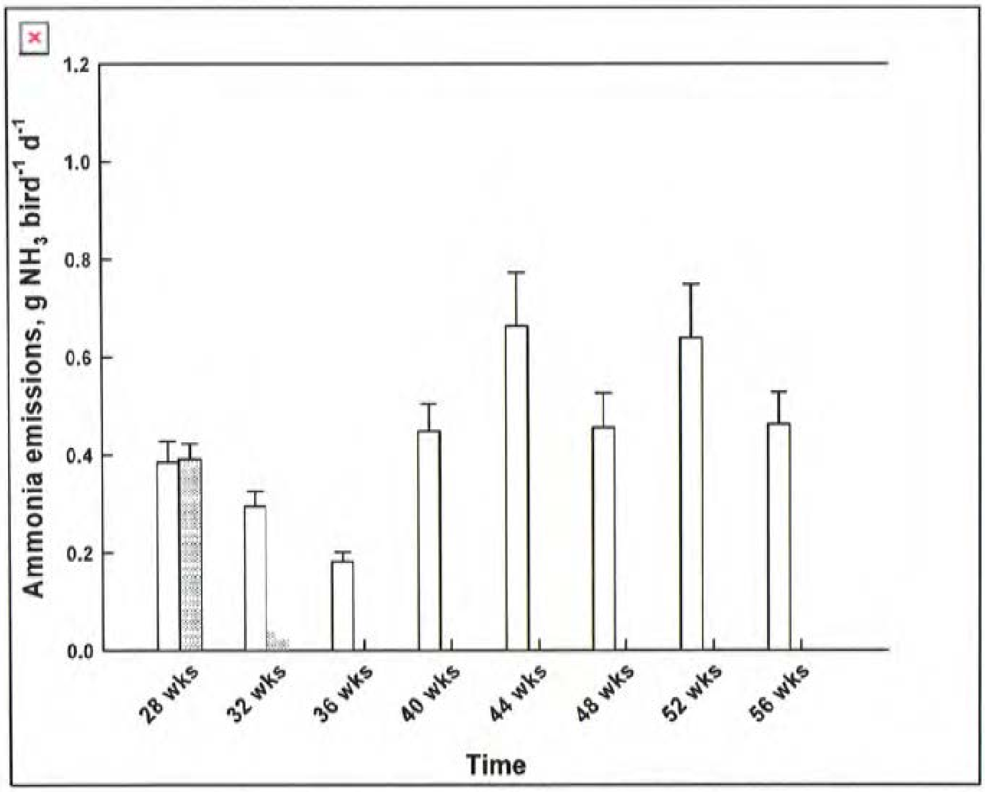

Figure 8. Average ammonia flux from 3d manure accumulation on manure belts of laying hens fed with three amino-acid balanced diets and average air temperature within the house during data collection (typically 10:30-16:00). Four times had statistically significant differences among the diets (P<0.10): week *32,* P=0.030, week 36; P=0.064: week 48*,* P=0.078: week 56, P=0.084. Compared to Control: DDGS -48 to +77%; DDGS+ Probiotic -40 to +40%.

Table 6.Manure pH of samples collected at hen age 65 wk for Control (CON), DDGS (D) and DDGS+ probiotic (D+P) dietary treatments. Manure belt samples of 3 d accumulation of fresh manure while storage pile manure samples are from the top few centimeters of month-old manure.

Diet	Hen House Manure Belt pH		Manure Storage Pile pH	
	average (n=6)	stdev	average (n=2)	stdev
CON	7.21	0.14	8.22	0.04
D	7.41	0.56	8.38	0.15
D+P	7.20	0.24	8.22	0.29

Conclusions

- Including DDGS at 10% with or without Provalen probiotic had both economical and environmental benefits on a commercial scale.

- 10% DDGS diets Improved:
  - Egg production
  - Albumen height
  - Yolk color
  - Producer revenue
  - Manure total phosphorus, via a reduction in content
- DDGS diet ammonia flux from belt manure was variable and offered no consistent improvement
- Significant increase in methane flux was observed in the DDGS diets with carbon dioxide flux also typically higher indicating a higher greenhouse gas footprint from recently excreted manure in the hen house environment but these trends did not hold for the long-term manure storage environment.

The goal of the project was to document the impact of DDGS-based hen diets on ammonia emissions, manure nutrients, hen production and egg quality. The diets, corn-soybean Control, 10% DDGS, and 10% DDGS with Probiotic, showed no consistent, clear improvement on NH_3 emissions measured at the manure belt. At 32 and 36 wks of age, NH_3 emissions were significantly higher in the DDGS treatment while DDGS +Probiotic diet was similar to Control diet. At 48 and 52 wks, NH_3 emissions from the two DDGS diets were significantly lower than Control ($P < 0.10$).

Dietary treatments did not significantly impact hen body weight, egg weight, and most egg quality parameters ($P > 0.05$); however, the Control hens had lower egg production, albumen height and yolk color compared to the two DDGS diets ($P \leq 0.05$). Belt-manure moisture, total nitrogen, ammonium-N, organic-N, and potash (K_2O) did not differ significantly by dietary treatment, but manure total phosphorus (P_2O_5) was higher for Control samples ($P < 0.05$). Stored manure for Control diets had greater moisture and more ammonium-N compared to samples from the two groups of DDGS-fed hens ($P < 0.10$). Weekly egg income minus feed cost (e.g. farm revenue) was higher for the two DDGS diets versus the Control.

Acknowledgements

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APPENDIX

of FINAL PROJECT REPORT

Egg Production, Ammonia Emission, Manure Nutrients, and Economics of Laying Hens Fed Distiller Dried Grain Diets

Natural Resources Conservation Service-Conservation Innovation Grant (NRCS-CIG) Demonstration

Project- Pennsylvania Site

Time	Diet/Test of Significance[1]	NH_3	CH_4	CO_2	N_2O	Air Temperature
			-----------------mg m^{-2} hr^{-1} -----------------			°C
28wks	Control	465 ± 52.3	80.0 ± 9.85*b*	6915 ± 675	0.871± 0.344	29.8
	DDGS	473 ± 38.7	124 ± 20.9*ab*	8595 ± 709	0.573 ± 0.507	29.6
	DDGS+Probiotics	563 ± 62.6	171 ± 25.1*a*	7571± 662	1.93 ± 0.460	29.6
	SEM	30.2	12.7	400	0.268	
	P-value	0.359	0.0113	0.2392	0.096	
32wks	Control	356 ± 37.3*b*	113 ± 20.6	6292 ± 611*b*	0.607 ± 0.260	24.5
	DDGS	667 ± 79.7*a*	156 ± 26.0	9394 ± 864*a*	1.12 ± 0.213	25.3
	DDGS+Probiotics	487 ± 68.0*b*	215 ± 41.6	8822 ± 1017*ab*	1.13 ± 0.270	26.3
	SEM	42	18.6	527	0.146	
	P-value	0.003	0.0826	0.0341	0.2328	
36wks	Control	220 ± 24.0*b*	74.8 ± 20.0	2060 ± 348*b*	0.373 ± 0.386	21.1
	DDGS	334 ± 51.7*a*	98.0 ± 16.7	4228 ± 453*a*	0.514 ± 0.371	23.4
	DDGS+Probiotics	228 ± *30.6b*	93.9 ± 24.1	4108 ± 472*a*	0.531± 0.234	23.6
	SEM	22.7	11.5	293	0.189	
	P-value	0.064	0.6728	0.0008	0.9355	
40wks	Control	542 ± 68.3	133 ± 20.1	5675 ± 756	0.700 ± 0.131	22.7
	DDGS	582 ± 62.6	118 ± 16.3	6601± 694	0.821± 0.252	24.3
	DDGS+Probiotics	689 ± 92.1	178 ± 55.7	7682 ± 855	1.32 ± 0.362	25.8
	SEM	43.6	20.3	454	1.08	
	P-value	0.387	0.4839	0.2021	0.2289	
44wks	Control	801± 133	99.4 ± 14.3	5391± 364*b*	0.807 ± 0.129	18.3
	DDGS	522 ± 79.3	127 ± 19.3	5763 ± 532*ab*	0.413 ± 0.218	20.3
	DDGS+Probiotics	710 ± 145	133 ± 14.3	7490 ± 710*a*	0.614 ± 0.239	20
	SEM	70.6	9.48	345	0.117	
	P-value	0.24	0.3222	0.0296	0.3482	
48wks	Control	550 ± 85.8a	121± 24.1	6346 ± 660	0.507 ± 0.474	17.8
	DDGS	276 ± 30.4*b*	100 ± 14.4	4306 ± 515	0.261± 0.495	18.3
	DDGS+Probiotics	400 ± 118ab	111± 20.4	4210 ± 987	0.487 ± 0.228	18.5
	SEM	51.8	11.3	451	0.235	
	P-value	0.078	0.7669	0.0936	0.8945	
52 wks	Control	772 ± 133*a*	128 ± 28.9	7660 ± 1625	0.414 ± 0.293	18.9
	DDGS	405 ± 96.5*b*	95.5 ± 14.8	5246 ± 957	0.157 ± 0.196	18.5
	DDGS+Probiotics	478 ± 147*ab*	125 ± 22.9	5462 ± 863	-0.175 ± 0.387	19.3
	SEM	76.2	13.1	696	0.174	
	P-value	0.084	0.543	0.3123	0.4026	
56wks	Control	559 ± 80.0	79.4 ± 15.1	3341 ± 501*b*	-0.171± 0.337	16.4
	DDGS	652 ± 100	155 ± 28.1	5700 ± 652*a*	0.152 ± 0.168	16.7
	DDGS+Probiotics	410 ± 88.5	124 ± 25.9	5558 ± 662*a*	0.489 ± 0.232	18.3
	SEM	53.6	14.5	390	0.147	
	P-value	0.188	0.1112	0.0173	0.205	
Overall	Control	533 ± 34.7	104 ± 7.16*b*	5482 ± 325	0.521± 0.111	21.2
	DDGS	489 ± 28.6	122 ± 7.35*ab*	6224 ± 298	0.501 ± 0.118	22.1
	DDGS+Probiotics	496 ± 38.2	143 ± 11.3*a*	6362 ± 323	0.729 ± 0.124	22.7
	SEM	13.5	11.5	273	0.094	
	P-value	0.6172	0.005	0.0999	0.1446	

Table A1. Belt manure mean NH_3, CH_4, CO_2, and N_2O emissions and air temperature from manure of laying hens fed with various poultry diets

Time	Diet/Test of Significance[1]	NH_3	CH_4	CO_2	N_2O	Air Temperature
			-----------------mg m^{-2} hr^{-1} -----------------			°C
28wks	Control	465 ± 52.3	80.0 ± 9.85*b*	6915 ± 675	0.871± 0.344	29.8
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	SEM	42	18.6	527	0.146	
	P-value	0.003	0.0826	0.0341	0.2328	
36wks	Control	220 ± 24.0*b*	74.8 ± 20.0	2060 ± 348*b*	0.373 ± 0.386	21.1
	DDGS	334 ± 51.7*a*	98.0 ± 16.7	4228 ± 453*a*	0.514 ± 0.371	23.4
	DDGS+Probiotics	228 ± *30.6b*	93.9 ± 24.1	4108 ± 472*a*	0.531± 0.234	23.6
	SEM	22.7	11.5	293	0.189	
	P-value	0.064	0.6728	0.0008	0.9355	
40wks	Control	542 ± 68.3	133 ± 20.1	5675 ± 756	0.700 ± 0.131	22.7
	DDGS	582 ± 62.6	118 ± 16.3	6601± 694	0.821± 0.252	24.3
	DDGS+Probiotics	689 ± 92.1	178 ± 55.7	7682 ± 855	1.32 ± 0.362	25.8
	SEM	43.6	20.3	454	1.08	
	P-value	0.387	0.4839	0.2021	0.2289	
44wks	Control	801± 133	99.4 ± 14.3	5391± 364*b*	0.807 ± 0.129	18.3
	DDGS	522 ± 79.3	127 ± 19.3	5763 ± 532*ab*	0.413 ± 0.218	20.3
	DDGS+Probiotics	710 ± 145	133 ± 14.3	7490 ± 710*a*	0.614 ± 0.239	20
	SEM	70.6	9.48	345	0.117	
	P-value	0.24	0.3222	0.0296	0.3482	
48wks	Control	550 ± 85.8a	121± 24.1	6346 ± 660	0.507 ± 0.474	17.8
	DDGS	276 ± 30.4*b*	100 ± 14.4	4306 ± 515	0.261± 0.495	18.3
	DDGS+Probiotics	400 ± 118ab	111± 20.4	4210 ± 987	0.487 ± 0.228	18.5
	SEM	51.8	11.3	451	0.235	
	P-value	0.078	0.7669	0.0936	0.8945	
52 wks	Control	772 ± 133*a*	128 ± 28.9	7660 ± 1625	0.414 ± 0.293	18.9
	DDGS	405 ± 96.5*b*	95.5 ± 14.8	5246 ± 957	0.157 ± 0.196	18.5
	DDGS+Probiotics	478 ± 147*ab*	125 ± 22.9	5462 ± 863	-0.175 ± 0.387	19.3
	SEM	76.2	13.1	696	0.174	
	P-value	0.084	0.543	0.3123	0.4026	
56wks	Control	559 ± 80.0	79.4 ± 15.1	3341 ± 501*b*	-0.171± 0.337	16.4
	DDGS	652 ± 100	155 ± 28.1	5700 ± 652*a*	0.152 ± 0.168	16.7
	DDGS+Probiotics	410 ± 88.5	124 ± 25.9	5558 ± 662*a*	0.489 ± 0.232	18.3
	SEM	53.6	14.5	390	0.147	
	P-value	0.188	0.1112	0.0173	0.205	
Overall	Control	533 ± 34.7	104 ± 7.16*b*	5482 ± 325	0.521± 0.111	21.2
	DDGS	489 ± 28.6	122 ± 7.35*ab*	6224 ± 298	0.501 ± 0.118	22.1
	DDGS+Probiotics	496 ± 38.2	143 ± 11.3*a*	6362 ± 323	0.729 ± 0.124	22.7
	SEM	13.5	11.5	273	0.094	
	P-value	0.6172	0.005	0.0999	0.1446	

[1] Gas emissions from various diet treatments within each time followed by the same letters are not significantly different at alpha= 0.05 for CH_4, CO_2 and N_2O and 0.10 for NH_3

[2] SEM is standard error of the means from 12 gas readings per diet treatment.

After 32 and 36 weeks, ammonia emissions were significantly high in DDGS treatments while NH_3 emissions from DDGS+Probiotics treatment were similar with control treatment. At the 48 to 52 weeks feeding, NH_3 emissions from DDGS were significantly lower than control but identical with DDGS+Probiotics. There was no clear trend in the magnitude of ammonia emissions between DDGS and DDGS+Probiotics during the 56 weeks feeding period.

Methane emissions were generally high in DDGS+Probiotics, however out of nine sampling dates, only at 28 weeks of age were there significant differences in methane emissions in the three diets. CO_2 emissions from DDGS and DDGS+Probiotics diets were generally higher than control in all sampling dates. N_2O emissions remained below 2.0 mg N2O m^{-2} hr^{-1} regardless of diet treatment and increasing air temperature. N_2O emissions were not significantly different among diet treatments in all sampling dates.

Table A2. Analysis of covariates, significant in the determination of variation observed in diet treatment comparisons.

1. NH_3

Variable	F-value	*P*
Diet Treatment	0.46	0.6428
Position (3 sampling sites)	2.16	0.1135
Cage (2 cage sites)	1.46	0.2275
Date	3.43	0.0238

2. CH_4

Variable	F-value	*P*
Diet Treatment	5.90	0.0138
Position (3 sampling sites)	11.25	<0.0001
Cage (2 cage sites)	0.03	0.8726
Date	2.47	0.0710

3. CO_2

Variable	F-value	*P*
Diet Treatment	1.62	0.2334
Position (3 sampling sites)	5.25	0.0058
Cage (2 cage sites)	9.88	0.0019
Date	4.60	0.0074

4. N_2O

Variable	F-value	*P*
Diet Treatment	0.19	0.8299
Position (3 sampling sites)	2.55	0.0807
Cage (2 cage sites)	1.73	0.1902
Date	4.18	0.0110

Using SAS proc mixed, above tables show that the position of the chamber in the manure belt did not affect the measurements of ammonia in relation to Sites of measurements. However, methane, CO_2 and N_2O gas fluxes were affected by the measurement Sites of chamber in the manure belt. The Date of gas measurements was a significant factor in estimates all gases except CH_4. F-values in these gases show the Date strongly affected the variation observed in NH_3 and CO_2 emissions and diet treatments. Hence, gas emissions from three diet treatments were compared by gas measurements Date.

Table A3. Relationship of gas emissions to temperature and relative humidity.

Variables	**NH_3**		**CH_4**		**CO_2**		**N_2O**	
				mg m^{-2} hr^{-1}				
	coefficient	*P*[1]	*coefficient*	*P*	*coefficient*	*P*	*coefficient*	*P*
NH_3			0.254	<0.0001	0.618	<0.0001	0.162	0.006
CH_4	0.254	<0.0001			0.402	<0.0001	0.206	0.0004
CO_2	0.618	<0.0001	0.402	<0.0001			0.365	<0.0001
N_2O	0.162	0.006	0.206	0.0004	0.365	<0.0001		
Air Temperature	0.001	0.984	0.129	0.028	0.331	<0.0001	0.283	<0.0001
Relative Humidity	0.189	0.001	0.042	0.480	0.049	0.411	-0.100	0.091

[1]P value less than 0.05 is significant at 95% confidence level.

Using Pearson correlation analysis, greenhouse gases were significantly and positively correlated to NH_3 emissions. Highest correlation coefficient calculated among all gas emissions was CO_2 (coefficient= 0.618). By removing the emissions measured during the 23 weeks period, the variations measured in NH_3 emissions appear not affected significantly by air temperature. However, for all greenhouse gases, gas emission was correlated with air temperature.

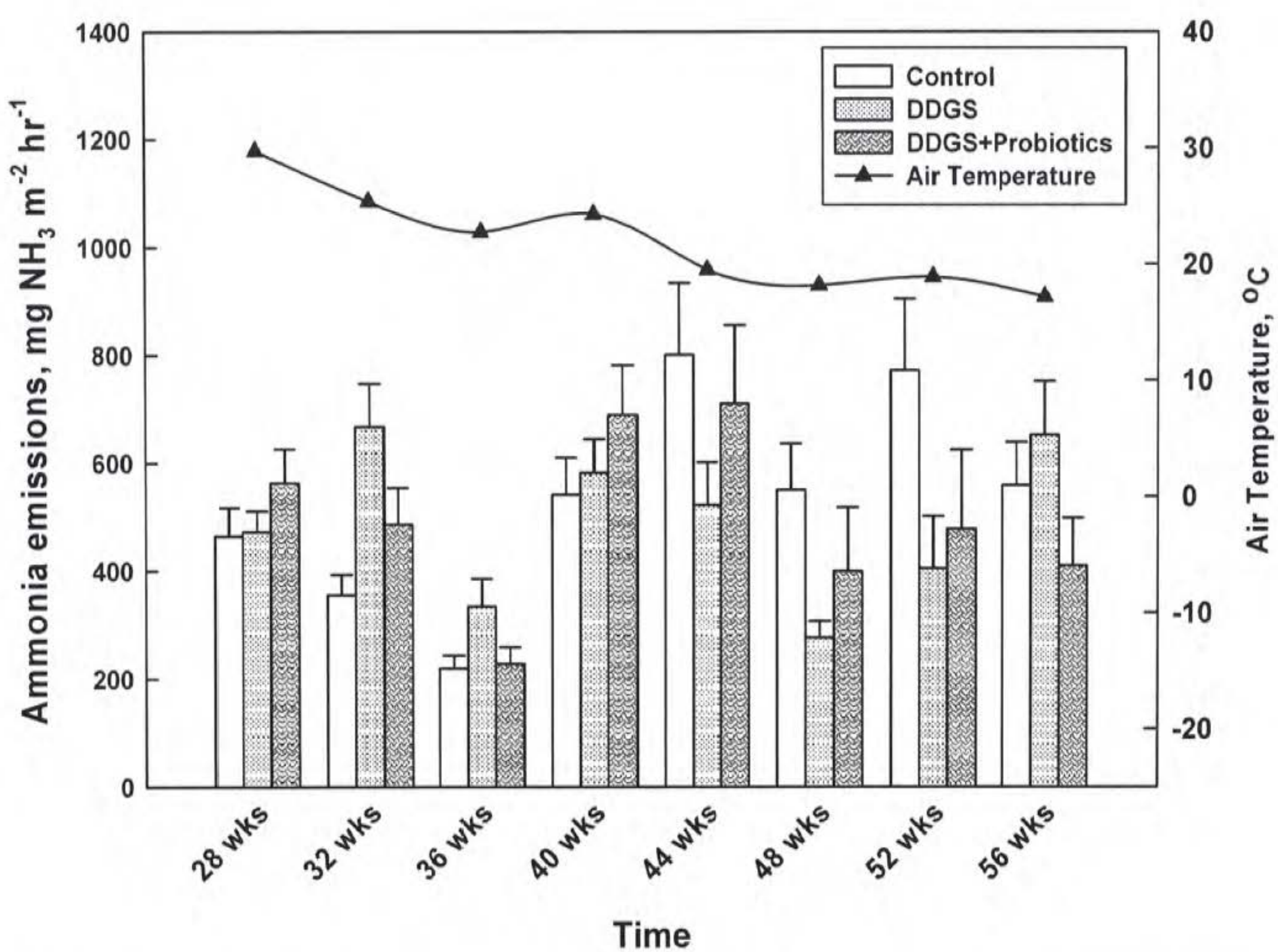

Figure A1. Average ammonia flux and air temperature from manure of laying hens fed with various poultry diets.

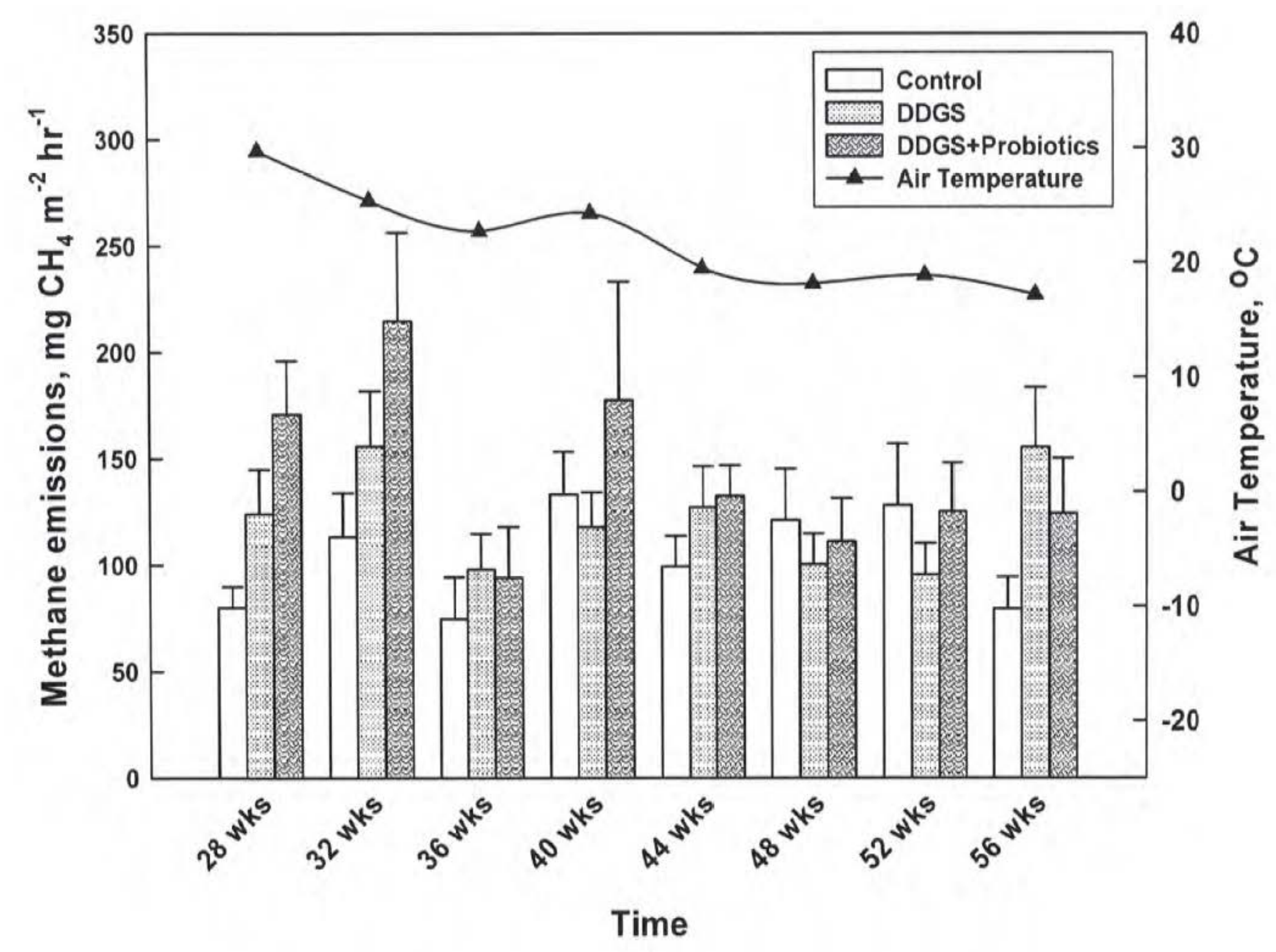

Figure A2. Average methane emissions and air temperature from manure of laying hens fed with various poultry diets.

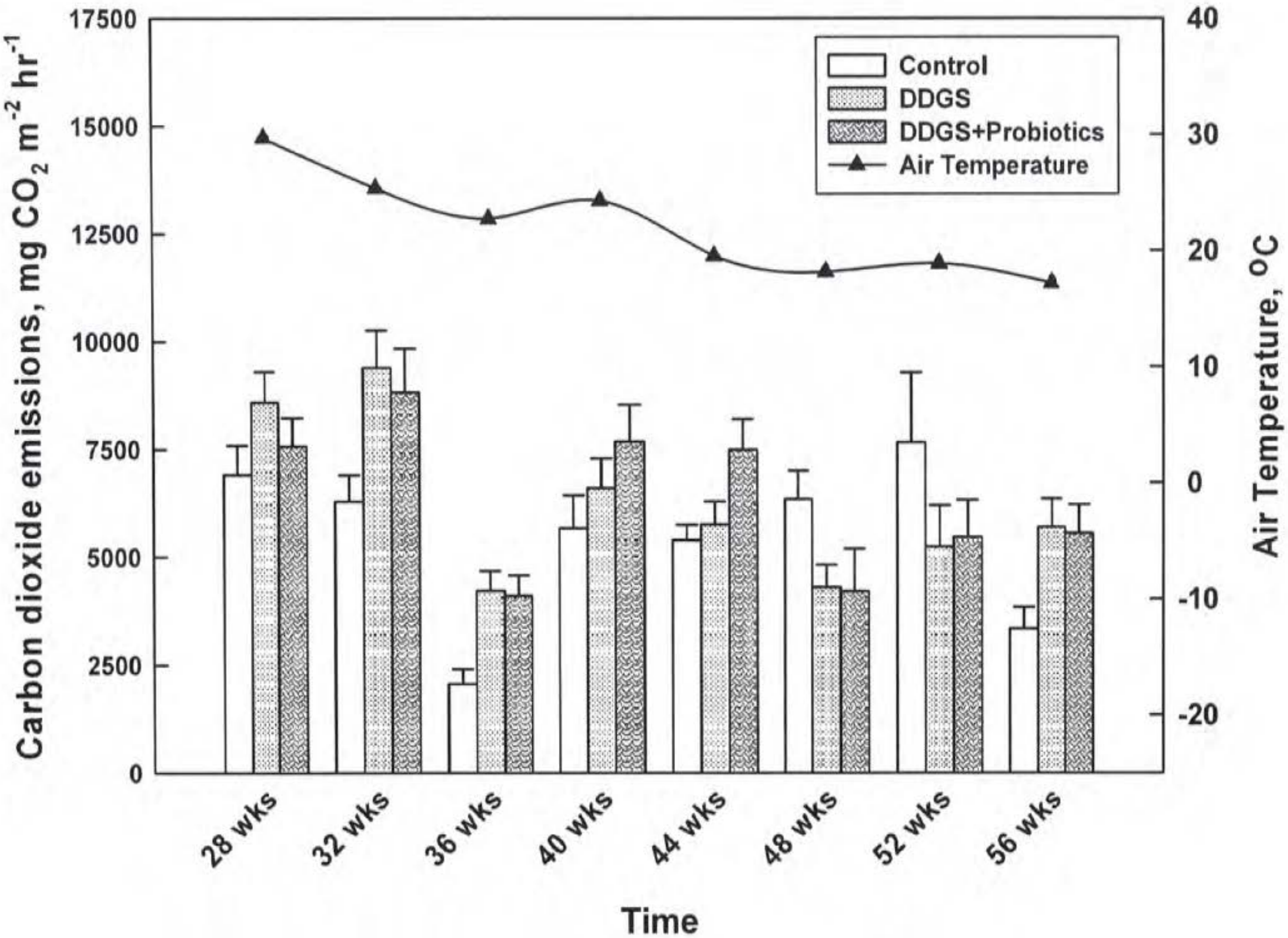

Figure A3. Average carbon dioxide emissions and air temperature from manure of laying hens fed with various poultry diets.

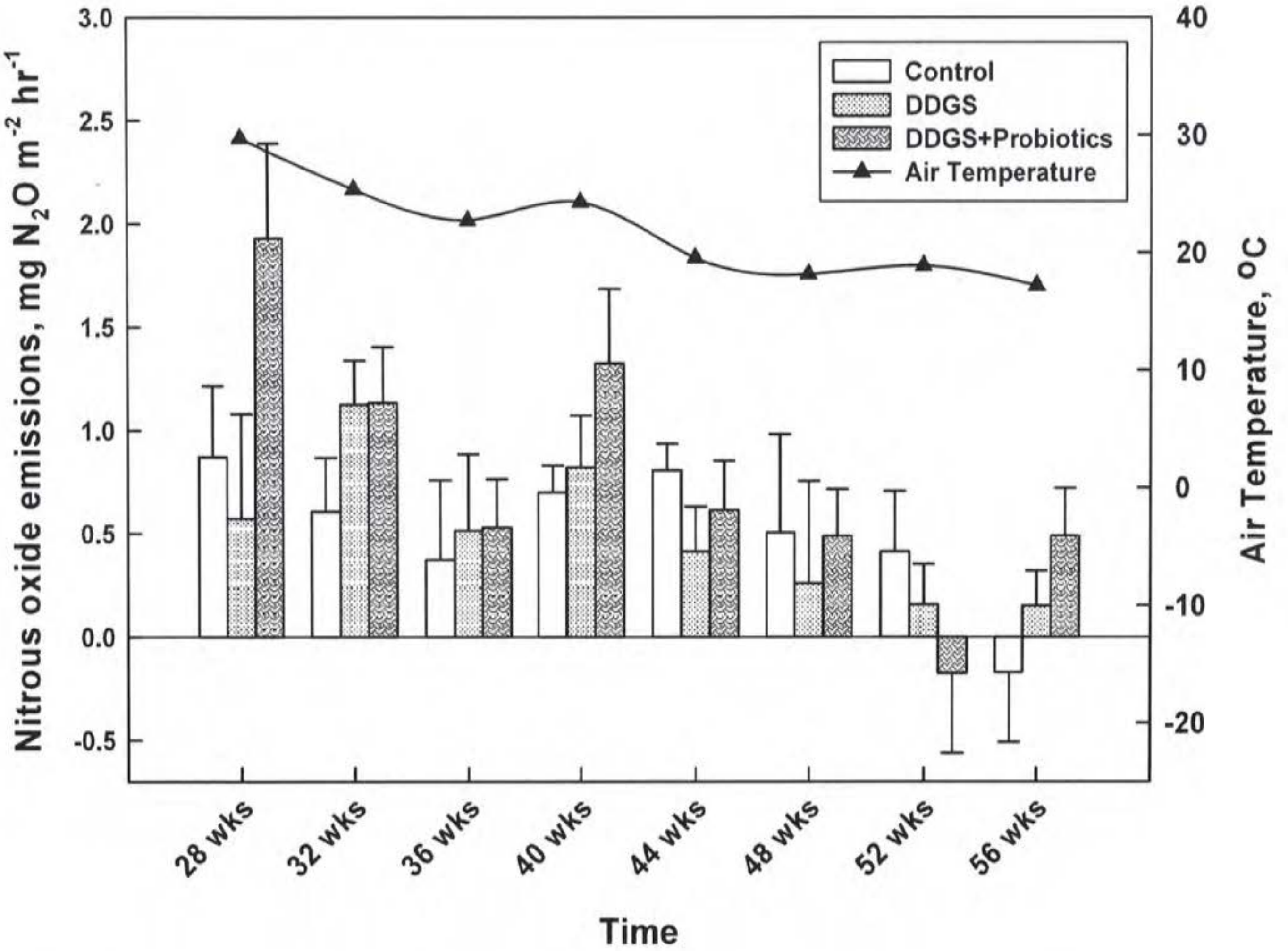

Figure A4. Average nitrous oxide emissions and air temperature from manure of laying hens fed with various poultry diets.

Table A4. Mean NH_3, CH_4, CO_2, and N_2O emissions and air temperature from manure pile of laying hens fed with various poultry diets

Time	Diet/Test of Significance[1]	NH_3	CH_4	CO_2	N_2O	Air Temperature
			------------------mg m^{-2} hr^{-1}	-----------------		°C
28wks	Control	5676	-14.0	46819	9.38	25.4
	DDGS	2557	-7.74	24441	1.94	26.4
	DDGS+Probiotics	7719	-25.2	47969	3.21	27.2
	SEM	-	-	-	-	-
	P-value	-	-	-	-	-
32wks	Control	7087 ± 1214	5.94	53062 ± 5534	7.01± 1.38*a*	25.3
	DDGS	5153 ± 662	-	48721± 143	3.27 ± 0.13*b*	25.3
	DDGS+Probiotics	5341± 483	-	39840 ± 12119	2.24 ± 0.08*b*	25.3
	SEM	543	-	4230	0.98	
	P-value	0.3407	-	0.5249	0.0154	
36wks	Control	3623 ± 1404	579 ± 587	22589 ± 11507	6.89 ±4.11	10
	DDGS	4994 ± 488	-23.4 ± 1.18	15843 ± 2280	3.25 ± 1.06	9.92
	DDGS+Probiotics	4982 ± 2316	-21.9 ± 11.5	18531± 964	3.24 ± 1.25	10.6
	SEM	767	198	3282	1.38	
	P-value	0.7661	0.4509	0.8962	0.6591	
40wks	Control	1746 ± 366	256 ± 247	21059 ± 2935	7.04 ± 0.92	12.3
	DDGS	1441± 110	-5.61± 4.25	8465 ± 3061	2.30 ± 0.66	11.9
	DDGS+Probiotics	1079 ± 390	-2.87 ± 0.50	13242 ± 7222	3.89 ± 1.67	11.4
	SEM	186	84.2	3173	1.02	
	P-value	0.4323	0.4357	0.3809	0.1789	
44wks	Control	1627 ± 77*a*	57.5 ± 55.0	20467 ± 125*a*	6.82 ± 0.05	6.32
	DDGS	1265 ± 24.3*a*	-7.87 ± 1.01	20030 ± 3063*a*	6.25 ± 0.801	5.68
	DDGS+Probiotics	632 ± 43.8*b*	-1.94 ± 0.00	3858 ± *585b*	3.75 ± 0.57	5.63
	SEM	187	16.6	3282	0.88	
	P-value	0.0019	0.3937	0.0039	0.0626	
48wks	Control	524 ± 387	10.0 ± 8.06*a*	11918 ± 1849	3.65 ± 0.26	2.97
	DDGS	608 ± 188	9.75 ± 5.68*a*	46267 ± 14814	15.1± 4.96	1.96
	DDGS+Probiotics	754 ± 26.3	-38.8 ± *2.02b*	25664 ± 6239	14.5 ± 8.2	1.58
	SEM	119	9.97	7570	3.42	
	P-value	0.6768	0.0177	0.079	0.187	
52 wks	Control	714 ± 575	36.0 ± 33	43409 ± 37494	19.7 ± 17.6	1.37
	DDGS	399 ± 33.8	12.9 ± 2.56	12537 ± 3202	4.79 ± 0.86	1.06
	DDGS+Probiotics	372 ± 10.1	7.28 ± 6.79	9326 ± 3708	7.98 ± 5.98	1.08
	SEM	164	10.4	11939	5.6	
	P-value	0.9899	0.6015	0.7329	0.9002	
56wks	Control	1664 ± 190	7.65 ± 33.8	13601± 9146	8.22 ± 4.46	-8.21
	DDGS	1118 ± 460	4.18 ± 3.99	16760 ± 1374	9.33 ± 1.30	-8.83
	DDGS+Probiotics	468 ± 193	0.744 ± 0.42	5431± 248	4.01± 0.16	-8.76
	SEM	7.53	2820	1.39		
	P-value	0.9699	0.3698	0.3749		
Overall	Control	2833 ± 733	125 ± 77	29116 ± 7391	8.59 ± 2.23	9.43
	DDGS	2192 ± 864	-2.55 ± 3.44	24133 ± 9433	5.78 ± 1.62	9.16
	DDGS+Probiotics	2668 ± 1163	-11.4 ± 4.66	20483 ± 10408	5.35 ± 1.53	9.25
	SEM	192	34	2502	1.02	
	P-value	0.7333	0.3644	0.3142	0.1006	

[1] Gas emissions from various diet treatments within each time followed by the same letters are not significantly different at alpha= 0.05

[2] SEM is standard error of the means from 2 gas readings per diet treatment.

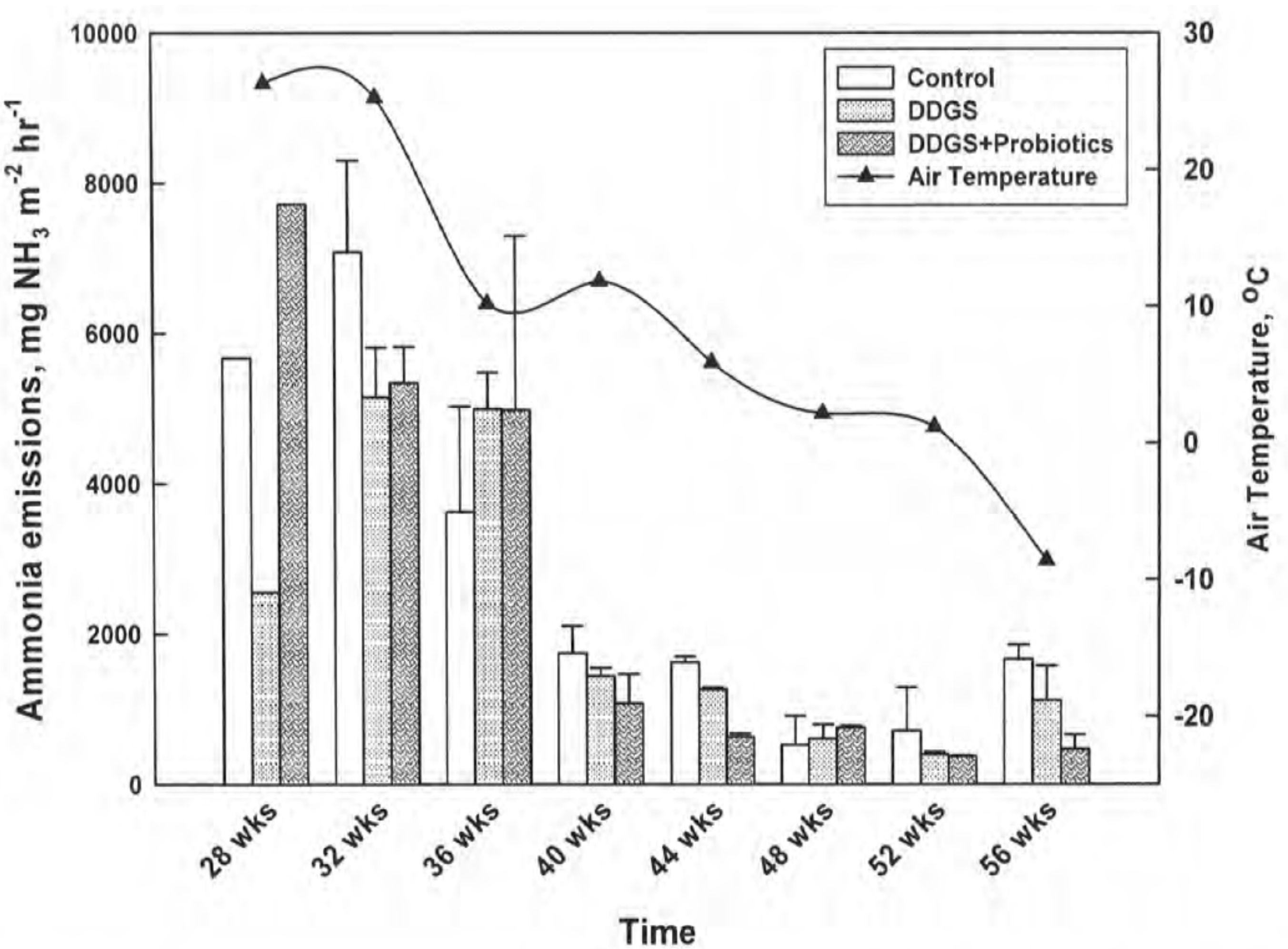

Figure A5. Average ammonia emissions and air temperature from manure pile of laying hens fed with various poultry diets.

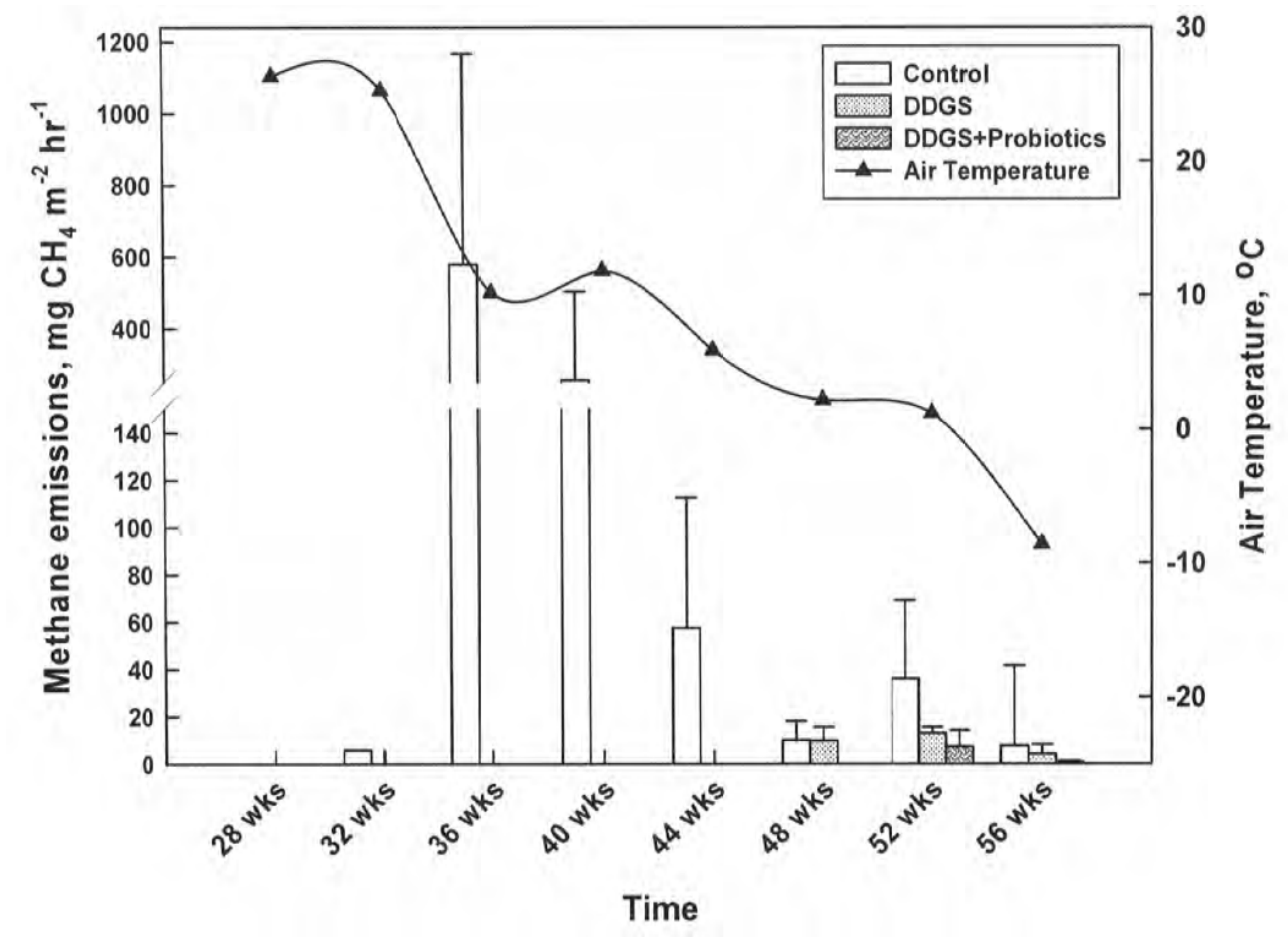

Figure A6. Average methane emissions and air temperature from manure pile of laying hens fed with various poultry diets.

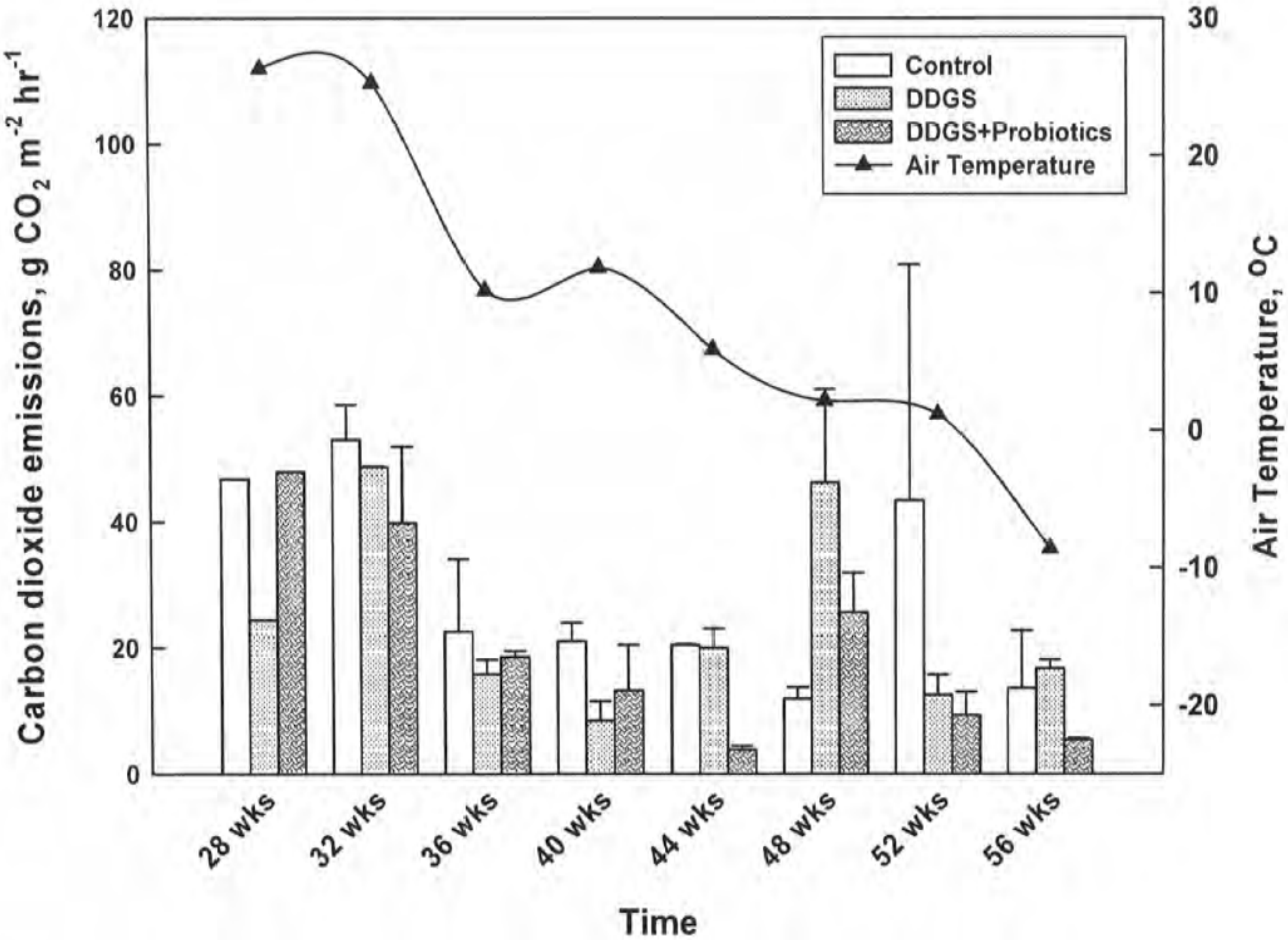

Figure A7. Average carbon dioxide emissions and air temperature from manure pile of laying hens fed with various poultry diets.

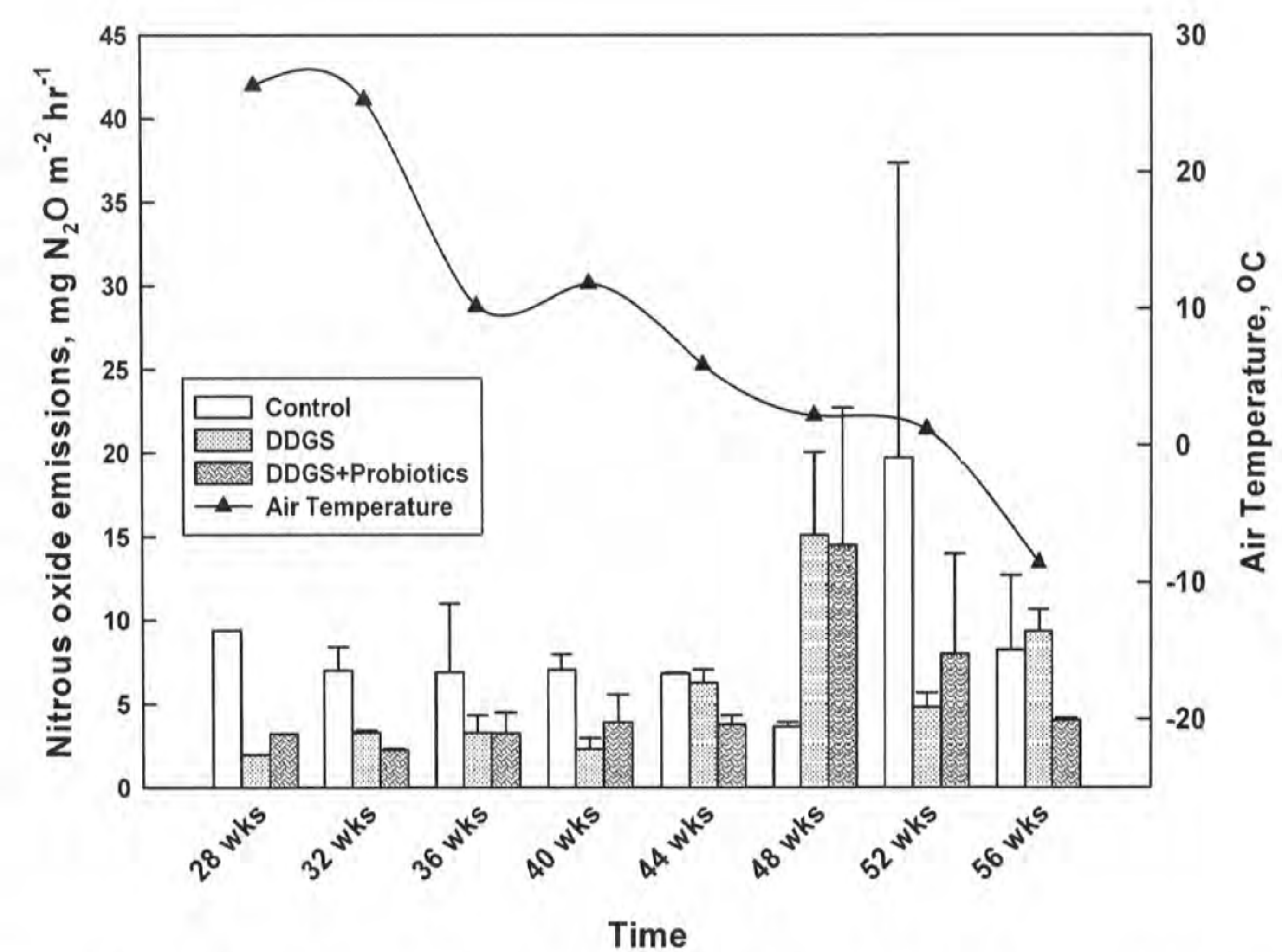

Figure A8. Average nitrous oxide emissions and air temperature from manure pile of laying hens fed with various poultry diets.

Table A2. Diet crude protein (CP), metabolizable energy (ME), amino acids Lycine (Lys), Methonine and Cystine (Met+Cys), calcium (Ca), available phosophorus (aP), and diet total cost per ton ($/Ton). DDGS+P = DDGS+Provalen.

Date	Wks	Diet	CP%	ME	Lys	Met+Cys	Ca	aP	$/Ton
7/4/2008	22	Control	18.375	1, 305	0.976	0.798	4.530	0.480	267.18
7/4/2008	22	DDGS	18.978	1' 305	0.984	0.803	4.520	0.484	261.35
7/4/2008	22	DDGS+P	19.007	1, 305	0.986	0.804	4.522	0.485	263.01
7/14/2008	23	Control	18.375	1, 305	0.976	0.798	4.530	0.480	267.18
7/14/2008	23	DDGS	18.978	1, 305	0.984	0.803	4.520	0.484	261.35
7/14/2008	23	DDGS+P	19.007	1, 305	0.986	0.804	4.522	0.485	263.01
7/15/2008	24	Control	17.748	1' 305	0.934	0.767	4.289	0.449	258.97
7/15/2008	24	DDGS	18.261	1' 305	0.943	0.772	4.297	0.446	253.61
7/15/2008	24	DDGS+P	18.253	1' 305	0.943	0.772	4.298	0.446	255.10
7/29/2008	25	Control	17.748	1, 305	0.934	0.767	4.289	0.449	258.97
7/29/2008	25	DDGS	18.261	1, 305	0.943	0.772	4.297	0.446	253.61
7/29/2008	25	DDGS+P	18.253	1' 305	0.943	0.772	4.298	0.446	255.10
7/30/2008	26	Control	17.040	1, 300	0.885	0.732	4.117	0.430	251.39
7/30/2008	26	DDGS	17.661	1, 300	0.900	0.739	4.111	0.433	246.82
7/30/2008	26	DDGS+P	17.644	1, 300	0.899	0.738	4.111	0.432	248.58
8/4/2008	27	Control	17.040	1, 300	0.885	0.732	4.117	0.430	251.39
8/4/2008	27	DDGS	17.661	1, 300	0.900	0.739	4.111	0.433	246.82
8/4/2008	27	DDGS+P	17.644	1' 300	0.899	0.738	4.111	0.432	248.58
8/11/2008	28	Control	17.040	1, 300	0.885	0.732	4.117	0.430	251.39
8/11/2008	28	DDGS	17.661	1, 300	0.900	0.739	4.111	0.433	246.82
8/11/2008	28	DDGS+P	17.644	1' 300	0.899	0.738	4.111	0.432	248.58
8/18/2008	29	Control	17.040	1, 300	0.885	0.732	4.117	0.430	251.39
8/18/2008	29	DDGS	17.661	1, 300	0.900	0.739	4.111	0.433	246.82
8/18/2008	29	DDGS+P	17.644	1' 300	0.899	0.738	4.111	0.432	248.58
8/25/2008	30	Control	16.880	1, 299	0.883	0.727	4.072	0.430	265.20
8/25/2008	30	DDGS	17.536	1, 299	0.898	0.735	4.074	0.433	258.88
8/25/2008	30	DDGS+P	17.519	1, 300	0.897	0.734	4.074	0.432	260.65
9/1/2008	31	Control	16.884	1' 299	0.883	0.727	4.072	0.430	259.45
9/1/2008	31	DDGS	17.536	1' 299	0.898	0.735	4.074	0.433	253.25
9/1/2008	31	DDGS+P	17.519	1, 300	0.897	0.734	4.074	0.432	255.01
9/8/2008	32	Control	16.960	1,300	0.781	0.650	4.110	0.430	239.14
9/8/2008	32	DDGS	16.950	1,300	0.780	0.650	4.110	0.430	232.59
9/8/2008	32	DDGS+P	16.950	1,300	0.780	0.650	4.110	0.430	234.01
9/15/2008	33	Control	17.456	1,300	0.898	0.737	4.061	0.430	243.55
9/15/2008	33	DDGS	17.723	1,300	0.899	0.737	4.061	0.430	244.47
9/15/2008	33	DDGS+P	19.103	1,300	0.904	0.738	4.063	0.430	250.72
9/22/2008	34	Control	16.884	1' 299	0.883	0.727	4.072	0.430	246.02
9/22/2008	34	DDGS	17.536	1' 299	0.898	0.735	4.074	0.433	241.08
9/22/2008	34	DDGS+P	17.519	1' 300	0.897	0.734	4.074	0.432	242.80
9/29/2008	35	Control	16.823	1, 299	0.882	0.724	4.121	0.453	233.56
9/29/2008	35	DDGS	17.442	1, 299	0.897	0.732	4.115	0.452	229.04
9/29/2008	35	DDGS+P	17.425	1, 300	0.896	0.731	4.114	0.451	230.73
10/6/2008	36	Control	16.823	1, 299	0.882	0.724	4.121	0.453	231.32
10/6/2008	36	DDGS	17.442	1, 299	0.897	0.732	4.115	0.452	225.31
10/6/2008	36	DDGS+P	17.425	1, 300	0.896	0.731	4.114	0.451	226.98
10/13/2008	37	Control	17.243	1, 299	0.887	0.731	4.114	0.430	198.64
10/13/2008	37	DDGS	17.496	1, 300	0.898	0.731	4.107	0.430	195.25
10/13/2008	37	DDGS+P	17.486	1, 299	0.897	0.730	4.115	0.432	196.78

Date	Wks	Diet	CP%	ME	Lys	Met+Cys	Ca	aP	$/Ton
10/20/2008	38	Control	17.030	1' 299	0.866	0.700	4.322	0.419	196.06
10/20/2008	38	DDGS	17.341	1, 299	0.877	0.707	4.317	0.420	192.31
10/20/2008	38	DDGS+P	17.344	1' 299	0.877	0.706	4.320	0.420	193.94
10/27/2008	39	Control	17.030	1, 299	0.866	0.700	4.322	0.419	201.33
10/27/2008	39	DDGS	17.341	1' 299	0.877	0.707	4.317	0.420	197.69
10/27/2008	39	DDGS+P	17.344	1, 299	0.877	0.706	4.320	0.420	199.60
11/3/2008	40	Control	17.030	1, 299	0.866	0.700	4.322	0.419	199.43
11/3/2008	40	DDGS	17.341	1' 299	0.877	0.707	4.317	0.420	195.68
11/3/2008	40	DDGS+P	17.344	1, 299	0.877	0.706	4.320	0.420	197.26
11/10/2008	41	Control	16.877	1, 299	0.870	0.698	4.362	0.443	190.38
11/10/2008	41	DDGS	16.910	1, 299	0.876	0.696	4.331	0.429	189.85
11/10/2008	41	DDGS+P	16.903	1' 299	0.876	0.696	4.333	0.429	191.36
11/17/2008	42	Control	16.877	1,300	0.870	0.698	4.362	0.443	192.38
11/17/2008	42	DDGS	16.910	1,300	0.876	0.696	4.331	0.429	191.20
11/17/2008	42	DDGS+P	16.903	1,300	0.876	0.696	4.333	0.429	192.70
11/24/2008	43	Control	16.877	1,300	0.870	0.698	4.362	0.443	188.95
11/24/2008	43	DDGS	16.910	1,300	0.876	0.696	4.331	0.429	187.42
11/24/2008	43	DDGS+P	16.903	1,300	0.876	0.696	4.333	0.429	188.83
12/1/2008	44	Control	16.877	1,300	0.876	0.698	4.362	0.443	185.80
12/1/2008	44	DDGS	16.910	1,300	0.876	0.696	4.331	0.429	183.88
12/1/2008	44	DDGS+P	16.903	1,300	0.876	0.696	4.333	0.429	185.38
12/8/2008	45	Control	16.617	1,300	0.876	0.688	4.355	0.459	179.92
12/8/2008	45	DDGS	16.627	1,300	0.882	0.688	4.328	0.435	178.68
12/8/2008	45	DDGS+P	16.620	1,300	0.882	0.688	4.330	0.435	180.19
12/15/2008	46	Control	16.617	1,300	0.876	0.688	4.355	0.459	192.16
12/15/2008	46	DDGS	16.627	1,300	0.882	0.688	4.328	0.435	188.93
12/15/2008	46	DDGS+P	16.620	1,300	0.882	0.688	4.330	0.435	190.42
12/22/2008	47	Control	16.950	1,299	0.869	0.698	4.315	0.420	197.77
12/22/2008	47	DDGS	16.964	1,300	0.877	0.700	4.311	0.420	190.64
12/22/2008	47	DDGS+P	16.966	1,300	0.877	0.700	4.311	0.420	192.12
12/29/2008	48	Control	16.950	1,300	0.869	0.698	4.315	0.420	203.28
12/29/2008	48	DDGS	16.964	1,300	0.877	0.700	4.311	0.420	196.33
12/29/2008	48	DDGS+P	16.966	1,300	0.877	0.700	4.311	0.420	197.81
1/5/2009	49	Control	16.950	1,300	0.869	0.698	4.315	0.420	206.31
1/5/2009	49	DDGS	16.964	1,300	0.877	0.700	4.311	0.420	200.59
1/5/2009	49	DDGS+P	16.966	1,300	0.877	0.700	4.311	0.420	202.07
1/12/2009	50	Control	16.950	1,300	0.869	0.698	4.315	0.420	200.86
1/12/2009	50	DDGS	16.964	1,300	0.877	0.700	4.311	0.420	195.47
1/12/2009	50	DDGS+P	16.966	1,300	0.877	0.700	4.311	0.420	196.96
1/19/2009	51	Control	16.951	1,300	0.870	0.699	4.315	0.420	205.41
1/19/2009	51	DDGS	16.949	1,300	0.874	0.701	4.318	0.420	199.36
1/19/2009	51	DDGS+P	16.945	1,300	0.874	0.701	4.321	0.420	200.87
1/26/2009	52	Control	16.951	1,300	0.870	0.699	4.315	0.420	206.27
1/26/2009	52	DDGS	16.949	1,300	0.874	0.701	4.318	0.420	200.26
1/26/2009	52	DDGS+P	16.945	1,300	0.874	0.701	4.321	0.420	201.77
2/2/2009	53	Control	16.951	1,300	0.870	0.699	4.315	0.420	202.01
2/2/2009	53	DDGS	16.949	1,300	0.874	0.701	4.318	0.420	196.67
2/2/2009	53	DDGS+P	16.945	1,300	0.874	0.701	4.321	0.420	198.18
2/9/2009	54	Control	16.544	1,300	0.857	0.667	4.661	0.400	203.68
2/9/2009	54	DDGS	16.535	1,300	0.867	0.671	4.651	0.399	197.39
2/9/2009	54	DDGS+P	16.540	1,300	0.867	0.671	4.653	0.400	198.90

Date	Wks	Diet	CP%	ME	Lys	Met+Cys	Ca	aP	$/Ton
2/16/2009	55	Control	16.544	1,300	0.857	0.667	4.661	0.400	196.95
2/16/2009	55	DDGS	16.535	1,300	0.867	0.671	4.651	0.399	190.63
2/16/2009	55	DDGS+P	16.540	1,300	0.867	0.671	4.653	0.400	191.99
2/23/2009	56	Control	16.223	1,291	0.847	0.659	4.329	0.394	191.04
2/23/2009	56	DDGS	16.657	1,290	0.860	0.661	4.357	0.396	185.10
2/23/2009	56	DDGS+P	16.655	1,290	0.860	0.661	4.357	0.395	186.51
3/2/2009	57	Control	16.634	1,300	0.857	0.668	4.648	0.394	192.73
3/2/2009	57	DDGS	16.593	1,300	0.867	0.672	4.641	0.395	186.63
3/2/2009	57	DDGS+P	16.599	1,300	0.867	0.672	4.643	0.395	187.99
3/9/2009	58	Control	16.151	1,294	0.845	0.657	4.345	0.400	188.74
3/9/2009	58	DDGS	16.216	1,290	0.852	0.655	4.357	0.401	186.31
3/9/2009	58	DDGS+P	16.216	1,290	0.853	0.655	4.359	0.401	187.66
3/16/2009	59	Control	16.151	1,294	0.845	0.657	4.345	0.400	195.40
3/16/2009	59	DDGS	16.216	1,290	0.855	0.655	4.357	0.401	191.63
3/16/2009	59	DDGS+P	16.216	1,290	0.853	0.655	4.359	0.401	192.97
3/23/2009	60	Control	16.151	1,294	0.845	0.657	4.345	0.400	197.07
3/23/2009	60	DDGS	16.216	1,290	0.852	0.655	4.357	0.401	193.64
3/23/2009	60	DDGS+P	16.216	1,290	0.853	0.655	4.359	0.401	194.64
3/30/2009	61	Control	16.151	1,294	0.845	0.657	4.345	0.400	195.17
3/30/2009	61	DDGS	16.216	1,290	0.852	0.655	4.357	0.401	191.88
3/30/2009	61	DDGS+P	16.216	1,290	0.853	0.655	4.359	0.401	193.22
4/6/2009	62	Control	16.218	1,294			4.357	0.394	197.97
4/6/2009	62	DDGS	16.232	1,290			4.360	0.400	195.06
4/6/2009	62	DDGS+P	16.231	1,290			4.362	0.400	196.40
4/13/2009	63	Control	16.218	1,294			4.357	0.394	199.07
4/13/2009	63	DDGS	16.232	1,290			4.360	0.400	196.76
4/13/2009	63	DDGS+P	16.231	1,290			4.362	0.400	198.13
4/20/2009	64	Control	16.544	1,300			4.666	0.400	203.39
4/20/2009	64	DDGS	16.568	1,299			4.670	0.400	197.08
4/20/2009	64	DDGS+P	16.565	1,300			4.667	0.399	198.69