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Feeding, defecation and gaseous emission dynamics of W-36 laying hens

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Feeding, defecation and gaseous emission dynamics of W-36 laying hens

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ABSTRACT

Livestock and poultry producers face increasing challenge to reduce the negative impacts of their operations on the environment. Ammonia (NH_3) released from animal manure to the atmosphere is one of the major environmental concerns associated with poultry production. There have been growing research efforts toward documenting or improving the inventory of NH_3 emissions from animal production systems. Efforts also continue to develop process-based models for predicting gaseous, particularly NH_3, emissions from animal feeding operations. In this thesis research, an environmentally -controlled dynamic gas emission chambers system was used to investigate the dynamic gaseous emissions, ingestion, and defecation activities of laying hens. Chapter 2 of this thesis describes the dynamic emissions of NH_3 and carbon dioxide (CO_2) relative to feeding and defecation activities of W-36 laying hens. Results presented include average daily feed consumption, manure production, relation of manure surface area to manure weight, daily NH_3 and CO_2 emission rates, and relations of NH_3 and CO_2 emissions to manure accumulation. The study revealed an inverse relationship between dynamic NH_3 emissions and defecation events of the hens as manure accumulates. Results from this study will contribute to development and validation of process-based emission models for predicting NH_3 emissions from laying-hen houses. The dynamic nature of NH_3 emissions vs. defecation event of the hen may help guide the application timing of manure treatment agents to reduce NH_3 emissions from laying-hen houses.

Chapter 3 assesses the effect of a diet containing corn distiller's dried grain with solubles (DDGS, 15% by weight) vs. control diet (no DDGS added) on NH_3 emission and production performance of W-36 laying hens. Compared with hens fed the control diet,

hens fed the DDGS diet had 16% higher manure mass production ($P<0.001$) and 13% higher egg mass production ($P<0.05$). After 6 days of manure accumulation, NH_3 emissions for the DDGS diet regimen showed considerable reduction, as expressed in the units of g/hen-d (26%, $P<0.1$), g/kg manure-d (32%, $P<0.05$), g/kg egg-d (38%, $P<0.01$), or g/kg N intake-d (31%, $P<0.01$), when compared to the control diet regimen. Results of this study involving manure accumulation from live hens support previous findings of the NH_3 emission-lowering effect of corn DDGS as observed in lab-scale studies involving static manure storage. Hence, corn DDGS (at 15% inclusion rate) seems to be a viable feed ingredient for laying hens that will lead to reduced NH_3 emissions without negatively affecting the hen production performance. However field verification of hen production performance is warranted.

CHAPTER 1. GENERAL INTRODUCTION

Introduction

Ammonia (NH_3) is the major pollutant gas released from poultry feeding operations. There have been growing research efforts toward documenting or improving the inventory of NH_3 emissions from animal production systems. One classical multi-national study concerning NH_3 concentrations and emissions from animal housing in northern Europe was reported by Groot Koerkamp *et al.* (1998). The most recent studies on NH_3 emissions from commercial U.S. poultry operations include those reported by Liang *et al.* (2005) for laying hens, Wheeler *et al.* (2006) and Burns *et al.* (2007) for broiler chickens, and Li *et al.* (2008) for turkeys. Ammonia emissions from poultry manure storage as affected by different environmental conditions (e.g., stacking configuration, moisture content of manure, and storage temperature) have also been investigated (Li, 2006). Researchers have shown that prolonged exposure to high levels of NH_3 can cause reduced body weight gain and egg production in laying hens (Deaton *et al.,* 1982). High NH_3 concentration inside livestock facilities can have negative impacts on farm workers (Donham, 2000). Ammonia released from livestock operations may also pose health risks on vicinal residents (McCubbin *et al.,* 2002, Auvermann and Rogers, 2002, Wing and Wolfe, 2000).

The Occupational Safety and Health Administration (OSHA) of the United States has set permissible NH_3 level for 8-hr exposure to 50 ppm, whereas the National Institute of Occupational Safety and Health (NIOSH) has set the 8-hr permissible NH_3 level to 25 ppm. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a limit of 35 ppm for a 15-minute exposure. Increasing attention is being

directed toward seeking practical strategies to mitigate air emissions from animal feeding operations, e.g., through dietary manipulation (Liang *et al.*, 2005; Roberts *et al.*, 2007) and topical application of treatment agents on manure (Li *et al.*, 2008).

The 2002 report by the National Academy of Sciences called for development of process-based models to enhance the ability to better understand and predict NH_3 emissions from animal feeding operations. To that end, multi-disciplinary efforts have been made to develop such models, as reported by Mansell *et al.* (2005) and Zhang *et al.* (2005). In this process, it became clear that information is missing or lacking concerning the dynamics of NH_3 emissions as affected by the biophysical factors in animal housing.

Laying-hen houses in the United States generally use high-rise (HR) or manure-belt (MB) style, with MB style gaining popularity because of improved indoor air quality. The HR houses feature in-house manure storage for an extended period (typically one year), whereas MB houses feature more frequent removal of manure (daily to weekly).

The objective of the first part of this thesis research, as reported in Chapter 2, was to delineate dynamic emissions of NH_3 and CO_2 as related to feeding and defecation of laying hens under different manure accumulation durations, as may be encountered in commercial MB houses.

In recent years, with the increasing production of fuel ethanol with corn, its co-product, distiller's dried grain with solubles (DDGS), has gained increasing attention as feedstuff for poultry production. The DDGS contains 7% to 10% fiber (Spiehs *et al.,* 2002). Researchers have reported increasing dietary fiber supplement in the diet leads to transfer of nitrogen (N) from urinary excretion to fecal excretion for rats (Tetens *et al*., 1996) and also for pigs (Kreuzer and Machmuller, 1993). Roberts *et al.* (2007) reported

laying-hen diets containing 10 % corn DDGS decreased NH_3 emission from the hen manure for up to 50% during 7-day storage tests. However, Roberts *et al.* (2007) did not find significant redistribution of N in poultry manure, and the reduction of NH_3 emission was believed to mainly result from the lower pH value in the manure of DDGS diet group. More information regarding the effect of DDGS diet on laying-hen manure NH_3 and CO_2 emissions, particularly with live hens as manure is produced and accumulated, needs to be gathered. Hence, the objective of the second part of the thesis research, as reported in Chapter 3, was to compare a DDGS diet vs. Control diet in terms of feed intake, manure production, egg production, and NH_3 and CO_2 emissions of W-36 laying hens.

Thesis organization

This thesis has been prepared in journal paper format of *Transactions of the ASABE*, with two manuscripts. The thesis includes four chapters − a General Introduction, one manuscript entitled "Ammonia and Carbon Dioxide Emissions *vs.* Feeding and Defecation Activities of Laying Hens," another manuscript entitled "Feeding, Defecation and Gaseous Emission Dynamics of W-36 Laying Hens," and a General Conclusion. Figures and tables relevant to each paper are included at the end of each chapter.

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CHAPTER 2. AMMONIA AND CARBON DIOXIDE EMISSIONS *vs.* FEEDING AND DEFECATION ACTIVITIES OF LAYING HENS

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Abstract

This study involved two experiments (Experiments 1 and 2) that characterize dynamic ammonia (NH_3) and carbon dioxide (CO_2) emissions associated with feeding and defecation activities of W-36 laying hens. The manure handling scheme used was reflective of commercial manure-belt (MB) housing operations. Four dynamic emission chambers and measurement system were developed and used in the study, featuring continuous measurement of the following variables: (a) NH_3 and CO_2 concentrations of inlet and outlet air, (b) air temperature and relative humidity, (c) airflow rate through the chambers, (d) feeder weight and thus feeding activity, and (e) manure pan weight and thus defecation activity. Daily feed use of the hens averaged 102 g/hen-d and manure production averaged 117 g/hen-d (as-is). A regression equation was developed that relates manure projected surface area to manure weight. Ammonia emission rate (ER) ranged from 0.03 g/hen-d on the first day of manure accumulation to 0.23 g/hen-d after 6 d of manure accumulation or 0.37 g/hen-d after 8 d of manure accumulation. Ammonia emissions tend to be inversely related to defecation events as manure accumulates.

Namely, higher manure production during light hours is associated with slower increase of NH_3 emission, and lower manure production during dark hours yields faster increase of NH_3 emission. Ammonia emission rate (ER, g/hen-d) shows an exponential relation with manure accumulation time (T, day), of the form, $ER_{NH_3} = 0.0027 \times T^2 + 0.025 \times T$ (R^2=0.998). CO_2 ER was relatively steady throughout the trial period, averaging 3.3 and 2.5 g/hen-hr, respectively, during light and dark hours of the day. Results from this study will contribute to development and validation of process-based farm emission models for predicting NH_3 emissions from laying-hen houses. The dynamic nature of NH_3 emissions vs. defecation can help guide application timing of manure treatment agents to mitigate NH_3 emissions from laying-hen houses.

Keywords: NH_3 emission, CO_2 emission, defecation, laying-hen house, process-based modeling

Introduction

Ammonia (NH_3) is the major gas of environmental concern associated with poultry feeding operations. There have been growing research efforts toward documenting or improving the inventory of NH_3 emissions from animal production systems. One classical multi-national study concerning NH_3 concentrations and emissions from animal housing in northern Europe was reported by Groot Koerkamp *et al.* (1998). The most recent studies on NH_3 emissions from commercial U.S. poultry operations include those reported by Liang *et al.* (2005) for laying hens, Wheeler *et al.* (2006) and Burns *et al.* (2007) for broiler chickens, and Li *et al.* (2008) for turkeys. Ammonia emissions from poultry manure storage as affected by different environmental conditions (e.g., stacking configuration, moisture content of manure, storage temperature)

have also been investigated (Li, 2006). Moreover, increasing attention is being directed toward seeking practical strategies to mitigate air emissions from animal feeding operations, e.g., through dietary manipulation (Liang *et al.*, 2005; Roberts *et al.*, 2007) and topical application of treatment agents on manure (Li *et al.*, 2008).

The 2002 report by the National Academy of Sciences called for development of process-based modeling to enhance the ability to better understand and predict NH_3 emissions from animal feeding operations. To that end, multi-disciplinary efforts have been made to develop such models as reported by Mansell *et al.* (2005) and Zhang *et al.* (2005). In this process, it became clear that information is missing or lacking about the dynamics of NH_3 emissions as affected by the biophysical factors in animal housing.

Laying-hen housing in the United States generally uses either high-rise (HR) or manure-belt (MB) style, with the MB style gaining popularity because of improved indoor air quality. High-rise houses feature in-house manure storage for an extended period (typically one year), whereas MB houses feature more frequent removal of manure (daily to weekly).

The objective of this study was to delineate dynamic emissions of NH_3 and CO_2 as related to feeding and defecation of laying hens under different manure accumulation durations, as may be encountered in commercial MB houses.

Materials and Methods

Feeding, Defecation and Gas Emissions Measurement System

This study was conducted using four newly developed dynamic gas emission chambers, each measuring 86 cm L × 45 cm W × 66 cm H, that were located inside an environmentally-controlled room at the Iowa State University Livestock Environment

and Animal Physiology (LEAP) Lab II (figs. 1a & 1b). The chamber walls were constructed with transparent plexiglass panels (5-mm thickness). Inside each transparent emission chamber was an iron-framed wire-mesh cage (44 cm L × 34 cm W × cm 58 H cm) that was able to accommodate up to three adult hens with a floor space of 500 cm^2/hen (77 in^2/hen). Fresh air to each chamber was supplied through an air distribution plenum to improve spatial uniformity, and the air supply was powered with a diaphragm air pump (100 l/min capacity, DDL 120-101, GAST Manufacturing Inc., Benton Harbor, Michigan, USA[1]) placed in the inlet side of the chamber, thereby creating a positive pressure ventilation system. Airflow rate through each chamber was measured with a thermoelectric air mass flow meter (GFM57, Aalborg Instruments & Controls Inc., Orangeburg, NY, USA) placed in the supply air stream. Before the first trial, all four flow meters were connected in series to check interchangeability or consistency and the results were within the performance specification without any inter-meter correction. Air flow through each chamber was adjustable via a by-pass, so that the target concentrations of NH_3 or CO_2 inside the chamber could be controlled.

To capture the feeding and defecation events, two electronic balances (2200±0.1 g, Model GX2000, A&D Company Limited, Tokyo, Japan) with a 0–2.2 VDC analog output (sampling rate of 0.1 s by the data acquisition system) were used in each chamber, one for measurement of the feeder weight or feeding activity and the other for the manure pan weight or defecation activity of the birds. The balances had automatic response adjustment to compensate for vibration or drafts. One air temperature and relative humidity (RH) sensor (HMP45A/D, Vaisala, Woburn, MA, USA) was placed in

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

each cage to measure the dry-bulb temperature and RH. The exhaust air from each chamber was connected to a 5 cm (2 inch) PVC pipe that was routed to the building vent outlet. A nipple drinker was used to supply drinking water. A plastic cup with tubing was placed underneath each drinker to catch and divert any water leakage into the manure pan.

Samples of the exhaust air from each chamber were successively taken by a sampling pump (0–20 L/min, Teflon wetted parts, Model No. 2107CA20B, Gardner Denver Inc., Sheboygan, WI, USA) at 3-min intervals, with the first 2 min for stabilization and the last 1 min for measurement. This sampling sequence yielded a measurement cycle of 12 min for each chamber. In addition, the supply air was sampled every 36 min (i.e., every three sampling cycles of the chambers) to obtain the background gas concentrations. The successive sampling was accomplished through controlled operation of eight solenoid valves (PKV-2R-D1/4NF, Takasago Electric Inc., Midori-ku, Nagoya, Japan). A Teflon filter (4.5 cm diameter) connected to a Teflon tubing (1.63 cm diameter) was placed in front of each solenoid valve. A photoacoustic multi-gas analyzer (Model 1412, INNOVA AirTech Instruments A/S, Ballerup, Denmark) was used to measure NH_3 and CO_2 concentrations and dew-point temperature of the sample air. The analyzer uses an internal pump to draw sample air at a flow rate of approximately 1.8 L/min, and operated in 22 s cycles (i.e., 2 s for chamber flushing, 3 s for tube flushing, 1 s for sample integration, and the rest for mechanical operation of the analyzer) for the measurements of the sample air. The multi-gas analyzer was challenged or calibrated, as needed, with zero air, 25 ppm NH_3 (balanced with air) span calibration gas and 3000 ppm CO_2 (N_2 balance) calibration gas every two weeks. Response of the

gas analyzer to changes in NH_3 concentration had been tested previously to confirm the validity of the 3-min sampling per chamber. Detailed description of the photoacoustic multi-gas analyzer performance has been given by Moody *et al*. (2008).

Analog outputs from the temperature and RH sensors, INNOVA gas analyzer, electronic balances, and the mass flow meters were logged at 10-s intervals into a measurement and control module (Model CR10, Campbell Scientific, Inc., Logan, UT). All measurements were recorded as average of output values over the 10-s intervals.

To assess the integrity of the dynamic emission chambers system, CO_2 recovery tests were performed on all chambers before the experiment. An alcohol lamp containing 100% alcohol (C_2H_5OH) was placed on the manure pan electronic balance in each chamber during the recovery test, so that the dynamic as well as cumulative alcohol consumption could be obtained from the weight changes. The theoretical volume of CO_2 generation by the alcohol combustion under standard temperature and pressure (STP) condition (T = 273.15K or 0°C, P = 101.325 kPa or 1 ATM), V_{CO2} (L), was calculated by the following equation,

$$V_{CO_2} = \frac{2 \times T \times M_{alcohol}}{46.068} \times 22.4 \qquad [1]$$

where $M_{alcohol}$ is the combustion rate of the 100% alcohol (g/hr); T is the duration of alcohol oxidation (hr); 46.068 is the molecular weight of alcohol (g/mole); and 22.4 is the gas molar volume under the STP of 0°C and 1 ATM (L/mole).

Next, the mass flow meter reading at T = 294.25K and P = 101.325 kPa was converted to the STP of 0°C and 1 ATM using the following ideal gas law equations:

$$\frac{P_{FM} \times V_{FM}}{T_{FM}} = \frac{P_{Ideal} \times V_{Ideal}}{T_{Ideal}} \qquad [2]$$

$$V_{Ideal} = \frac{T_{Ideal} \times P_{FM} \times V_{FM}}{T_{FM} \times P_{Ideal}} \quad [3]$$

where P_{FM} = 101.3 kPa and T_{FM}= 294.25K are, respectively, pressure and temperature corresponding to the air flow meter output V_{FM}; and P_{Ideal} = 101.323 kPa and T_{Ideal} = 273.15K are, respectively, pressure and temperature corresponding to 22.4 L/mole gas; V_{Ideal} is the air flow rate under STP of 0°C and 1 ATM (L/min). The measured CO_2 production of each chamber by the system, V'_{CO2}, is of the form,

$$V'_{CO_2} = (C_{Outlet} - C_{Inlet}) \times V_{Ideal} \times T \quad [4]$$

where C_{Outlet} and C_{Inlet} are, respectively, outlet and inlet CO_2 volumetric concentration in parts per million (ppm); T is the duration of alcohol combustione(hr).

The recovery ratio (RR) was expressed as:

$$RR = \frac{V'_{CO_2}}{V_{CO_2}} \times 100\% \quad [5]$$

The RR values for the chambers generally ranged from 95% to 104%. Gas emissions from each chamber measured subsequently were adjusted based on the respective RR.

Before the recovery test and the experimental trials, the four air mass flow meters were either connected in series to check the consistency (new flow meters in Experiment 1) or checked with one calibrated meter (#4) and calibration equations (in Experiment 2). The following calibration equations were developed for the four flow meters during Experiment 2.

$$CFR_1 = 0.928 \times OFR_1 + 12.29 \quad (R^2 = 0.997) \quad [6]$$

$$CFR_2 = 0.976 \times OFR_2 + 2.98 \quad (R^2 = 0.9999) \quad [7]$$

$$CFR_3 = 0.906 \times OFR_3 + 12.56 \quad (R^2 = 0.998) \quad [8]$$

$$CFR_4 = OFR_4 \qquad [9]$$

Where CFR is Corrected Flow Rate of the flow meter and OFR is the Output Flow Rate of the flow meter.

Experiments with W-36 Laying Hens

Experiment 1:

The experimental W-36 hens were procured from a commercial layer farm in Iowa. They were brought back to the LEAP Lab II and randomly assigned to the emission chambers, 3 hens per cage or chamber. The hens were given 7 days to acclimatize to the chamber environment, followed by 5 to 7 d of data collection. The hens were fed the same diet as used on the farm, with N content of 2.04% – 2.23%. A total of six trials were conducted, involving 36 hens, for this part of the study. The hens averaged 1.48 (± 0.03 S.D.) kg in starting body weight and ranged from 82 to 109 weeks in age. Detailed information about the hens and the dietary N contents is shown in Table 1.

During the experiment, fresh feed was added to the feeder between 18:00 and 19:00 hr daily. Fluorescent light was provided at an illumination intensity of 20 lux, on for 16 hr (05:00 to 21:00h) and off for the remaining 8 hr (21:00 to 05:00h). Manure pans were replaced after the acclimatization period and again after the data collection period. Eggs of each chamber were collected and weighed daily. Hens were weighed at the beginning and the end of each trial.

Experiment 2:

Experimental hens were obtained from a commercial farm in Iowa. A total of 12 Hy-Line W-36 hens were involved in this study. The hens had a starting body weight of

1.45 (± 0.06 S.D.) kg and 48 wk of age. The same diet as used on the farm with N content of 2.75% was fed. The same photoperiod of 16L:8D as used in Experiment 1 was used in this experiment.

A Latin Square Design was used to achieve the different manure accumulation periods of 1, 2, 4, or 8 d, each with a minimum of 4 replicates per accumulation period. In addition to those measurements made in Experiment 1, digital pictures of manure distribution in the pan were taken at the end of each accumulation period and the manure samples collected. Binary images were generated from the digital pictures and projected areas of the manure accumulation calculated. Moreover, at the end of each respective accumulation period, manure in the pan was collected, frozen and subsequently shipped to the collaborator's laboratory at University of California-Davis for manure property analysis (including TKN, urea, uric acid, ammonia, pH, total solids, and volatile solids). At the time of this thesis writing, the manure samples had not been analyzed due to lack of personnel in the Manure Analysis Laboratory at University of California in Davis; hence data were not available for inclusion.

Data Analysis

The NH_3 and CO_2 emissions were calculated from the following equations:

$$ER_{NH_3} = \frac{(C_{Outlet} - C_{Inlet}) \times V_{Ideal} \times 17.03}{22.4 \times 3} \quad [10]$$

$$ER_{CO_2} = \frac{(C_{Outlet} - C_{Inlet}) \times V_{Ideal} \times 44.01}{22.4 \times 3} \quad [11]$$

$$ER_{TWA} = (ER_L \times 16 + ER_D \times 8) / 24 \quad [12]$$

where ER_{NH3} is NH_3 emission rate (g/min); ER_{CO2} is CO_2 emission rate (g/min); 17.03 g/mol is the molecular weight of NH_3; 44.01 g/mol is the molecular weight of CO_2; 22.4

L/mol is the gas molar volume under STP of 0°C and 1 ATM. V_{ideal} is ventilation rate of the chamber at STP of 0°C and 1 ATM (L/min). ER_{TWA} is daily time weighted average ER; ER_L is light period average ER; ER_D is dark period average ER. 16 is total number of light hours in a day; 8 is total number of dark hours in a day; 24 is the daily hours.

To assess the influence of defecation events on dynamic gas emissions, dynamic defecation events in each chamber need to be detected and recorded. Because the manure pan weight was recorded continually every 10 s, defecation events were identified by comparing the adjacent manure pan weight data. Namely, when the difference between two adjacent manure pan weights exceeded the preset threshold (0.5 g), a defecation event was considered to have occurred and the difference in pan weight was considered as the amount of the defecation. Figure 2 shows a sample of defecation events in one cage of 3 hens for a 24-hr period. Since the raw output data from the manure pan scale contained inevitable sources of noise arising from things like vibration of the manure pan from manure dropping on it or vibration from movements of the hens, data filtration was applied to the raw data. Specifically, every manure pan weight reading was compared with its previous reading. If the current reading was 0.5 g higher than the previous reading a potential defecation event was considered to have occurred; then the manure pan weights 30 s before and after the potential event were examined to ensure that the manure pan weights were constant both before and after the event. Manure defecation and gas ER were determined for light or dark period, as well as the time-weighted daily mean or total.

Hourly feed use was calculated as the difference in stabilized feeder weight between start and end of each hour. Hourly defecation amount was calculated by

summing up the amount of all defecation events during that hour.

Projected area of the hen manure accumulated for 1, 2, 4 or 8 d in the manure pan was determined through image analysis generated from Experiment 2. Figure 3 shows photos of the manure pan for different manure accumulation durations, and Figure 4 shows the corresponding 2-dimensional binary images.

Statistical Analysis

Regression analysis was conducted to develop empirical relationships between the response variables (e.g., gaseous emissions vs. manure accumulation time, project surface area vs. manure weight). The significance of coefficient and intercept of each equation was tested, with a P-value of < 0.1 being considered significant. Student's t-test was used to test the significance of the difference between dark-time and light-time NH_3 ER increase rates. JMP 6.0 program (JMP Statistical Discovery 6.0.0, SAS Institute Inc., Cary, NC, USA) was used to carry out all the statistical analyses.

Results and Discussion

Feeding Activities and Defecation Behavior

The mean hourly feed intake and mean hourly defecation are shown in Table 2. The relationship between hourly feed intake and hourly defecation is shown in Figure 5 and further quantified with regression analysis. The hourly defecation ($W_{Defecation}$, g/hen-hr) and feed intake (W_{Feed}, g/hen-hr) had the following relationship,

$$W_{Defecation} = -0.046(0.008) \times W_{feed}{}^2 + 1.001(0.086) \times W_{feed} + 1.97(0.21) \quad (R^2 = 0.94) \text{ [13]}$$

All coefficients were significantly different from zero (P<0.0001). Values in parentheses are SE of the coefficients.

Equation [13] shows that the hourly defecation followed hourly feed intake in a quadratic fashion, although the relationship for feed intake of < 8 g/hen-hr was quite linear. Figure 6 shows the average value of hourly manure production *vs.* hourly feed intake within 24 hours. Data in Table 2 also show that, on average, hens consumed 4 grams of feed during the dark period and 98 grams of feed during the light period, accounting for 4% and 96%, respectively, of the total daily feed intake (102 g/hen-d). The laying hens produced about 20 grams of manure in the dark period and 97 grams of manure during the light period, i.e., 17% and 83%, respectively, of the total daily fresh manure production (117 g/hen-d).

Data on manure weight for different accumulation periods and the corresponding projected surface area (A, cm^2) are summarized in Table 3. The quadratic relationship between A and manure weight W (g) is shown in Figure 7, and of the following form ($P<0.0001$),

$$A = -0.0002(0.00003) \times W^2 + 0.75(0.05) \times W \quad (R^2 = 0.92) \qquad [14]$$

Ammonia (NH_3) Emission as Affected by Manure Accumulation Time

The NH_3 emission rates and related variables for different manure accumulation periods from Experiments 1 and 2 are shown in Tables 4 and 5. The mean NH_3 ER on the first day of manure accumulation was 0.03 g/hen-d in both experiments. Ammonia ER reached 0.23 g/hen-d after 6 d of manure accumulation in Experiment 1, as compared to 0.37 g/hen-d after 8 d of manure accumulation in Experiment 2. Ammonia ER observed in the current study compared fairly well with the 0.054 g/hen-d reported by Liang *et al.* (2005) for commercial MB layer house with daily manure removal. The somewhat higher ER for the commercial house could result from factors such as manure left on the

belt and/or higher temperature in the house during summertime and thus higher ventilation rate (thus higher air velocity over the manure surface). Based on the averaged daily NH_3 ER data from Experiments 1 and 2, the empirical relation of NH_3 ER (ER_{NH3}, g/hen-d) to manure accumulation time (T, day) were developed, and of the following form (P<0.001),

$$ER_{NH_3} = 0.0027(0.0003) \times T^2 + 0.025(0.0017) \times T \quad (R^2 = 0.998) \quad [15]$$

Effect of Defecation on NH_3 Emission

Figure 8 shows the hourly profiles of manure weight and NH_3 emissions of the 3-hen cage during a 7-d accumulation. It can be noted from the manure weight profiles that hens defecate very little during the dark period and much more during the light period of the day, coinciding with the feeding activities. The concurrent manure weight and NH_3 ER profiles also reveal the different ER behavior for light vs. dark period. Interestingly, ER seems to follow an inverse relationship with manure weight change. Namely, during the light period when most defecation occurred and manure weight steadily rose, NH_3 ER showed little increase or even some decrease. On the other hand, during the dark period when there was little defecation and manure weight declined (probably due to moisture evaporation), ER showed a steady increase. This trend was more apparent with longer duration of manure accumulation. In Experiment 1, during 6 d of manure accumulation, NH_3 ER increased at an average rate of 0.15 (P<0.0001) mg/hen-hr^2 for the dark hours, which was significantly higher (P<0.0001) than the rate of NH_3 ER increase of 0.02 (P<0.05) mg/hen-hr^2 for the light hours. In Experiment 2, during 8 d of manure accumulation, NH_3 ER increased at an average rate of 0.10 (P<0.0001) mg/hen-hr^2 for the dark hours, which was again significantly higher (P<0.0001) than the

NH_3 ER increase rate of 0.03 ($P<0.01$) mg/hen-hr^2 for the light hours. The inverse trend of NH_3 emission vs. defecation is further illustrated by the changes in ER relative to the defecation amount (Figures 9 and 10). The hourly changes in ER were determined by subtracting mean ER of the previous hour from mean ER of the current hour. The partitioning of daily NH_3 emissions and rate of change into light vs. dark periods is shown in Table 6 for Experiment 1 and in Table 7 for Experiment 2. Statistical analysis showed that for most of the experiment time, especially for longer manure accumulation durations, hourly NH_3 ER increase for the dark hours was significantly higher than that for the light hours. This inverse relationship presumably stems from that the newly defecated manure covers the old manure surface which is more responsible for NH_3 emission; that new manure needs time to decompose to generate NH_3. Hence the newly produced manure covers part of the old manure, thereby reducing the effective surface area for NH_3 emission. This may also explain why the inverse relationship was not as apparent during the first 2 d because the manure pan was mostly empty and there was not much NH_3 emission surface area to cover or block. This result has an important practical implication in that topical application of manure treatment agents, such as those reported by Li *et al.* (2008), would be more effective when applied during the dark period.

Effect of Feeding and Defecation on CO_2 Emission

Compared to NH_3 emission, CO_2 emission was relatively stable during the light or dark hours throughout the manure accumulation period. The higher CO_2 emission during the light period was mainly due to the higher feeding activities and thus the higher metabolic rate of the hens. Figure 11 shows a sample of CO_2 emission from one chamber for an 8 d period and the corresponding feed weight profile and daily feed intake during

the same period is showing in Figure 12. In Experiment 1, during 6 d of manure accumulation CO_2 production or emission averaged 3.4 g/hen-hr during light period (73.5% of daily emission) and 2.5 g/hen-hr during dark period (26.5% of daily emission). The daily time-weighted average (TWA) emission was 3.1 g/hen-hr (Table 8). Similar results were observed in Experiment 2. Namely, during the 8 d of manure accumulation, CO_2 ER averaged 3.2 g/hen-hr for light period (72.9% of daily emission), 2.5 g/hen-hr for dark period (27.1% of daily emission) and daily TWA of 3.0 g/hen-hr (Table 9). These values compared well with those as reported by Chepete *et al.* (2004), i.e., 3.5, 2.7 and 3.2 g/hen-hr for light, dark and TWA, respectively, for W-36 hens (1.53 kg at 64 wk of age) under thermoneutral conditions.

Although the CO_2 emissions remained relatively stable, some increase was noted as the manure accumulated. Using the CO_2 ER for light and dark hours for the first day as the respective base, in Experiment 1, over the 6 d of manure accumulation the subsequent daily CO_2 ER was shown to increase on average by 0.06 g/hen-hr for the light period and 0.11 g/hen-hr for the dark period, or 0.11% and 0.61% of the first day respective photoperiod CO_2 ER. The mean daily CO_2 emission level kept increasing until the 5^{th} day of the manure accumulation. In Experiment 2, over 8 d of manure accumulation the CO_2 increasing rate on average was 0.03 g/hen-hr for light period and 0.04 g/hen-hr for dark period, respectively, or 0.06% and 0.21% of the first day respective photoperiod CO_2 ER. The mean daily CO_2 emission level kept increasing until the 5^{th} day of the manure accumulation. The lower average increasing rates for both light period and dark period in Experiment 2 were due to the low increasing rates in the 7^{th} and 8^{th} days. This increase was speculated to arise from release of CO_2 from manure

(uric acid) decomposition. The increasing of CO_2 ER seems to coincide with the increasing of NH_3 ER. However, as shown in Tables 8 and 9 and Figure 13, CO_2 ER for longer manure accumulation tends to approach stabilization. This behavior of CO_2 production has an implication on use of metabolic CO_2-mass balance for indirectly estimating building ventilation rate, as illustrated by Li *et al.* (2005).

Summary and Conclusions

This study investigated NH_3 and CO_2 emissions from W-36 laying hens as related to feeding and defecation events of the birds and manure accumulation period (1 to 8 d). The hens were kept in 3-bird cages (500 cm^2/hen or 77 in^2/hen cage floor area) inside environmentally-controlled (24–26°C) dynamic emission chambers. The hens were provided a 16L:8D photoperiod and *ad-lib* feeding. The following observations and conclusions were made.

- The hens had a daily feed consumption of 102 g/hen-d and manure production of 117 g/hen-d (as-is basis). Daily feed use was partitioned as 96% during light period (L) and 4% during dark period (D). Similarly, daily manure production was partitioned into 83% L and 17% D.
- NH_3 emission rate ranged from 0.03 g/hen-d on day 1 of manure accumulation, 0.23 g/hen-d after 6 d of manure accumulation, and 0.37 g/hen-d after 8 d of manure accumulation. Daily NH_3 emission was partitioned into 69–70% L and 31–30% D.
- An empirical regression equation was developed that relates daily NH_3 emission to manure accumulation time under thermoneutral conditions. This relationship may be used to estimate the NH_3 emissions from manure-belt layer houses.

- NH_3 emissions of the hens show an inverse relation to defecation activities. This phenomenon is insightful to effective application of manure treatment agents for mitigating NH_3 emissions from hen manure.
- An empirical regression equation was developed that relates projected manure surface area to accumulated manure weight for the laying hens. The NH_3 emissions per unit projected manure surface area may be useful to assessing the impact of different production situations (e.g., cage-free) on NH_3 emissions.
- CO_2 emission was 70 g/hen-d on day 1 of manure accumulation and 78 g/hen-d after 6–8 d of manure accumulation. In both Experiments 1 and 2 CO_2 ER inclined in the first 5 days and then stabilized afterwards. Daily CO_2 emission was partitioned into 73% L and 27% D.

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Table 1. Information of the experimental hens and feed for Experiment 1

Trial	Hen Age (wk)	Hen Body Weight (kg), mean (±S.D.)		Feed Nitrogen Content (%)
		Start	End	
1	105	1.47(±0.04)	1.49 (±0.03)	2.12%
2	109	1.49 (±0.02)	1.46 (±0.04)	2.04%
3	98	1.47 (±0.01)	1.46 (±0.03)	2.36%
4	104	1.52 (±0.02)	1.49 (±0.03)	2.35%
5	82	1.46 (±0.02)	1.45 (±0.03)	2.23%
6	86	1.46 (±0.03)	1.49 (±0.03)	2.22%

Table 2. Hourly feed intake and defecation of Hy-Line W-36 laying hens in both experiments

Hour of Day	Light or Dark	FI (g/hen-hr)	SEM	Def. (g/hen-hr)	SEM	Hour of Day	Light or Dark	FI (g/hen-hr)	SEM	Def. (g/hen-hr)	SEM
0-1	D	0.37	0.07	2.51	0.19	12-13	L	5.29	0.21	6.04	0.36
1-2	D	0.24	0.05	2.14	0.16	13-14	L	5.37	0.2	6.13	0.31
2-3	D	0.4	0.1	2.56	0.17	14-15	L	6.04	0.23	6.9	0.34
3-4	D	0.21	0.03	2.73	0.18	15-16	L	6.08	0.27	6.58	0.3
4-5	D	0.54	0.08	2.82	0.19	16-17	L	5.91	0.21	6.18	0.3
5-6	L	1.39	0.14	3.23	0.21	17-18	L	8.01	0.34	7.96	0.37
6-7	L	4.31	0.24	4.11	0.28	18-19	L	11.73	0.43	7.4	0.38
7-8	L	4.51	0.17	5.32	0.33	19-20	L	11.99	0.38	7.09	0.3
8-9	L	4.66	0.21	5.87	0.31	20-21	L	6.34	0.36	5.75	0.27
9-10	L	4.8	0.21	6.63	0.34	21-22	D	1.54	0.17	2.77	0.19
10-11	L	5.63	0.22	5.81	0.3	22-23	D	0.43	0.07	1.9	0.15
11-12	L	5.67	0.23	6.22	0.34	23-24	D	0.24	0.05	2.25	0.18
						Daily total (g/hen-d)		102		117	

Table 3. Manure weight, projected area, and projected area to weight ratio of laying hens in groups of 3 hens vs. manure accumulation time in Experiment 2

Variables	Manure Accumulation Time, d			
	1	2	4	8
Number of observations	4	4	4	4
Start body weight, kg (SE)	1.45 (0.06)			
End body weight, kg (SE)	1.47 (0.08)			
Daily feed intake, g/hen (SE)	97 (1.5)			
Manure weight, g (SE)	277 (28)	514 (96)	1000 (11)	1904 (221)
Projected area, cm^2 (SE)	232 (41)	428 (55)	531 (32)	735 (64)
Area/weight, cm^2/g (SE)	0.82 (0.09)	0.87 (0.07)	0.53 (0.03)	0.39 (0.05)

Table 4. Ammonia emission rate vs. manure accumulation time of 3-hen cages in Experiment 1

Variables	Manure Accumulation Time, day							
	1	2	3	4	5	6	7	8
Number of Observation	16	12	7	7	4	4	4	4
NH_3 ER, mg/hen-hr (SE)	1.44 (0.25)	2.55 (0.54)	3.70 (0.70)	5.59 (0.86)	8.01 (2.28)	11.16 (2.88)	12.60 (2.80)	15.43 (3.16)
NH_3 ER, g/hen-d (SE)	0.03 (0.010)	0.06 (0.013)	0.09 (0.017)	0.13 (0.021)	0.19 (0.055)	0.27 (0.069)	0.30 (0.067)	0.37 (0.076)
NH_3 ER, g/kg egg-d (SE)	0.77 (0.13)	1.37 (0.28)	2.01 (0.39)	3.01 (0.47)	4.26 (1.19)	5.95 (1.51)	6.71 (1.46)	8.23 (1.63)
NH_3 ER, g/kg N intake-d (SE)	13.2 (2.3)	22.5 (4.4)	34.0 (6.9)	50.1 (8.2)	72.9 (21.5)	100.9 (29.7)	121.6 (33.2)	141.0 (31.2)
Manure weight, g (SE)	256 (14)	492 (32)	620 (71)	893 (32)	1054 (53)	1258 (57)	1430 (79)	1501 (119)
NH_3 ER, g/kg manure-d (SE)	0.13 (0.02)	0.12 (0.02)	0.13 (0.02)	0.15 (0.02)	0.18 (0.05)	0.21 (0.06)	0.21 (0.05)	0.24 (0.05)
Projected surface area*, cm^2 (SE)	178 (9)	319 (18)	420 (16)	510 (15)	567 (17)	625 (13)	660 (12)	667 (18)
Area/manure weight, cm^2/g (SE)	0.7 (0.003)	0.65 (0.01)	0.63 (0.01)	0.57 (0.01	0.54 (0.01)	0.5 (0.01)	0.46 (0.02)	0.45 (0.02)
NH_3 ER, g/m^2 manure area-d (SE)	5.6 (0.85)	5.4 (0.97)	6.2 (1.11)	7.2 (1.15)	10.1 (2.89)	12.8 (3.36)	13.7 (3.05)	16.5 (3.20)

*The projected surface area was calculated based on the regression equation [14] from Expt 2

Table 5. Ammonia emission rate for different days of manure accumulation of 3-hen cages in Experiment 2

Variables	Manure Accumulation Time, day							
	1	2	3	4	5	6	7	8
Number of Observation	16	12	7	7	4	4	4	4
NH_3 ER, mg/hen-hr (SE)	1.44 (0.25)	2.55 (0.54)	3.70 (0.70)	5.59 (0.86)	8.01 (2.28)	11.16 (2.88)	12.60 (2.80)	15.43 (3.16)
NH_3 ER, g/hen-d (SE)	0.03 (0.010)	0.06 (0.013)	0.09 (0.017)	0.13 (0.021)	0.19 (0.055)	0.27 (0.069)	0.30 (0.067)	0.37 (0.076)
NH_3 ER, g/kg egg-d (SE)	0.77 (0.13)	1.37 (0.28)	2.01 (0.39)	3.01 (0.47)	4.26 (1.19)	5.95 (1.51)	6.71 (1.46)	8.23 (1.63)
NH_3 ER, g/kg N intake-d (SE)	13.2 (2.3)	22.5 (4.4)	34.0 (6.9)	50.1 (8.2)	72.9 (21.5)	100.9 (29.7)	121.6 (33.2)	141.0 (31.2)
Manure weight, g (SE)	256 (14)	492 (32)	620 (71)	893 (32)	1054 (53)	1258 (57)	1430 (79)	1501 (119)
NH_3 ER, g/kg manure-d (SE)	0.13 (0.02)	0.12 (0.02)	0.13 (0.02)	0.15 (0.02)	0.18 (0.05)	0.21 (0.06)	0.21 (0.05)	0.24 (0.05)
Projected surface area*, cm^2 (SE)	178 (9)	319 (18)	420 (16)	510 (15)	567 (17)	625 (13)	660 (12)	667 (18)
Area/manure weight, cm^2/g (SE)	0.7 (0.003)	0.65 (0.01)	0.63 (0.01)	0.57 (0.01	0.54 (0.01)	0.5 (0.01)	0.46 (0.02)	0.45 (0.02)
NH_3 ER, g/m^2 manure area-d (SE)	5.6 (0.85)	5.4 (0.97)	6.2 (1.11)	7.2 (1.15)	10.1 (2.89)	12.8 (3.36)	13.7 (3.05)	16.5 (3.20)

*The projected surface area was calculated based on the regression equation [14] from Expt 2

Table 6. Partitioning of ammonia emission rate of the laying hens and hourly emission change by photoperiod in Experiment 1

Variables	Manure Accumulation Time, day					
	1	2	3	4	5	6
Number of Observation (day)	11	11	11	11	11	9
Light time NH_3 ER, mg/hen-hr (SE)	1.35 (0.14)	2.31 (0.22)	3.95 (0.46)	6.07 (0.60)	8.65 (0.79)	9.97 (0.74)
% of daily NH_3 emission in light hours (SE)	70% (1.0%)	72% (0.8%)	70% (0.5%)	69% (0.5%)	68% (0.4%)	68% (0.6%)
Dark time NH_3 ER, mg/hen-hr (SE)	1.18 (0.15)	1.78 (0.17)	3.39 (0.45)	5.36 (0.56)	8.15 (0.82)	9.16 (0.71)
% of daily NH_3 emission in dark hours (SE)	30% (1.0%)	28% (0.8%)	30% (0.5%)	31% (0.5%)	32% (0.4%)	32% (0.6%)
Light time NH_3 increase rate, mg/hen-hr^2 (SE)	0.01 (0.004)	0.05 (0.010)	0.02 (0.007)	0.03 (0.017)	0.00 (0.012)	0.04 (0.042)
Dark time NH_3 increase rate, mg/hen-hr^2 (SE)	-0.04** (0.02)	0.07 (0.01)	0.15**** (0.03)	0.22**** (0.02)	0.30**** (0.04)	0.23** (0.06)

P-value of the contrast of Light-hour NH_3 increase rate vs. dark-hour NH_3 increase rate: *P<0.1, **P<0.05, ***P<0.01, ****P<0.001

Table 7. Partitioning of ammonia emission rate of the laying hens and hourly emission change by photoperiod in Experiment 2

Variables	Manure Accumulation Time, day							
	1	2	3	4	5	6	7	8
Number of Observation (day)	16	11	7	8	4	4	4	4
Light time NH_3 ER, mg/hen-hr (SE)	1.54 (0.26)	2.77 (0.54)	3.93 (0.69)	5.97 (0.86)	8.55 (2.18)	11.51 (2.68)	13.13 (2.68)	16.29 (3.04)
% of daily NH_3 emission in light hours (SE)	71% (1.3%)	73% (0.7%)	71% (1.5%)	71% (0.8%)	71% (0.8%)	69% (0.8%)	69% (0.7%)	70% (0.4%)
Dark time NH_3 ER, mg/hen-hr (SE)	1.24 (0.23)	2.10 (0.46)	3.25 (0.67)	4.83 (0.76)	6.92 (2.05)	10.47 (2.88)	11.53 (2.45)	13.70 (2.69)
% of daily NH_3 emission in dark hours (SE)	29% (1.3%)	27% (0.7%)	29% (1.5%)	29% (0.8%)	29% (0.8%)	31% (0.8%)	31% (0.7%)	30% (0.4%)
Light time NH_3 increase rate, mg/hen-hr^2 (SE)	0.02 (0.01)	0.05 (0.01)	0.04 (0.01)	0.06 (0.02)	0.08 (0.04)	0.08 (0.08)	0.01 (0.03)	0.03 (0.08)
Dark time NH_3 increase rate, mg/hen-hr^2 (SE)	-0.05^{***} (0.01)	0.07 (0.02)	0.12^{***} (0.02)	0.16^{**} (0.03)	0.19^{*} (0.04)	0.30^{****} (0.09)	0.33^{***} (0.06)	0.31^{**} (0.10)

P-value of the contrast of Light-hour NH_3 increase rate vs. dark-hour NH_3 increase rate: $^{*}P<0.1$, $^{**}P<0.05$, $^{***}P<0.01$, $^{****}P<0.001$

Table 8. Carbon dioxide emission rate (ER), hourly change rate and light-dark hour partitioning of 3-hen cages – Experiment 1

Variables	Manure Accumulation Time, day					
	1	2	3	4	5	6
Light time CO_2 ER, g/hen-hr (SE)	3.26 (0.09)	3.31 (0.10)	3.39 (0.08)	3.46 (0.08)	3.56 (0.10)	3.54 (0.11)
% of daily CO_2 emission in light hours (SE)	75% (0.3%)	74% (0.3%)	73% (0.5%)	73% (0.4%)	73% (0.4%)	72% (0.5%)
Dark time CO_2 ER, g/hen-hr (SE)	2.17 (0.04)	2.26 (0.06)	2.46 (0.07)	2.53 (0.04)	2.67 (0.05)	2.70 (0.06)
% of daily CO_2 emission in dark hours (SE)	25% (0.3%)	26% (0.3%)	27% (0.5%)	27% (0.4%)	27% (0.4%)	28% (0.5%)
Daily TWA CO_2 ER, g/hen-hr (SE)	2.90 (0.07)	2.96 (0.09)	3.08 (0.07)	3.15 (0.06)	3.27 (0.08)	3.26 (0.09)
Daily TWA CO_2 ER, g/hen-d (SE)	69.5 (1.66)	71.0 (2.06)	74.0 (1.64)	75.7 (1.46)	78.4 (1.89)	78.2 (2.07)
Daily CO_2 ER increase, g/hen-d^2 (SE)	N/A	1.44 (1.0)	3.04 (1.2)	1.65 (0.8)	2.75 (0.9)	-0.18 (1.0)
% of daily CO_2 increase (relative to the first day value) (SE)	N/A	2.1% (1.5%)	4.4% (1.7%)	2.4% (1.1%)	4.0% (1.4%)	-0.3% (1.4%)

Table 9. Carbon dioxide emission rate (ER), hourly change rate and light-dark hour partitioning of 3-hen cages – Experiment 2

Variables	Manure Accumulation Time, day							
	1	2	3	4	5	6	7	8
Light time CO_2 ER, g/hen-hr (SE)	3.05 (0.05)	3.09 (0.06)	3.21 (0.07)	3.30 (0.08)	3.36 (0.06)	3.37 (0.04)	3.42 (0.12)	3.26 (0.11)
% of daily CO_2 emission in light hours (SE)	72% (0.3%)	72% (0.5%)	72% (0.4%)	72% (0.5%)	72% (0.2%)	72% (0.5%)	72% (0.3%)	72% (0.8%)
Dark time CO_2 ER, g/hen-hr (SE)	2.35 (0.06)	2.36 (0.08)	2.44 (0.08)	2.56 (0.11)	2.68 (0.04)	2.61 (0.05)	2.62 (0.07)	2.61 (0.07)
% of daily CO_2 emission in light hours (SE)	28% (0.3%)	28% (0.5%)	28% (0.4%)	28% (0.5%)	28% (0.2%)	28% (0.5%)	28% (0.3%)	28% (0.8%)
Daily TWA CO_2 ER, g/hen-hr (SE)	2.81 (0.05)	2.85 (0.06)	2.95 (0.07)	3.05 (0.09)	3.13 (0.05)	3.12 (0.03)	3.15 (0.11)	3.05 (0.09)
Daily TWA CO_2 ER, g/hen-d (SE)	73.2 (1.3)	74.3 (1.4)	77.0 (1.6)	79.2 (1.9)	80.6 (1.3)	80.9 (1.1)	82.0 (3.0)	78.3 (2.6)
Daily CO_2 ER increase, g/hen-d^2 (SE)	N/A	2.87 (0.7)	2.47 (0.8)	2.38 (1.0)	1.95 (0.9)	-0.35 (1.2)	0.81 (1.1)	-2.43 (1.2)
% of daily CO_2 increase (SE) (relative to the first day value)	N/A	3.9% (1.0%)	3.4% (1.2%)	3.3% (1.5%)	2.7% (1.3%)	-0.5% (1.8%)	1.1% (1.6%)	-3.3% (1.8%)

Figure 1a. An overview of the dynamic gas emissions chambers and measurement setup located in the Iowa State University Livestock Environment and Physiology (LEAP) Lab II.

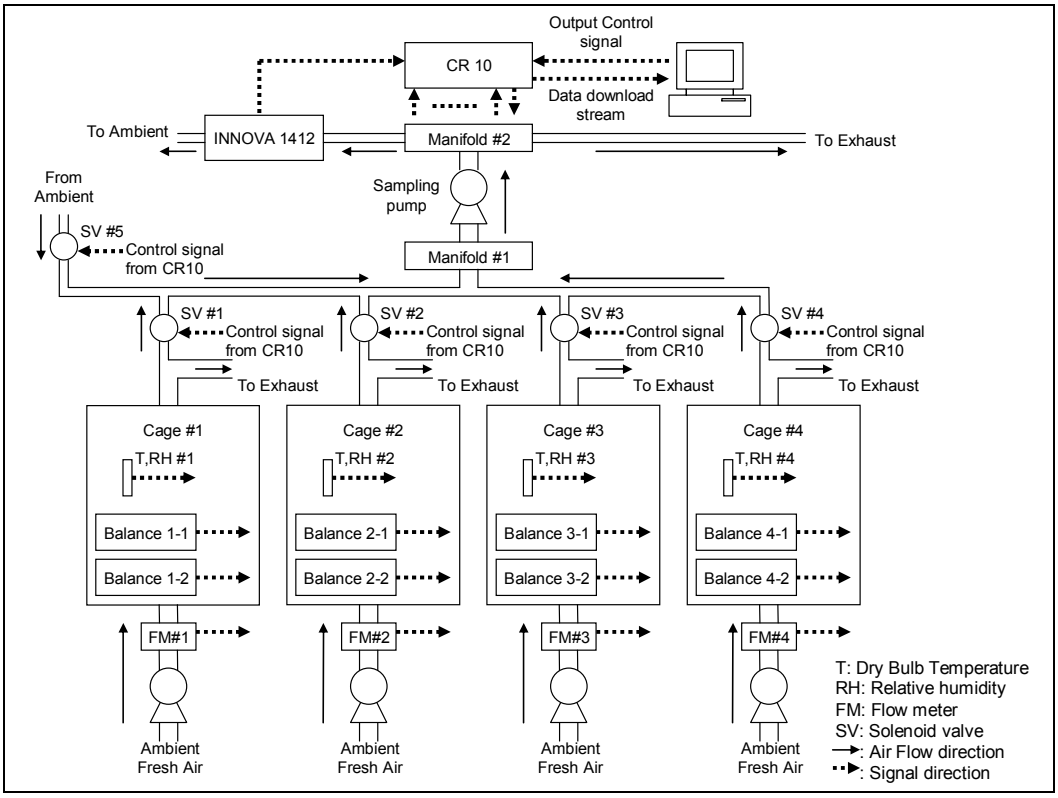

Figure 1b. Schematic representation of the dynamic gas emissions chambers and control and measurement setup located in the Iowa State University LEAP Lab II.

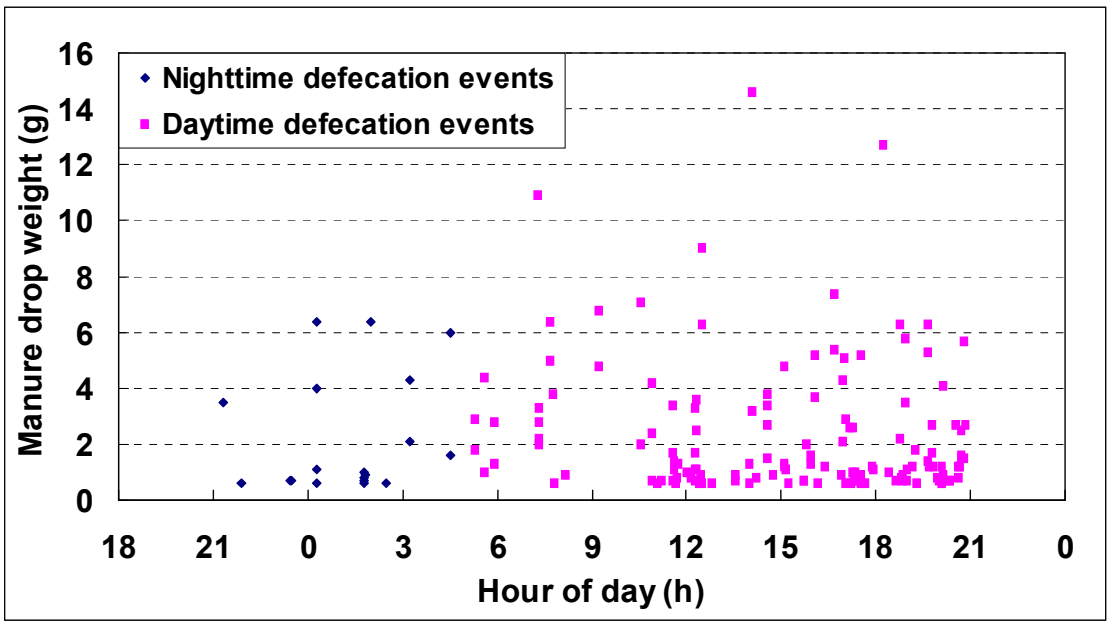

Figure 2. An example of diurnal defecation activities by a cage of 3 laying hens.

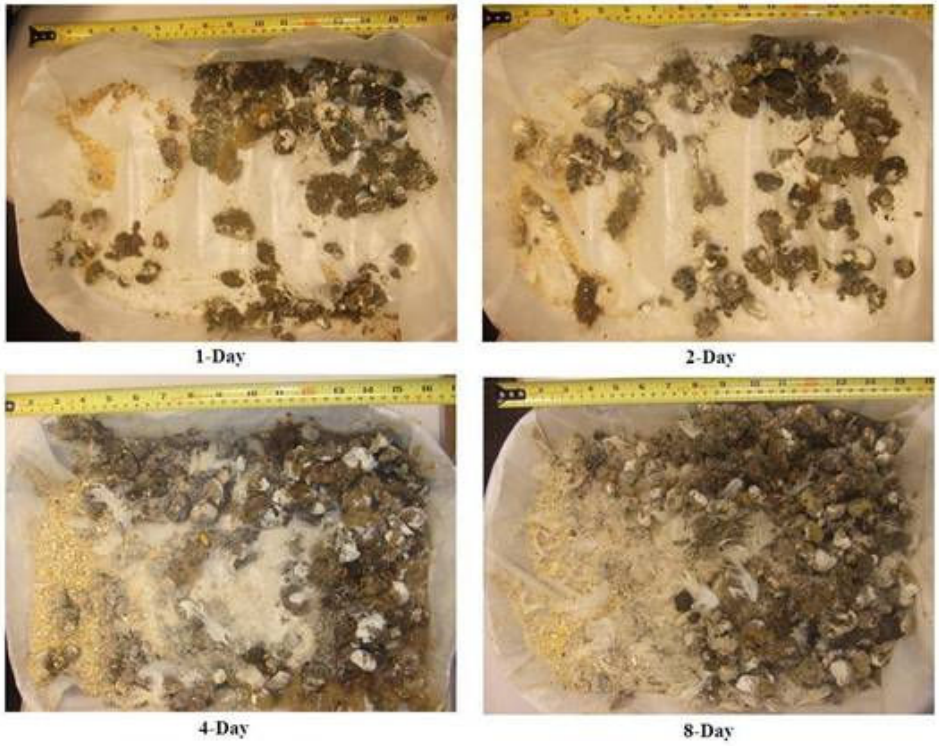

Figure 3. Photos of manure accumulation from a cage of 3 hens for 1, 2, 4 or 8 d.

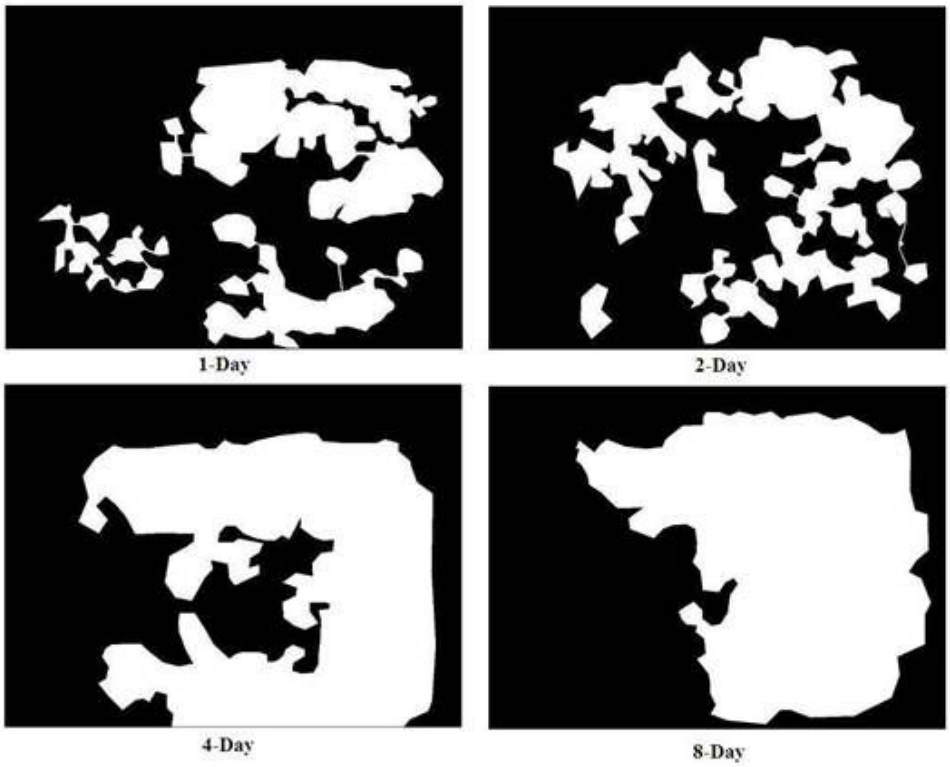

Figure 4. Binary images of manure accumulation for 1, 2, 4 or 8 d corresponding to the digital images shown in Figure 3.

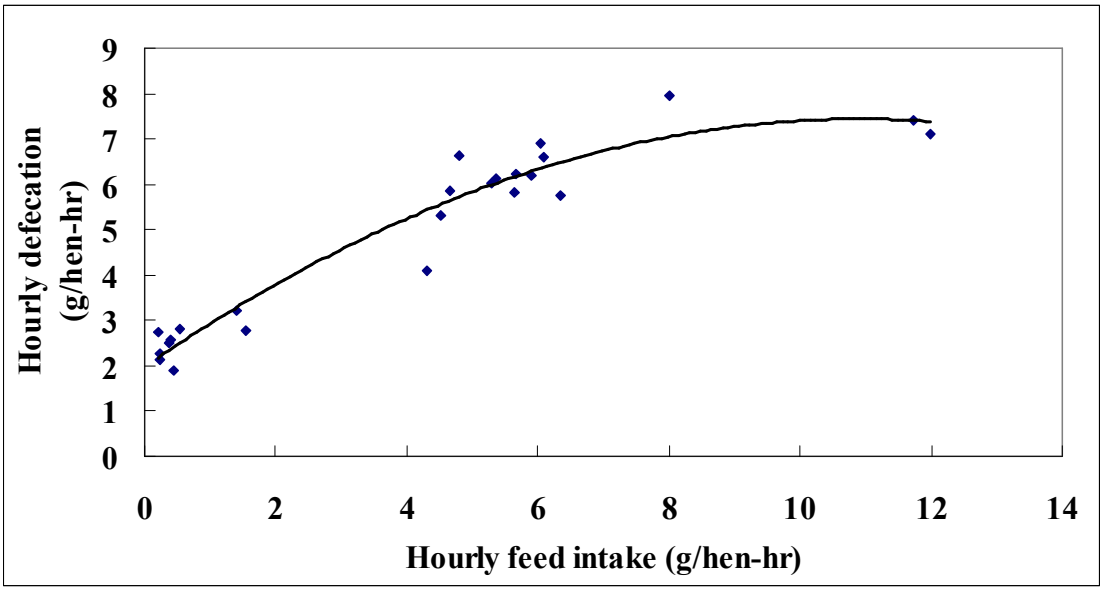

Figure 5. Relationship between Hourly defecation *vs.* hourly feed intake of laying hens.

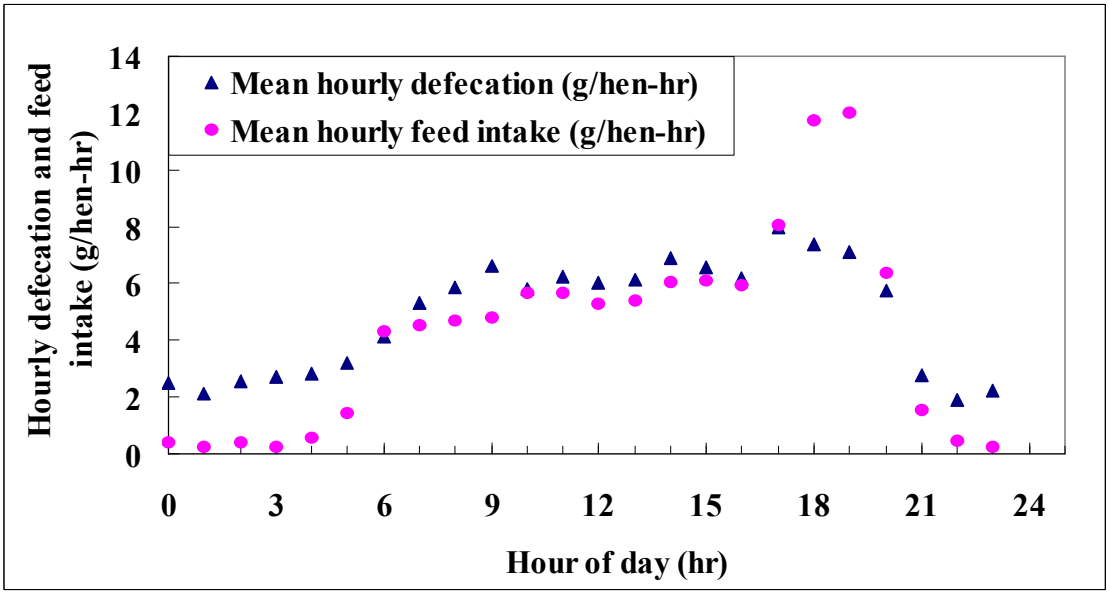

Figure 6. Average hourly manure production *vs.* hourly feed intake of laying hens. Lights were on from 0500 to 2100 h and off from 2100 to 0500 h.

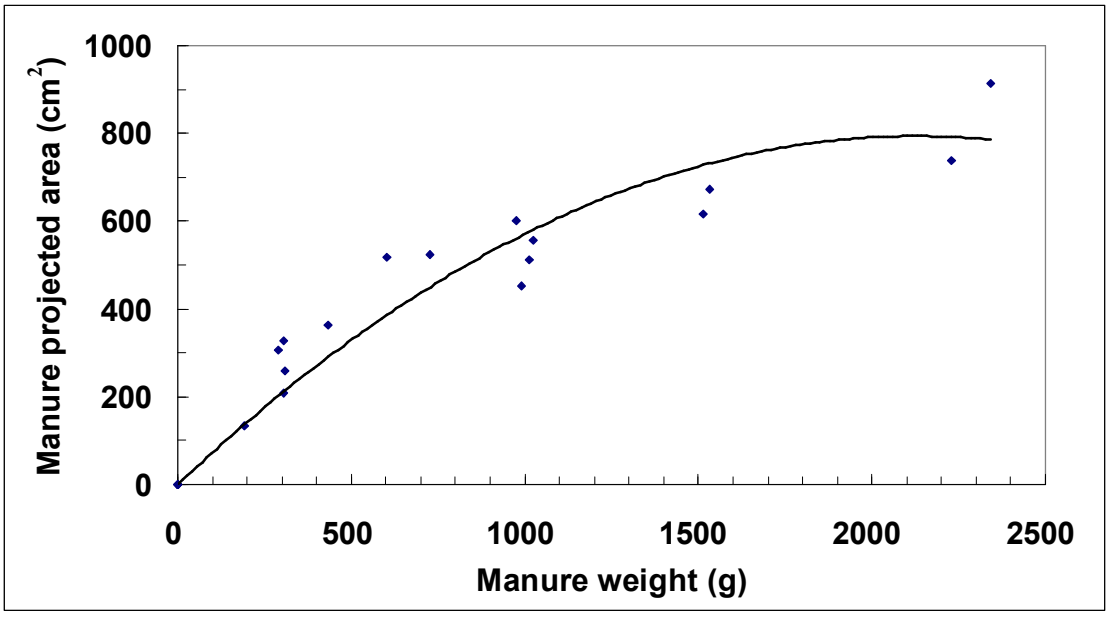

Figure 7. Relationship between projected surface area and weight of laying-hen manure.

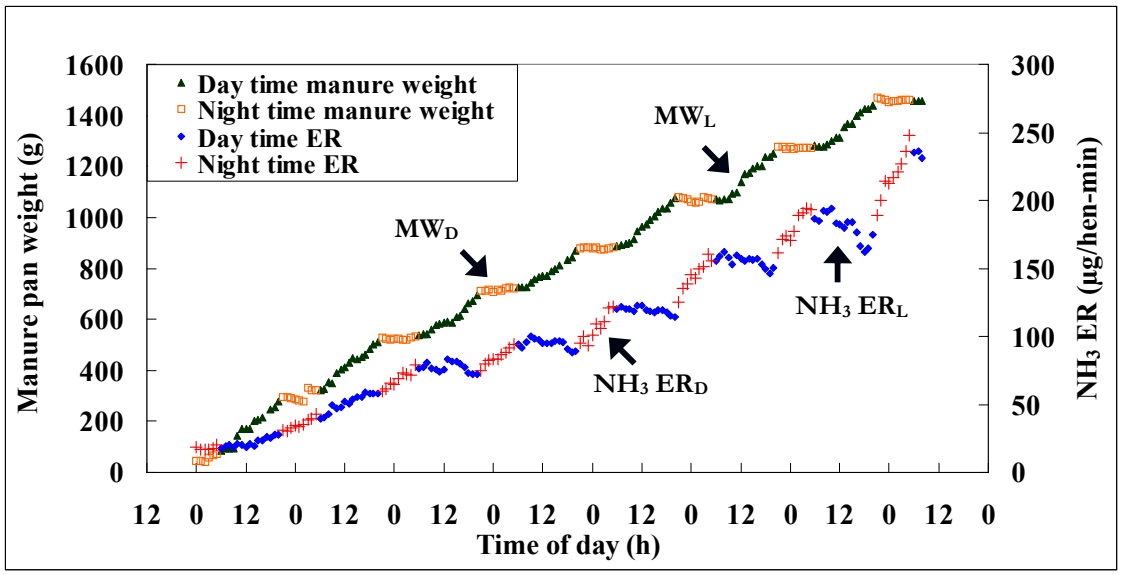

Figure 8. NH_3 ER and manure weight profiles of 3-hen cage over a 7-day manure accumulation(MW_D: Dark period manure weight; MW_L: Light period manure weight; NH_3ER_D: Dark period NH_3 ER; NH_3ER_L: Light period NH_3 ER)

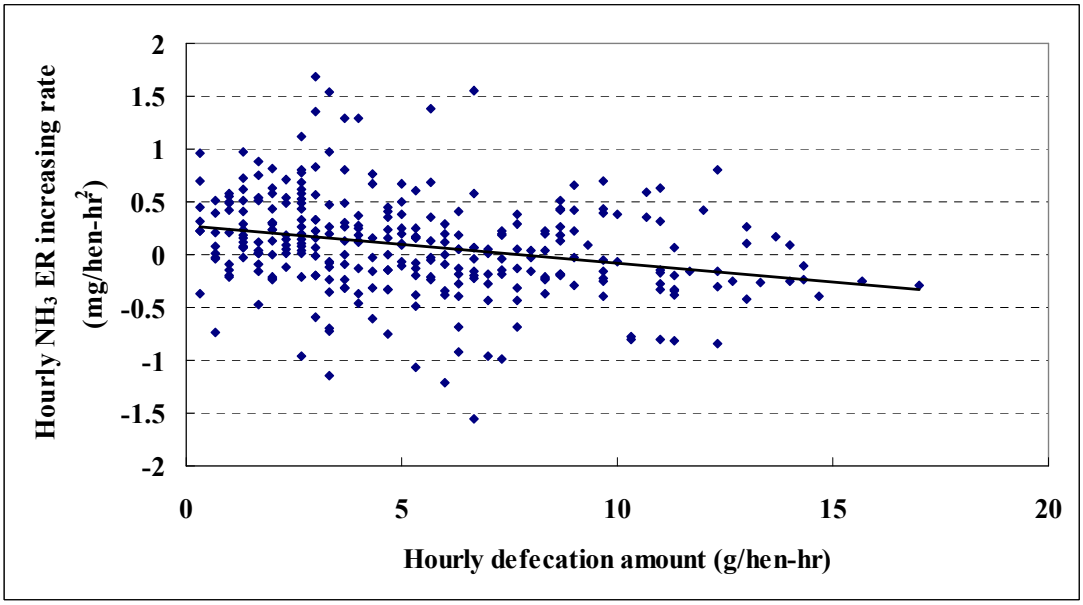

Figure 9. Hourly NH_3 ER change vs. hourly defecation of Hy-LineW-36 laying hens on the 6th day of manure accumulation.

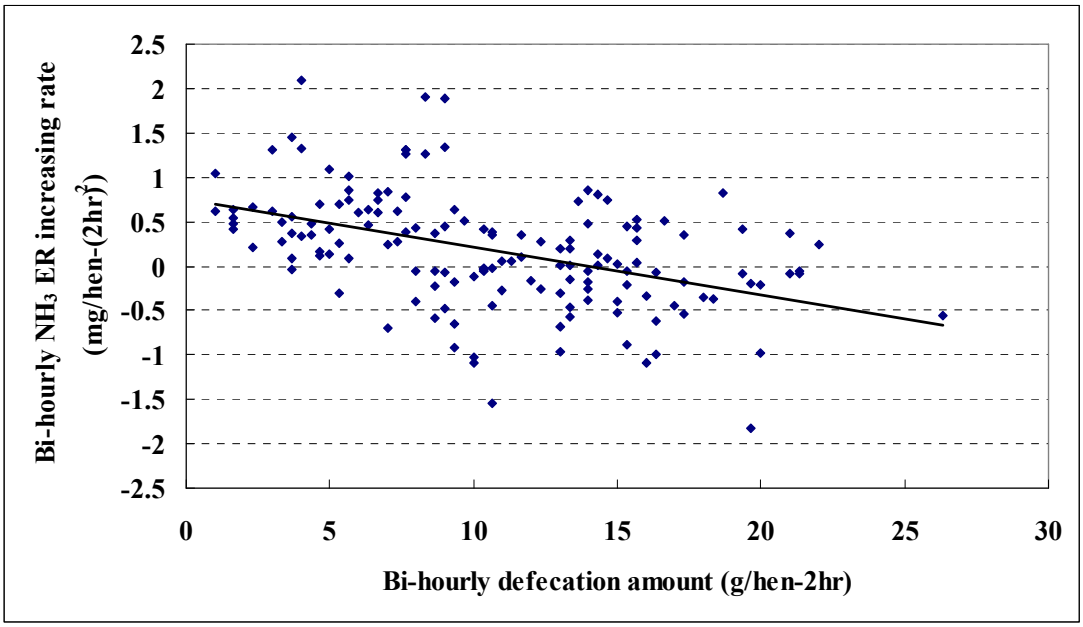

Figure 10. Bi-hourly NH_3 ER change *vs.* bi-hourly defecation of Hy-LineW-36 laying hens on the 6th day of manure accumulation.

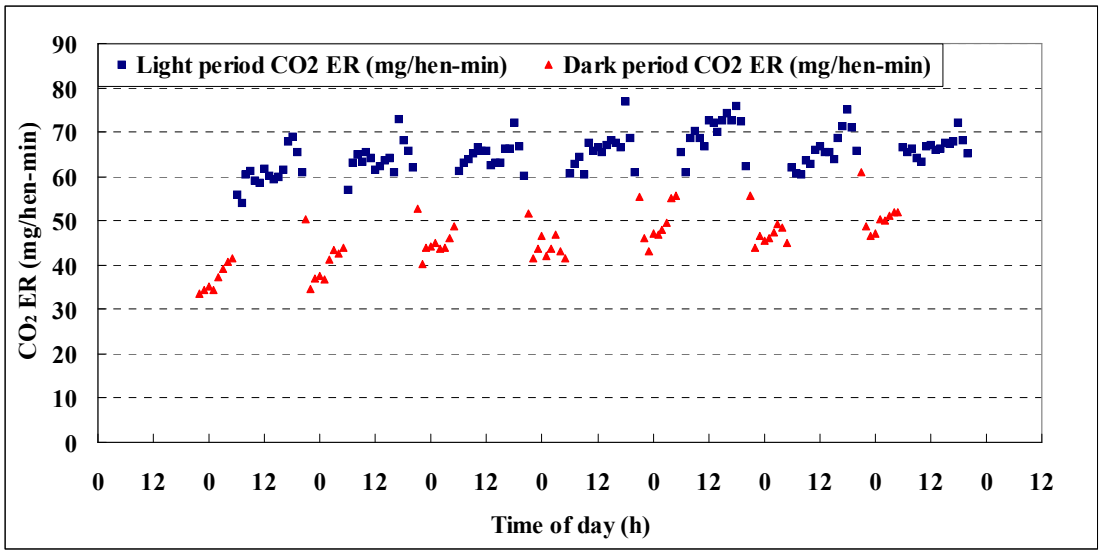

Figure 11. A sample of CO_2 emission rate from laying hens during an 8-day monitoring period.

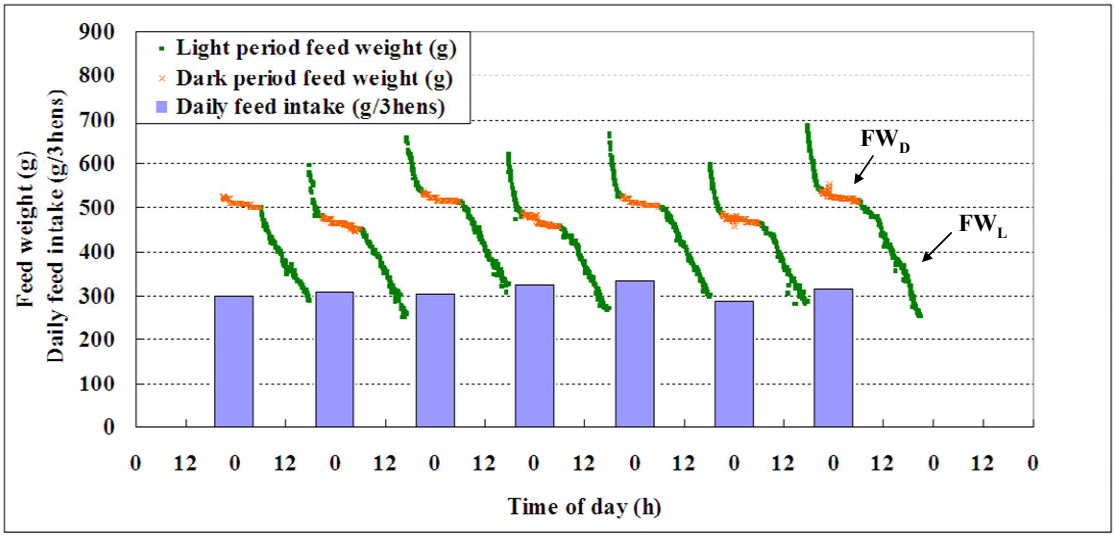

Figure 12. A sample of feed weight profile and daily feed intake from laying hens during an 8-day monitoring period (FW_L: Light period feed weight; FW_D: Dark period feed weight)

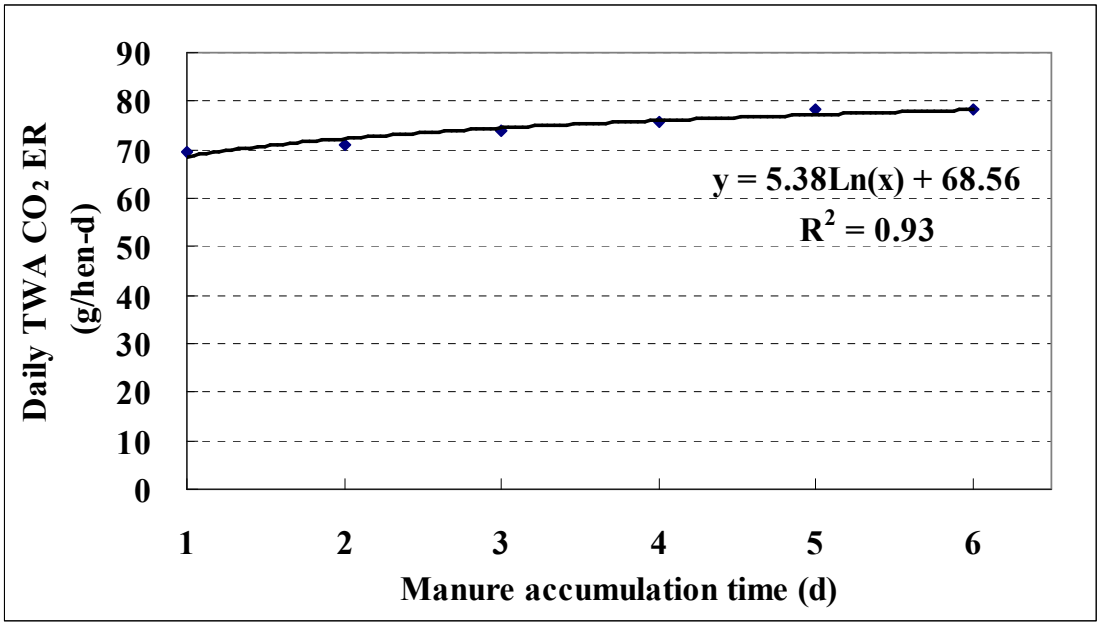

Figure 13. Mean daily time-weighted average (TWA) CO_2 ER during 6 days of manure accumulation.

CHAPTER 3. EFFECTS OF DIETARY CORN DISTILLER'S DRIED GRAIN WITH SOLUBLES (DDGS) ON GASEOUS EMISSIONS AND PERFORMANCE OF W-36 LAYING HENS

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Abstract

This study evaluates the effect of corn distiller's dried grain with solubles (DDGS) diet (15% by weight) vs. standard or control (Ctrl) diet on W-36 laying hens in terms of feed intake, manure production, egg production, and ammonia (NH_3) and carbon dioxide (CO_2) emissions. Four dynamic emission chambers and measurement system were developed and used in the study, continually measuring the gaseous (NH_3 and CO_2) concentrations of inlet and outlet air, temperature and relative humidity, airflow rate through each chamber, feeder weight, manure pan weight and thus feeding and defecation activities of the hens. Daily feed consumption of the hens was similar for both dietary regimens, averaging 102 g/hen-d for the DDGS hens and 105 g/hen-day for the Ctrl hens. Manure production of the DDGS hens was 16% higher than that of the Ctrl hens, 133 *vs.* 115 g/hen-d g/hen-d (as-is) ($P<0.001$). Egg production of the DDGS hens was 13% higher than that of the Ctrl hens, 48 *vs.* 42 g/hen-d ($P<0.05$). After 3 days of manure accumulation, NH_3 emission rate (ER) for the DDGS hens was 19% lower than that for the Ctrl hens, 0.07 *vs.* 0.09 g/hen-d ($P=0.23$). After 6 days of manure

accumulation, NH_3 emission rate (ER) of the DDGS hens was 26% lower than that of the Ctrl hens, 0.17 *vs.* 0.23 g/hen-d ($P<0.1$). Hence this study shows that inclusion of DDGS in laying-hen diet may be a viable strategy to reduce NH_3 emission without adversely affecting production performance of the hens. Field-scale verification test is necessary to confirm the lab-scale results.

Keywords. Laying hen, DDGS, Ammonia emission mitigation

Introduction

Ammonia (NH_3) is an irritant, colorless gas with a characteristic pungent odor. It is a common by-product generated from the decomposition of organic components in animal waste. Ammonia has various potential negative impacts on the environment (NRC, 2003). Ammonia can also be harmful to both animals and human beings. Research has shown that prolonged exposure to high concentrations of NH_3 can cause significant lower body weight gain and reduced egg production in laying hens (Deaton *et al.,* 1982). Ammonia released from livestock operations may also pose risks on human health (McCubbin *et al.,* 2002, Auvermann and Rogers, 2002, Wing and Wolfe, 2000). Each year about 30% of total NH_3 generated from made-made activities is released from poultry facilities (Battye *et al.*, 1994). There have been growing research efforts toward documenting or improving the inventory of NH_3 emissions from animal production systems. One classical multi-national study concerning NH_3 concentrations and emissions from animal housing in northern Europe was reported by Groot Koerkamp *et al.* (1998). The most recent studies on NH_3 emissions from commercial U.S. poultry operations include those reported by Liang *et al.* (2005) for laying hens, Wheeler *et al.* (2006) and Burns *et al.* (2007) for broiler chickens, and Li *et al.* (2008) for turkeys.

Ammonia emissions from poultry manure storage as affected by different environmental conditions (e.g., stacking configuration, moisture content of manure, storage temperature) have also been investigated (Li, 2006).

The Occupational Safety and health Administration (OSHA) has set permissible NH_3 level for 8-hr exposure to 50 ppm, whereas the National Institute of Occupational Safety and Health (NOISH) has set the 8-hr permissible NH_3 exposure level to 25 ppm. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a limit of 35 ppm for 15-minute exposures. Various practical strategies such as dietary manipulation (Liang *et al.*, 2005; Roberts *et al.*, 2007) and topical application of treatment agents on manure (Li *et al.*, 2008) have been investigated in order to mitigate NH_3 emission from animal feeding operations.

Corn distiller's dried grain with solubles (DDGS) is a co-product of fuel ethanol production. With the accelerating development of biofuel industry, DDGS with its relatively low price and valuable nutrient content is becoming more available as feedstuff in the poultry industry. The DDGS contains high levels of dietary fiber (Spiehs *et al.,* 2002), which has been reported by researchers to increase the transfer of nitrogen from urinary excretion to fecal excretion for rats (Tetens *et al*., 1996) and pigs (Kreuzer and Machmuller, 1993). Roberts *et al.* (2007) reported laying hen diet containing 10% corn DDGS led to as much as 50% reduction in NH_3 emission from the laying-hen manure over a 7-day storage period as compared with NH_3 emission from hen manure from standard or control diet. However, Roberts *et al.* (2007) did not find significant redistribution of N in poultry manure, and the reduction of NH_3 emission was believed to mainly result from the lower pH value in the manure of the DDGS diet group. The study

by Roberts *et al.* (2007) involved storage of the hen manure in a static state. In commercial production, fresh manure will be added to the existing accumulation and it is removed out of the hen house at intervals ranging from daily to weekly.

Therefore, the objective of this study was to characterize and compare gaseous (NH_3, CO_2) emissions, feeding and defecation activities, feed intake, and egg production of laying hens fed diet containing DDGS (15% by weight) *vs.* standard or Control (Ctrl) control diet containing no DDGS.

Materials and Methods

Feeding, Defecation and Gas Emissions Measurement System

This study was conducted using four newly developed dynamic gas emission chambers (figs. 1a & 1b). An iron-framed wire-mesh cage was placed inside each transparent emission chamber. Fresh air to each chamber was supplied through an air distribution plenum to improve spatial uniformity. To capture the feeding and defecation events, two electronic balances were used in each chamber, one for measurement of the feeder weight or feeding activity and the other for the manure pan weight or defecation activity of the birds. Samples of the exhaust air from each chamber and supply air were successively taken by a sampling pump (0–20 L/min, Teflon wetted parts, Model No. 2107CA20B, Gardner Denver Inc., Sheboygan, WI, USA). A photoacoustic multi-gas analyzer (Model 1412, INNOVA AirTech Instruments A/S, Ballerup, Denmark) was used to measure NH_3 and CO_2 concentrations and dew-point temperature of the sample air. To assess the integrity of the dynamic emission chambers system, CO_2 recovery tests were performed on all chambers before the experiment. Gas emissions from each chamber measured subsequently were adjusted based on the result of recovery test. Detailed

description of the dynamic emissions measurement system has been given in Chapter 2 of this thesis (Ning *et al.*, 2008).

Experimental Design

Experimental hens were obtained from a commercial farm in Iowa, where a field comparative study was conducted. A total of six hen houses were involved in this study, with three of them receiving a diet that contained 15% (by weight) corn DDGS and the other three paired houses receiving commercial diet or control (Ctrl) diet that contained no DDGS. Each trial of the experiment involved 12 W-36 hens that came from one pair of the houses, 6 from DDGS house and 6 from Ctrl house. Hens in each dietary regimen were randomly assigned to 2 cages or chambers, 3 hens per cage or chamber. Hens were fed the same diet as used on the originating farm throughout the experiment. Each trial consisted of 7 d of acclimatization, followed by 5 to 7 d of data collection. A total of 6 trials were conducted, involving a total of 72 hens. The hens weighed 1.48 (± 0.03 S.D.) kg and ranged from 79 to 109 wk of age at the start of the trials. Detailed information concerning the experimental hens and diets is shown in Table 1.

During the experiment, fresh feed was added to the feeder between 18:00 and 19:00h daily. Fluorescent light was provided at an illumination intensity of 20 lux, on for 16 hr (05:00 to 21:00h) and off for the remaining 8 hr (21:00 to 05:00h). Manure pans were replaced after the acclimatization period and again after the data collection period. Eggs from each chamber were collected and weighed daily. Hens were weighed at the beginning and the end of each trial.

Data Analysis

The NH_3 and CO_2 emissions were calculated from the following equations:

$$ER_{NH_3} = \frac{(C_{Outlet} - C_{Inlet}) \times V_{Ideal} \times 17.03}{22.4 \times 3} \quad [1]$$

$$ER_{CO_2} = \frac{(C_{Outlet} - C_{Inlet}) \times V_{Ideal} \times 44.01}{22.4 \times 3} \quad [2]$$

where ER_{NH3} is NH_3 emission rate (g/min); ER_{CO2} is CO_2 emission rate (g/min); 17.03 is the molecular weight of NH_3 (g/mole); 44.01 is the molecular weight of CO_2 (g/mole); 22.4 is the gas molar volume under STP of 0°C and 1 ATM (L/mole); and V_{ideal} is ventilation rate of the chamber at STP of 0°C and 1 ATM (L/min).

Emission rates, expressed in 5 different units, were calculated based on equations [1] and [2] and hens' performance data. The respective calculation equations are as follows:

a. Emission rate in g/chamber-d:

$$ER_{g/chamber-d} = (\frac{ER_{g/\min,1} + ER_{g/\min,2} + ... + ER_{g/\min,N}}{N}) \times 1440 \quad [3]$$

where $ER_{g/min,N}$ is the ER at N^{th} minute of the day; 1440 is the total daily minutes.

b. Emission rate in g/hen-d:

$$ER_{g/hen-d} = \frac{ER_{g/chamber-d}}{H} \quad [4]$$

where H is the number of hens per cage.

c. Emission rate in g/kg manure-d:

$$ER_{g/kgManure-d} = \frac{ER_{g/chamber-d}}{W} \quad [5]$$

where W (kg) is the weight of accumulated manure (as-is basis) at the end of the day.

d. Emission rate in gram NH_3 per kg N intake per day (g NH_3/kg N intake-d):

$$ER_{g/kgNIntake-d} = \frac{ER_{g/chamber-d}}{F \times NC} \quad [6]$$

where F is daily feed intake (kg) and NC is feed N content.

e. Emission rate in gram NH_3 per kg egg produced per day (g/kg egg-d):

$$ER_{g/kgEgg-d} = \frac{ER_{g/chamber-d}}{E_{Total} / D} \quad [7]$$

where E_{total} (kg) is the total egg mass production during the manure accumulation time. D (d) is the number of days of manure accumulation.

Daily defecation amount was calculated by adding all the defecation events within 24 hr, which was essentially exclusive of manure moisture evaporation. In other words, the daily manure production determined with the electronic monitoring system by and large represents the fresh manure amount.

Daily egg mass production for each chamber was calculated by adding up the weight of eggs produced with in 24 hr in one chamber. Daily hen-day performance for each chamber was calculated by using the total number of eggs produced in 24 hr divided by the number of hens in that chamber.

Statistical Analysis

Emission data for the DDGS and Ctrl hens were compared by using Student's t-test with P-value of 0.10 considered statistically significant. JMP 6.0 (JMP Statistical Discovery 6.0.0, SAS Institute Inc., Cary, NC, USA) was used to carry out all the statistical analyses.

Results and Discussion

The DDGS and Ctrl hens showed similar daily feed intake, 102 (± 11.2) vs. 105 (± 13.3) g/hen-d, respectively (Table 2). The DDGS hens defecated 16% more than the

Ctrl-fed hens, 133 *vs.* 115 g/hen-d, respectively ($P<0.001$). The higher defecation for the DDGS hens might have resulted from lower dry-matter digestibility of the higher-fiber diet. The DDGS hens had a mean daily egg mass production of 48 g/hen-d, which was 13% higher ($P=0.04$) than the 42 g/hen-d egg mass production of the Ctrl hens (Table 2). However this result does not necessarily indicate that hens fed with DDGS diet will have higher egg production. As shown by the data in Table 1, the DDGS hens were younger than the Ctrl hens in all trials. Egg production performance of W-36 hens from 72 to 108 weeks has a negative relationship with hen age (Hy-Line Commercial Management Guide, 2008). The average hen age in DDGS and Ctrl groups was 96 week and 100 week, respectively, which would correspond to a standard egg production performance of 77% and 75%. The average performance obtained in this study was 78% for the DDGS group and 69% for the Ctrl group. With the very limited number of hens in this small lab-scale study, the data should be considered as preliminary and field verification is needed to further assess the effect of DDGS diet on egg production.

Table 3 shows the daily NH_3 ER during 6 days of manure accumulation. On the 6^{th} day, the DDGS regimen showed an NH_3 ER of 0.17 g/hen-d, or 26% lower than the ER of 0.23 g/hen-d for the Ctrl regimen ($P<0.1$). There was no significant difference between the two regimens until the 5^{th} day ($P=0.03$). The accumulative NH_3 emissions for both DDGS and Ctrl groups were also calculated based on daily emission data and are shown in Figure 2.

Considering the DDGS hens had a higher daily fresh manure production than the Ctrl hens, ER with the unit of g/kg manure-d was used as another way to express the impact of DDGS diet on NH_3 emission. On this basis, ER of the DDGS regimen showed

32% less than the Ctrl regimen on the 6th day's manure accumulation ($P<0.05$). Roberts *et al.* (2007) reported up to 50% NH_3 ER reduction from hen manure that was collected from 10% corn DDGS diet vs. Ctrl diet during a 7-day static manure storage.

Also as shown in Table 1, N content of the DDGS diet was higher than N content of the Ctrl diet. Hence, comparison of NH_3 ER between the DDGS and Ctrl regimens in the unit of g/kg N intake-d was made and presented in Table 3. The average NH_3 ER for the DDGS hens was 70 g/kg N intake-d which was 31% lower than the average NH_3 ER of 101 g/kg N intake-d for the Ctrl hens on the 6th day of manure accumulation ($P<0.01$).

NH_3 ER in the unit of g NH_3/kg egg-d production was further compared and presented in Table 3. The average NH_3 ER for the DDGS hens on the 6th day was 3.5 g/kg egg-d which was 38% less than the average NH_3 ER 5.7 g/kg egg-d for the Ctrl hens ($P<0.01$).

Considering different manure removal schedules in MB houses, for daily manure removal there would be no significant reduction in NH_3 ER for the DDGS diet group as compared to the Ctrl diet group. For MB houses with 3-day manure removal schedule, the DDGS diet group would lead to a significant reduction in NH_3 ER in 3 different units, i.e., g/kg manure-d, g/kg N intake-d, and g/kg egg-d. For 6-day manure removal schedule, the DDGS diet group would have a significant lower NH_3 emission in all four units expressed in this study.

The CO_2 ERs for both dietary regimens during the 6 days of manure accumulation are shown in Table 4. The results show that on the 6th day of manure accumulation, CO_2 ER for the DDGS group (71.5 g/hen-d) tended to be lower than that for the Ctrl diet group (78.8 g/hen-d) ($P<0.1$). This result seems to imply that less NH_3

production in the DDGS regimen was also associated with lower CO_2 generation/emission, as manure CO_2 and NH_3 both result from the break-down of uric acid.

Summary and Conclusions

This study investigated the effect of corn distiller's dried grain with solubles (DDGS) diet (15% inclusion by weight) vs. control (Ctrl) diet on W-36 laying hens in terms of feed intake, manure production, egg production, and ammonia (NH_3) and carbon dioxide (CO_2) emissions. The hens were kept in 3-bird cages (500 cm^2/hen or 77 in^2/hen cage floor area) that were placed inside environmentally-controlled (24–26°C) emission chambers. A 16L:8D photoperiod and *ad-lib* feeding program were used. The following conclusions and observations were made.

- Hens fed the DDGS diet had an average daily feed intake of 102 g/hen-d, as compared with 105 g/hen-d for hens fed the Ctrl diet.
- The DDGS hens had an average daily manure production of 133 g/hen-d, which is 16% higher than the 115 g/hen-d produced by the Ctrl hens ($P<0.001$).
- The DDGS hens had an average egg mass production of 48 g/hen-d which is 13% higher than the 42 g/hen-d egg mass production for the Ctrl hens ($P<0.05$), although the DDGS hens averaged 4 weeks younger than the Ctrl hens. This information should be considered preliminary and further field evaluation is needed.
- The DDGS diet yielded 24% to 33% (varying from 5% to 38%) overall reduction in NH_3 emission during a 6-day manure accumulation as compared to the Ctrl diet. The reduction magnitude depended on the physical unit of the emission

(g/hen-d, g/kg manure-d, g/kg egg-d, or g/kg N intake-d) and the manure accumulation time, with longer accumulation time tending to have greater reduction.

- CO_2 emission was somewhat lower for the DDGS diet.

Acknowledgements

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Table 1: Information on the experimental W-36 hens and diets

Pair	Trial #	Diet type	Feed Nitrogen (%)	Hen Age (wk)
1	1	Control	2.12%	105
1	1	DDGS	2.36%	104
1	2	Control	2.04%	109
1	2	DDGS	2.35%	108
2	3	Control	2.20%	102
2	3	DDGS	2.36%	98
2	4	Control	2.06%	108
2	4	DDGS	2.35%	104
3	5	Control	2.23%	82
3	5	DDGS	2.41%	79
3	6	Control	2.22%	86
3	6	DDGS	2.40%	83
Average (SE)		Control	2.15% (0.03%)	99 (4.8)
		DDGS	2.37% (0.01%)	96 (4.9)

Table2: Feed use, manure production and egg production of Hy-Line W-36 hens fed DDGS or control (Ctrl) diet

Manure Accumulation Time, day		Feed Use (g/hen-d)		Manure Production (g/hen-d)		Egg Mass (g/hen-d)		Performance (%)	
		Ctrl	DDGS	Ctrl	DDGS	Ctrl	DDGS	Ctrl	DDGS
1	mean (SE)	107 (5.6)	101 (2.4)	106 (7.0)	129* (7.0)	39 (5.9)	40 (4.9)	64% (9.5%)	67% (8.2%)
2	mean (SE)	109 (4.1)	100 (3.0)	106 (11.4)	121 (10.7)	40 (5.3)	52* (4.1)	64% (8.4%)	83%* (6.5%)
3	mean (SE)	105 (3.7)	103 (3.8)	106 (5.0)	119 (7.8)	42 (6.0)	44 (4.4)	67% (9.0%)	72% (6.9%)
4	mean (SE)	108 (3.4)	108 (4.7)	119 (6.4)	142** (6.7)	42 (5.3)	46 (4.4)	70% (8.4%)	75% (7.3%)
5	mean (SE)	102 (2.9)	99 (3.1)	133 (5.4)	150* (7.3)	42 (4.2)	50 (4.1)	70% (7.0%)	83% (6.5%)
6	mean (SE)	105 (5.1)	102 (4.0)	130 (7.8)	140 (9.8)	47 (4.6)	53 (4.5)	78% (7.9%)	87% (7.4%)
Overall Mean (SE)		105 (1.7)	102* (1.3)	115 (1.9)	133**** (2.8)	42 (2.0)	48** (1.7)	69% (3.3%)	78%** (2.8%)

P-value of the DDGS diet group vs. control diet group: *P<0.1, **P<0.05, ***P<0.01, ****P<0.001

Table 3: Ammonia emission of Hy-Line W-36 hens fed DDGS or control (Ctrl) diet and emission reduction by DDGS diet (n=11)

Manure Accumulation Day		Daily NH_3 ER (g/hen-d)			Daily NH_3 ER (g/kg manure-d)			Daily NH_3 ER (g/kg N intake-d)			Daily NH_3 ER (g/kg egg-d)		
		Ctrl	DDGS	% Red.	Ctrl	DDGS	% Red.	Ctrl	DDGS	% Red.	Ctrl	DDGS	% Red.
1	mean (SE)	0.03 (0.003)	0.03 (0.002)	5%	0.34 (0.04)	0.28 (0.02)	18%	13 (1.5)	12 (0.9)	11%	0.7 (0.07)	0.6 (0.05)	16%
2	mean (SE)	0.05 (0.005)	0.04 (0.004)	15%	0.33 (0.03)	0.26** (0.02)	22%	23 (2.4)	19 (1.7)	17%	1.3 (0.11)	1.0* (0.09)	24%
3	mean (SE)	0.09 (0.011)	0.07 (0.008)	19%	0.40 (0.04)	0.30** (0.03)	26%	40 (5.0)	30* (2.7)	27%	2.2 (0.24)	1.6* (0.18)	27%
4	mean (SE)	0.14 (0.014)	0.11 (0.011)	22%	0.48 (0.04)	0.35** (0.04)	27%	62 (7.9)	43** (4.2)	31%	3.4 (0.31)	2.3** (0.22)	32%
5	mean (SE)	0.20 (0.019)	0.14** (0.016)	28%	0.57 (0.04)	0.39*** (0.04)	32%	92 (8.8)	61** (6.3)	34%	4.8 (0.39)	3.0*** (0.28)	37%
6	mean (SE)	0.23 (0.017)	0.17* (0.023)	26%	0.61 (0.04)	0.42** (0.07)	32%	101 (6.6)	70** (8.9)	31%	5.7 (0.49)	3.5*** (0.39)	38%
Overall mean		0.11	0.08**	24%	0.43	0.32****	26%	54	38***	29%	2.9	1.9***	33%

P-value of the DDGS vs. control dietary regimens: *P<0.1, **P<0.05, ***P<0.01, ****P<0.001

Table 4: Carbon dioxide emission of Hy-Line W-36 laying hen fed DDGS or control diet.

Manure Accumulation, d	CO_2 ER, g/hen-day		
	Control (SE)	DDGS (SE)	% Reduction by DDGS
1	71.6 (1.6)	68.5 (1.2)	4%
2	73.7 (2.3)	70.9 (2.3)	4%
3	75.1 (1.9)	72.9 (2.3)	3%
4	76.8 (1.5)	75.0 (2.5)	2%
5	79.5 (2.0)	74.7 (2.3)	6%
6	78.8 (2.8)	71.5* (2.1)	9%

P-value of the DDGS *vs.* control dietary regimens: *P<0.1, **P<0.05, ***P<0.01, ****P<0.001

Figure 1a. An overview of the dynamic gas emissions chambers and measurement setup located in the Iowa State University Livestock Environment and Physiology (LEAP) Lab II.

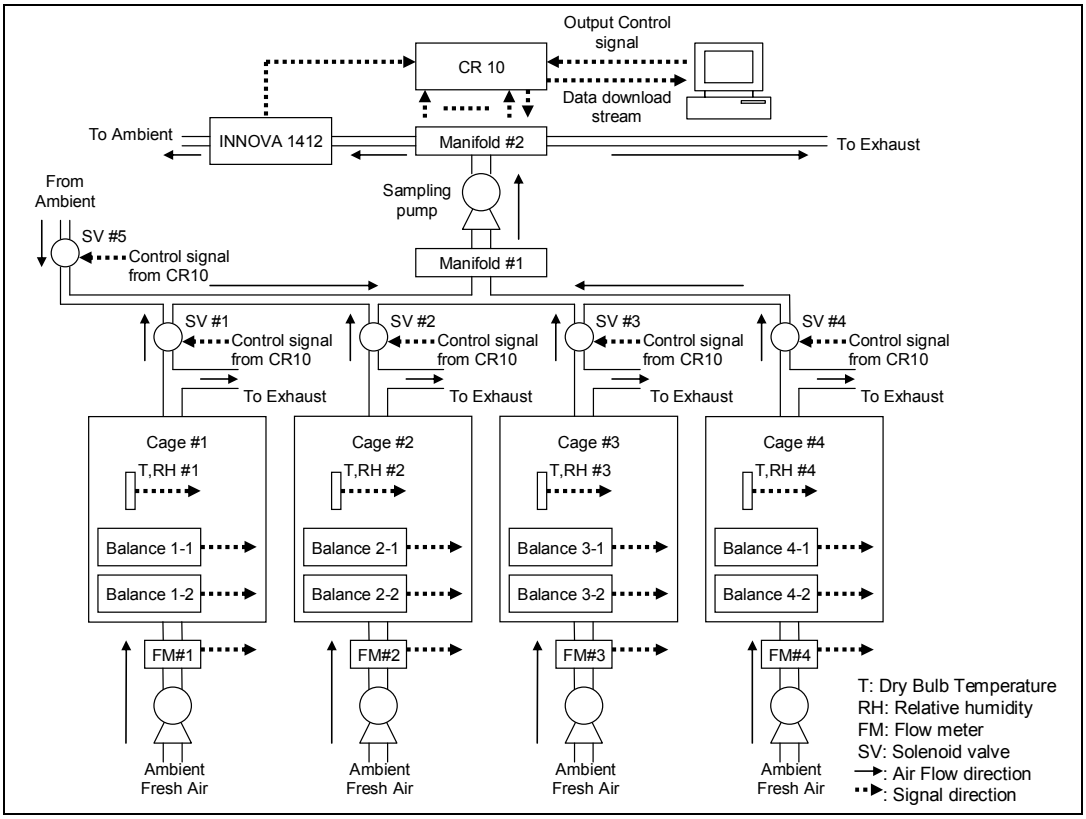

Figure 1b. Schematic representation of the dynamic gas emissions chambers and control and measurement setup located in the Iowa State University LEAP Lab II.

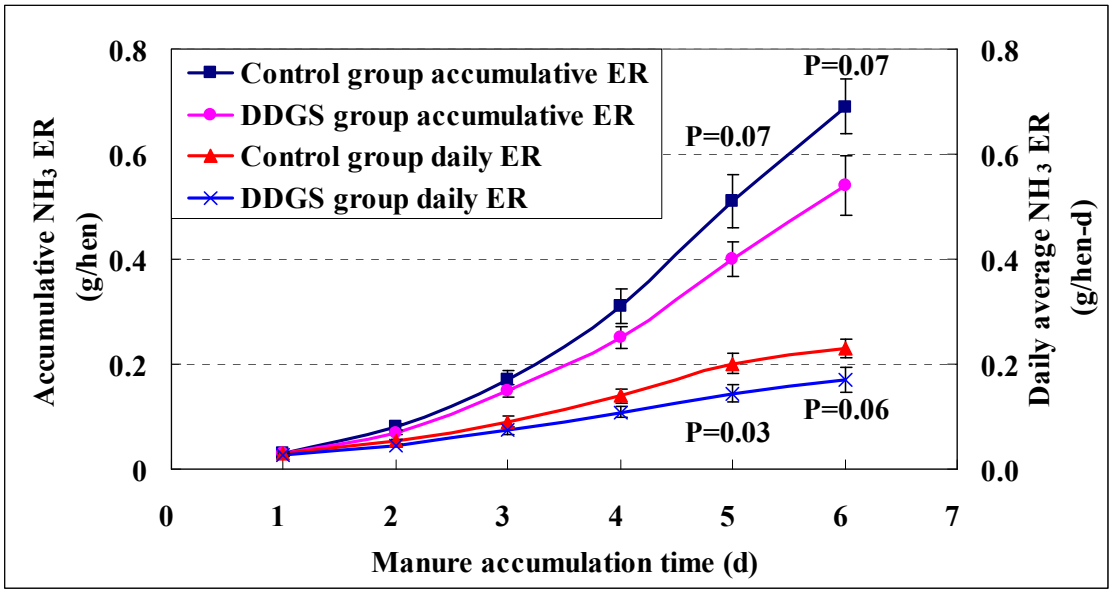

Figure 2: Comparison of daily NH_3 emission rate (ER) and accumulative NH_3 ER between DDGS and control dietary regimens.

CHAPTER 4. GENERAL CONCLUSIONS

This thesis research was conducted to fulfill two objectives: a) to delineate the dynamic behaviors of ammonia (NH_3) and carbon dioxide (CO_2) emissions from laying-hen manure as it accumulates with time, and b) to quantify the impact of DDGS-supplemented diet on reduction of NH_3 emission from laying hens as compared with a standard or control (Ctrl) diet. The manure accumulation situation was reflective of potential operational practices with commercial manure-belt layer houses.

The first objective was accomplished by characterizing NH_3 and CO_2 emissions from Hy-Line W-36 laying hens as related to feeding and defecation events of the birds with manure accumulation period of 1–6 d. The hens were kept in 3-bird cages (500 cm^2/hen or 77 in^2/hen cage floor area) that were placed inside environmentally-controlled (24–26°C) emission chambers. A 16L:8D photoperiod and *ad-lib* feeding were used. The following conclusions were drawn.

- The hens had a daily feed use of 102 g/hen-d and manure production of 117 g/hen-d (as-is basis). Daily feed use was partitioned as 96% during light period (L) and 4% during dark period (D). Similarly, daily manure production was partitioned into 83% L and 17% D.
- NH_3 emission rate ranged from 0.03 g/hen-d on 1 day of manure accumulation, 0.23 g/hen-d after 6 d of manure accumulation, and 0.37 g/hen-d after 8 d of manure accumulation. Daily NH_3 emission was partitioned into 69-70% L and 31-30% D.

- An empirical equation was developed that relates daily NH_3 emission to manure accumulation time under thermoneutral conditions. This relationship may be useful to estimating NH_3 emissions from manure-belt layer houses.
- CO_2 emission was 70 g/hen-d on 1 day of manure accumulation and 78 g/hen-d after 6-8 d of manure accumulation. In both Experiments 1 and 2 CO_2 ER inclined in the first 5 days of manure accumulation, and stabilized afterwards. Daily CO_2 emission was partitioned into 73% L and 27% D.
- NH_3 emissions of the hens show an inverse relation to defecation activities. This phenomenon is insightful to effective application of manure treatment agents for mitigating NH_3 emissions from hen manure.
- An empirical equation was developed that relates projected manure surface area to accumulated manure weight for the laying hens. NH_3 emissions per unit projected manure surface area may be useful to assessing the impact of different production situations (e.g., cage–free) on NH_3 emissions.

The second objective was accomplished by quantifying the effect of 15% corn DDGS diet on Hy-Line W-36 laying hens, including feed intake, manure production, egg production and ammonia and carbon dioxide emissions. The study revealed the following:

- The hens fed the DDGS diet had an average daily feed use of 102 g/hen-d, as compared with 105 g/hen-d for hens fed control diet.
- The DDGS hens had an average daily manure production of 133 g/hen-d which is 16% higher than 115 g/hen-d for the control hens ($P<0.001$).
- The DDGS hens had an average egg production of 48 g/hen-d which is 13%

higher than the 42 g/hen-d egg production for the control hens ($P<0.05$), although the DDGS hens averaged 4 weeks younger than the Ctrl hens. This information should be considered preliminary and further field evaluation is needed.

- The DDGS diet yielded 24% to 33% (varying from 5% to 38%) overall reduction in NH_3 emission during a 6-day manure accumulation as compared to the Ctrl diet. The reduction magnitude depended on the physical unit of the emission (g/hen-d, g/kg manure-d, g/kg egg-d, or g/kg N intake-d) and the manure accumulation time, with longer accumulation time tending to have greater reduction.
- The DDGS diet regimen had somewhat lower CO_2 emission than the control diet regimen.

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