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

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Ammonia and Carbon Dioxide Emissions *vs.* Feeding and Defecation Activities of Laying Hens

Xiaopeng Ning[1]	**Hongwei Xin**[1]	**Hong Li**[1]	**Ruihong Zhang**[2]
Graduate Assistant	Professor	Assistant Scientist	Professor

[1]Department of Agricultural and Biosystems Engineering
Iowa State University, Ames, Iowa 50011, USA

[2] Department of Biological and Agricultural Engineering
University of California, Davis, CA 95616, USA

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Abstract. *This study characterizes dynamic ammonia (NH_3) and carbon dioxide (CO_2) emissions associated with feeding and defecation activities of laying hens. Manure handling scheme used was reflective of commercial manure-belt house operation. Four dynamic emission chambers and measurement system was developed, featuring continuous measurement of the following variables for each chamber: (a) NH_3 concentrations of inlet and outlet air, (b) air temperature and relative humidity, (c) airflow rate, (d) feeder weight and thus feeding activity, and (e) manure pan weight and thus defecation activity. Daily feed consumption of the hens averaged 103 g/hen-d and fresh manure production averaged 125 g/hen-d. Ammonia emission rate ranged from 1.26 mg/hen-hr on the first day of manure accumulation to 9.26 mg/hen-hr after 7 d of manure accumulation. CO_2 emission rate averaged 3.41 and 2.47 g/hen-hr during light and dark hours of the day, respectively. Dynamic NH_3 emissions tend to be inversely related to defecation events as manure accumulates. Results from this study will contribute to the development and/or validation of process-based farm emission model for predicting NH_3 emissions from laying-hen houses. The dynamic nature of NH_3 emissions vs. defecation may also provide insight concerning application timing of manure treatment agents to mitigate NH_3 emissions from laying-hen houses.*

Keywords. NH_3 emission, CO_2 emission, defecation, layer house, process-based modeling

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Introduction

Ammonia (NH_3) is a major gas of environmental concern associated with poultry feeding operations. There have 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 mitigation air emissions from animal feeding operations, e.g., 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 Science 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 houses generally use high-rise (HR) or manure-belt (MB) housing style, with the MB style gaining more popularity because of improved indoor air quality. HR houses feature in-house manure storage for an extended period (e.g., one year), whereas MB houses feature more frequent removal of manure (e.g., 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 MB layer 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 L $\times$ 45 W $\times$ 66 H cm, 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 plexiglas panels (5-mm thickness). Inside each transparent emission chamber was an iron-framed wire-mesh cage (44 L $\times$ 34 W $\times$ 58 H cm) that was able to accommodate up to three 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 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 system, so that the target concentrations of the 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 (sampled at 0.1 s intervals) 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 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. Nipple drinker was used to supply drinking water. A plastic cup with tubing was located underneath each drinker to catch and divert any water leakage from the manure pan.

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.

[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.

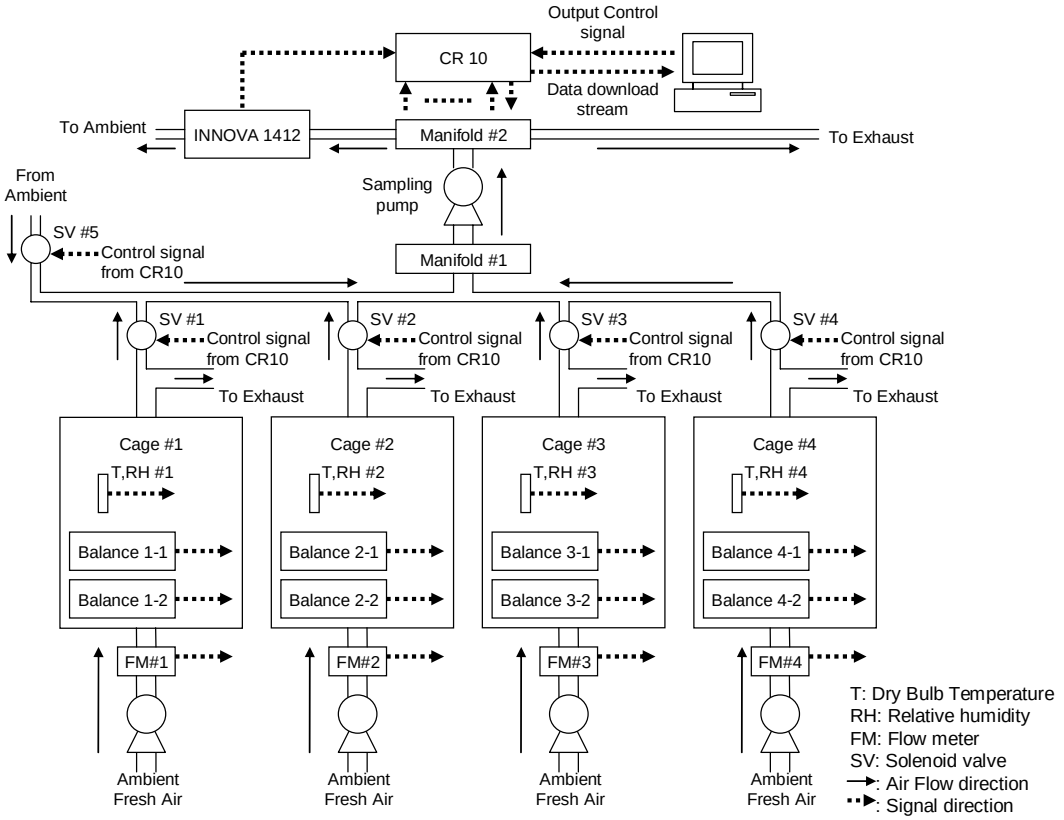

Figure 1b. Schematic representation of the dynamic gas emissions chambers and control and measurement setup located in the Iowa State University LEAP Lab II.

Samples of the exhaust air from each chamber were successively taken by a sampling pump (0~20 L/min, 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) 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 LPM, and operated in 22 s cycles for measurements of NH_3, CO_2 and dew-point temperature of the sample air (including 2 s for chamber flushing, 3 s for tube flushing, 1 s for sample integration, and the rest for mechanical operation of the analyzer). Analog outputs from the temperature and RH sensors, INNOVA analyzer, electronic scales, 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 the standard temperature and pressure (STP) condition (T=273.15K or 0°C, P=101.325 kPa or 1 ATM), V_{CO2} (L), can be 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 g/mol is the molecular weight of alcohol; and 22.4 L/mol is the gas molar volume under the STP of 0°C and 1 ATM.

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:

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

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

where P_{FM} =101.3 kPa and T_{FM}=294.25 K are, respectively, pressure and temperature corresponding to the air flow meter output V_{FM}r; 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 gas volume 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,

$$V'_{CO_2} = (C_{Outlet} - C_{Inlet}) \times 10^{-6} \times V_{Ideal} \times 60 \times T \qquad [4]$$

where C_{Outlet} and C_{Inlet} are, respectively, outlet and inlet CO_2 concentrations, ppm_v; T is the duration of alcohol oxidation (hr).

The recovery ratio (RR) is expressed as,

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

The RR values for the chambers were generally in the range of >95% to < 104%. Gas emissions from each chamber measured subsequently were adjusted based on the RR.

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

Table 1. Regression equations of corrected flow rate (CFR) *vs.* output flow rate (OFR) of the air mass flow meters using the output of the calibrated flow meter #4 as reference

Air Mass Flow Meter #	Corrected Flow Rate (CFR) Equation	R^2
1	$CFR_1 = 0.928 \times OFM_1 + 12.29$	0.997
2	$CFR_2 = 0.976 \times OFM_2 + 2.98$	1.000
3	$CFR_3 = 0.906 \times OFM_2 + 12.56$	0.998
4	$CFR_4 = OFM_4$	N/A

Experimental Design

A total of six trials were conducted. Each trial involved 12 hens, 3 hens per cage or chamber. Each trial had 7 days of acclimatization, followed by 5 to 7 days of data collection.

The experimental hens were fed between 18:00 and 19:00 hr daily. Fluorescent light was on for 16 hours (05:00 to 21:00 hr) and off for the remaining 8 hours (21:00 to 05:00 hr). Manure pans were replaced after the acclimatization period and again after the data collection period. Feed used at the commercial farm where the hens were procured was used in the study. Eggs of each chamber were collected and weighed daily. Hens were weighed at the beginning and the end of each trial.

Latin square design was used to achieve the different manure accumulation periods of 1, 2, 4, or 8 d, each with 4 replicates. Digital pictures for 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 pictures and projected area of the manure accumulation was calculated.

Data Analysis

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

$$ER_{NH_3} = \frac{(C_{Outlet} - C_{Inlet}) \times 10^{-6} \times V_{Ideal} \times 17.03}{22.4 \times 3} \quad [6]$$

$$ER_{CO_2} = \frac{(C_{Outlet} - C_{Inlet}) \times 10^{-6} \times V_{Ideal} \times 44.01}{22.4 \times 3} \quad [7]$$

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/mal is the molecular weight of CO_2; 22.4 L/mol is the gas molar volume under STP of 0°C and 1 ATM.

To assess the influence of defecation events on dynamic gas emissions, dynamic defecation events in each chamber need to be detected and recorded. Since the manure pan weight as well as the feeder weight in each chamber was recorded continually every 10 s, a defecation event was identified by comparing the adjacent manure pan weight data, and the difference between the two adjacent values, when exceeding the preset threshold (0.5 g), 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 and vibration from the hen movement, proper 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.

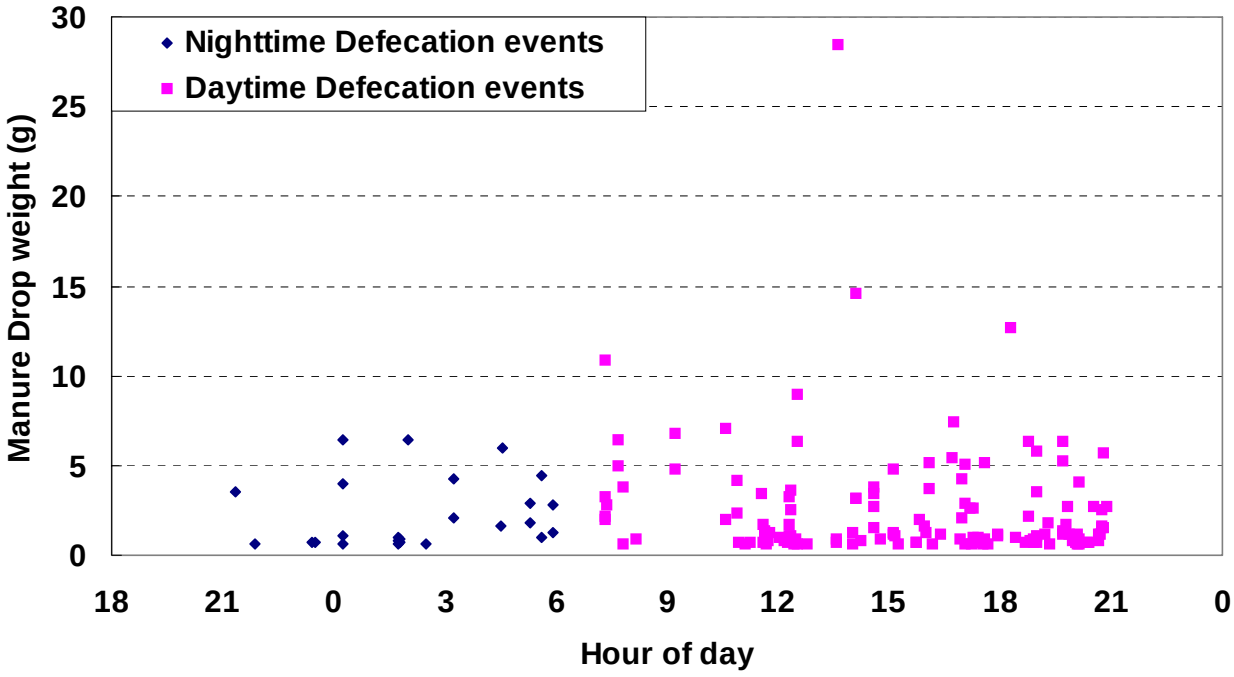

Figure 2. An example of diurnal defecation activities by a cage of 3 laying hens.

Projected area of the hen manure accumulated for 1, 2, 4 or 8 d in the manure pan were determined through image analysis. Figure 3 shows photos of the manure pan for different manure accumulation durations, and Figure 4 shows the corresponding 2-dimensional binary images. Table 2 lists an example of projected areas for the different manure accumulation periods and manure weight.

Table 2. Weight and projected area of hen manure for different periods of accumulation.

Variables	Duration of Manure Accumulation, d			
	1	2	4	8
Manure weight (g)	304	289	1023	1244
Manure projected area (cm^2)	326	307	558	625
Area per gram manure (cm^2/g)	1.07	1.07	0.57	0.5

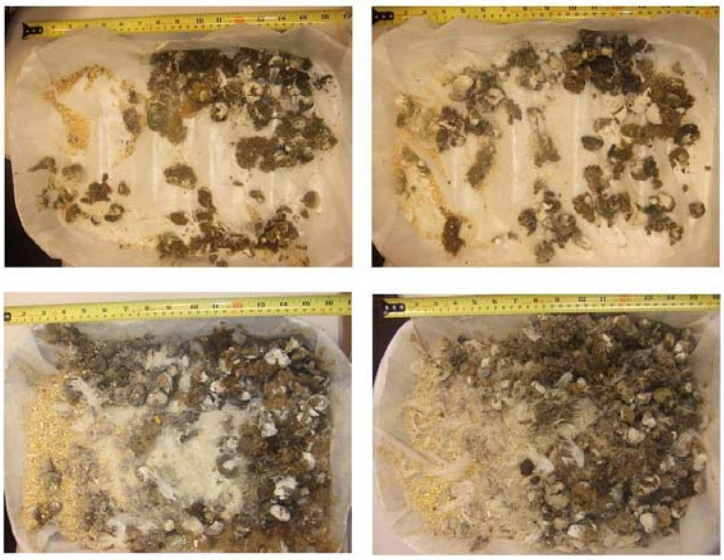

Figure 3. Photos of manure accumulation from a cage of 3 hens for 1, 2, 4 or 8 d.

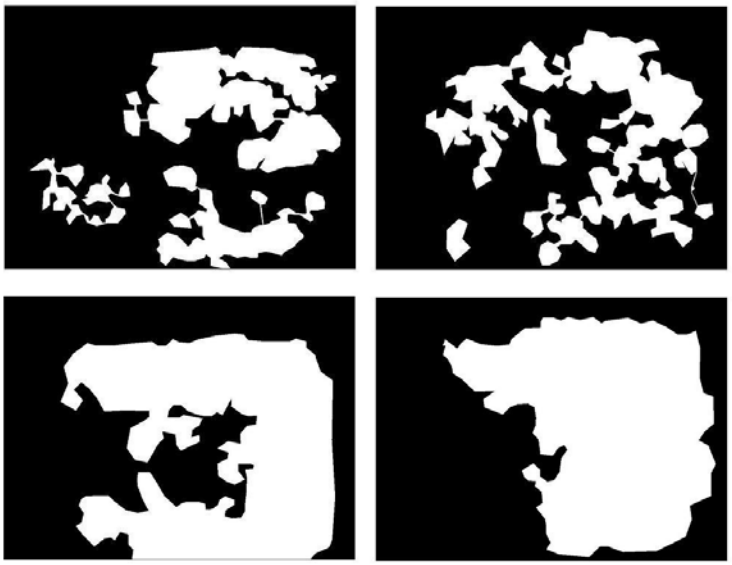

Figure 4. Binary images of manure accumulation for 1, 2, 4 or 8 d corresponding to figure 3,

Results and Discussion

Feeding Activities and Defecation Behavior

Hourly feed intake was calculated by subtracting the feeder weight at the end of one hour from the weight at the beginning of that hour. Hourly defecation amount was calculated by summing up the amount of all defecation events during that hour. All six trials had the same 16L:8D photoperiod schedule, hence mean hourly feed intake and mean hourly defecation could be generated and shown in Table 3. The relationship between hourly feed intake and hourly defecation is shown in Figure 5 and further analyzed with correlation analysis. The hourly defecation amount and hourly feed intake has a linear relationship that can be described as,

$$W_{Defecatoin} = 0.59 \times W_{feed} + 8.1 \qquad (R^2=0.81) \qquad [8]$$

where $W_{Defecation}$ is hourly defecation (g/hr); W_{feed} is hourly feed intake (g/hr)

From equation [8] we can see that the hourly defecation follows hourly feed intake very well. This means hens feed and defecate at the same time. Data in Table 3 also show that hens consumed little feed during the "dark" period, although they produced about one-third of the defecation in the dark compared to that in the light. Summing up the hourly feed intake and hourly defecation yields the daily feed intake of 103 g/hen-day and daily manure production of 125 g/hen-day (as-is basis), respectively.

Table 3. Diurnal hourly feed intake, defecation, NH_3 and CO_2 emissions of W-36 laying hens

Hour of day	Light or Dark	FI (g/hr-hen)	SEM	Def. (g/hr-hen)	SEM	Hour of day	Light or Dark	FI (g/hr-hen)	SEM	Def. (g/hr-hen)	SEM
0	D	0.41	0.07	2.42	0.19	12	L	6.01	0.37	6.77	0.39
1	D	0.35	0.08	2.44	0.18	13	L	5.87	0.27	6.68	0.34
2	D	0.42	0.09	2.84	0.22	14	L	5.61	0.21	7.13	0.34
3	D	0.23	0.05	2.81	0.18	15	L	6.03	0.25	6.11	0.30
4	D	0.37	0.07	3.00	0.22	16	L	5.64	0.21	6.48	0.35
5	D	0.91	0.12	3.95	0.26	17	L	7.47	0.34	8.71	0.45
6	L	5.52	0.25	5.10	0.31	18	L	11.51	0.54	6.94	0.47
7	L	5.23	0.18	5.36	0.34	19	L	10.90	0.36	8.31	0.37
8	L	4.93	0.20	6.58	0.39	20	L	6.29	0.29	7.23	0.28
9	L	5.39	0.19	6.44	0.36	21	D	1.28	0.09	2.55	0.17
10	L	5.95	0.22	6.82	0.34	22	D	0.30	0.05	1.53	0.14
11	L	5.79	0.21	6.78	0.37	23	D	0.31	0.10	2.21	0.19
						Daily total		103		125	

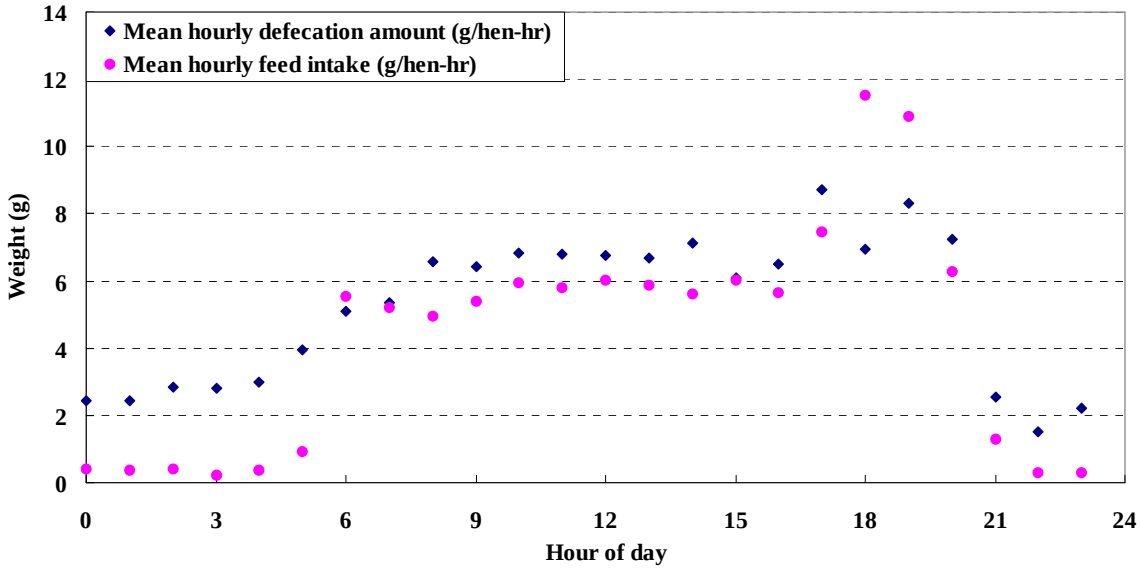

Figure 5. Hourly manure production *vs.* hourly feed intake of laying hens. Lights were on from 0500 to 2100 h and off from 2100 to 0500 h.

Manure weight for different accumulation periods and the corresponding projected surface areas are summarized in Table 4. The relationship between the projected surface area *A* (cm^2) and manure weight *W* (g) is shown in Figure 6, and expressed of the following format,

$$A = -0.0001*W^2 + 0.539*W + 126.35 \qquad (R^2 = 0.87) \qquad [9]$$

Table 4. Manure accumulation time, projected area, weight, and area to weight ratio of laying hens in group of three birds

	Manure Accumulation Time, d							
	1		2		4		8	
Number of observations	4		4		4		4	
Manure weight, g (SEM)	277	(28.4)	514	(96.1)	1000	(10.8)	1625	(266.3)
Projected area, cm^2 (SEM)	232	(40.7)	428	(54.8)	531	(31.7)	638	(44.6)
Area/weight, cm^2/g (SEM)	0.82	(0.09)	0.87	(0.07)	0.53	(0.03)	0.41	(0.04)

Ammonia (NH_3) Emission as Affected by Manure Accumulation Time

The NH_3 emission rates and related variables for manure accumulation period of 1 to 7 days are shown in Table 5. Ammonia ER observed in the current study compared well with that (annual mean of 0.054 g/hen-day) reported by Liang *et al.* (2005) for commercial manure-belt 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, higher temperature in the house during summertime and thus higher ventilation rate (thus higher air velocity over the manure surface).

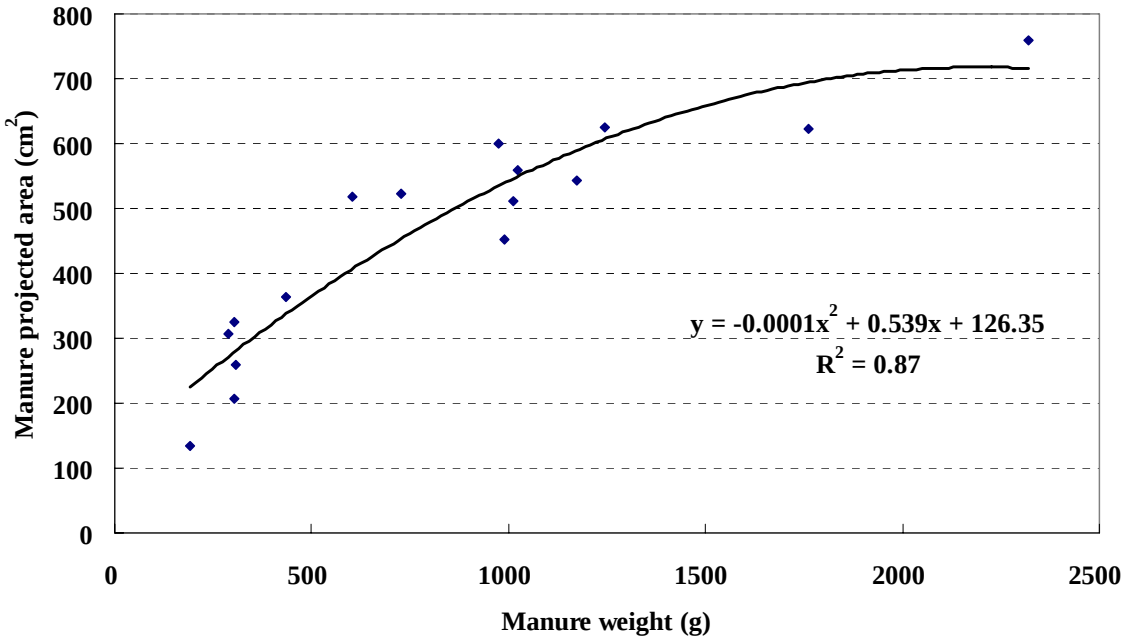

Figure 6. Relationship between projected surface area and weight of laying-hen manure.

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

Variables	Manure Accumulation Time, day						
	1	2	3	4	5	6	7
Number of observations	23	23	23	23	23	19	11
mg NH_3/hen-hr	1.25	2.16	3.63	5.48	7.66	8.69	9.23
g NH_3/hen-d	0.03	0.05	0.09	0.13	0.18	0.21	0.22
g NH_3/kg N intake	12.85	21.75	36.41	54.71	76.51	86.52	91.25
g NH_3/d-kg egg	0.70	1.19	1.99	2.99	4.18	4.72	4.98
Manure weight (g)	288	479	708	916	1096	1215	1424
g NH_3/d-kg manure	0.32	0.32	0.36	0.42	0.49	0.50	0.45
Manure surface area (cm^2)	273	362	458	536	597	634	691
Area/manure weight (cm^2/g)	0.95	0.76	0.65	0.59	0.54	0.52	0.49
g NH_3/d-m^2	1.11	1.42	1.88	2.41	3.02	3.22	3.11

Effect of Defecation on NH_3 Emission

Figure 7 shows the hourly profiles of manure weight and NH_3 emissions of the 3-hen cage during a 7-day 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. 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 (due to evaporation), ER showed a steady increase. This trend was more apparent with longer duration of manure accumulation. The overall ER increase for the dark hours was 0.14 (±0.29S.D.) mg/hen-hr, which was significantly higher than that (0.004 ± 0.29 mg/hen-hr) for the light hours ($P<0.0001$). The inverse trend of NH_3 emission vs. defecation is further illustrated by the changes in ER relative to the defecation amount (figures 8 and 9). The hourly changes in ER were determined by subtracting mean ER of the previous hour from mean ER of the current hour. This inverse relationship presumably stems from that the newly defecated manure covers the old manure surface which is essential to NH_3 emission; that new manure needs time to decompose and then 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 two days 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 most effective when applied during the dark period.

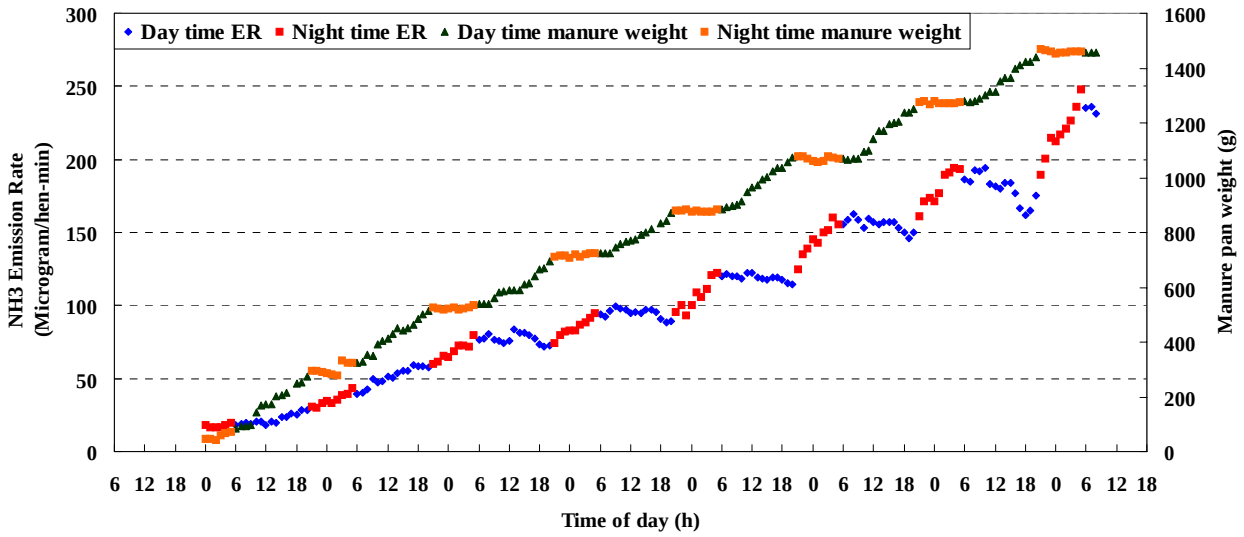

Figure 7. NH_3 ER and manure weight profiles of 3-hen cage over a 7-day manure accumulation.

Effect of Feeding and Defecation on CO_2 Emission

Compared with NH_3 emissions, CO_2 emissions were relatively constant during the light or dark period. The higher emissions during the light period were mainly due to the higher feeding activities and thus higher metabolic rate of the hens. Figure 10 shows a sample of CO_2 emission from one chamber for an 8-d period. The CO_2 production or emission averaged 3.35 g/hen-hr during light period and 2.37 g/hen-hr during dark period, with a daily time weighted average (TWA) of 2.99 g/hen-hr. These values compared well with those (3.50, 2.73 and 3.24 g/hen-hr for light, dark and TWA, respectively) derived from the heat production data for W-36 hens (1.53 kg at 64 wk of age) under thermoneutral conditions as reported by Chepete *et al.* (2004).

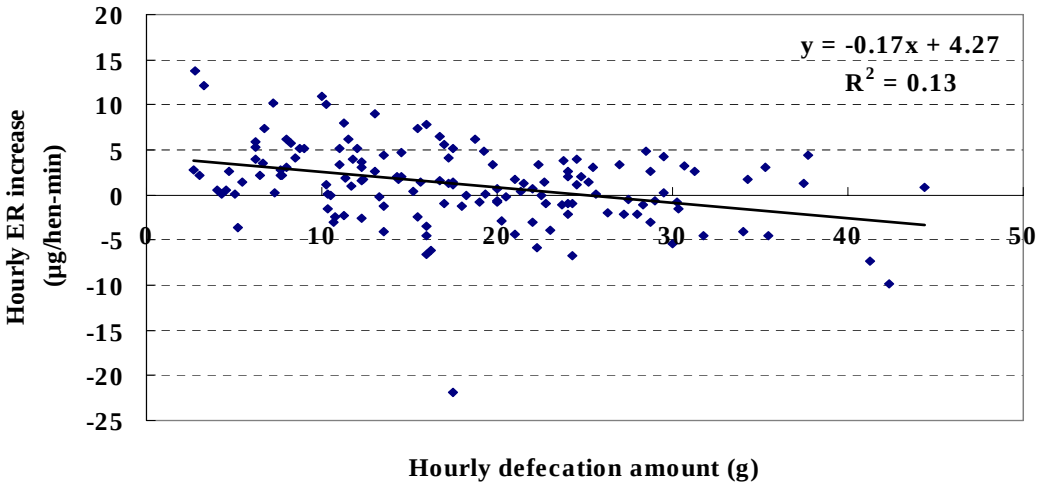

Figure 8. Sample of hourly NH_3 ER increase vs. hourly manure accumulation.

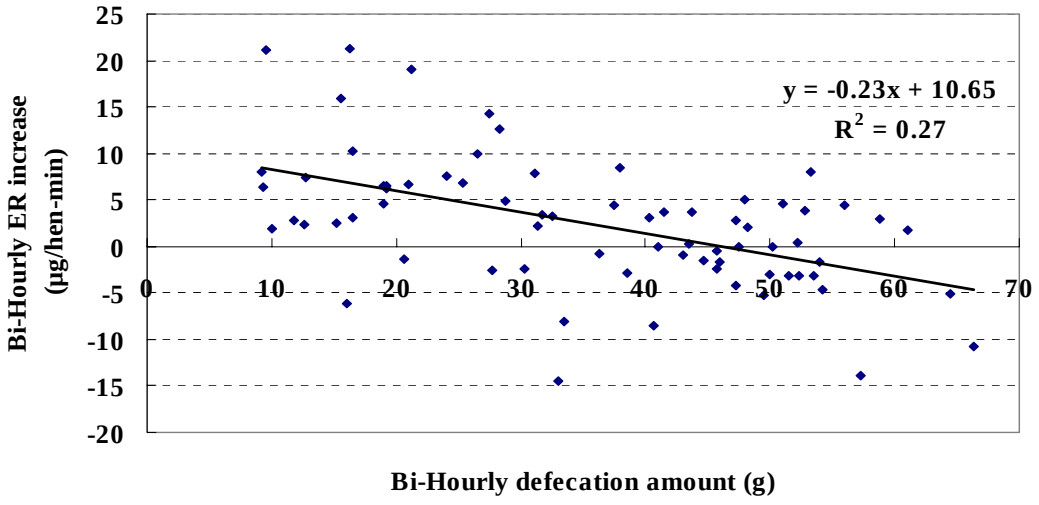

Figure 9. Sample of bi-hourly NH_3 ER change *vs.* bi-hourly defecation of laying hens.

The CO_2 emissions remained relatively stable, although 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, the subsequent daily CO_2 ER was shown to increase by 1.56 g/hen-d for the light period and 3.00 g/hen-d for the dark period, or 2% and 5.8% of the first day respective CO_2 ER. This increase was speculated to arise from release of CO_2 from manure (uric acid) decomposition. The dark hour increase was significantly higher than that of the light hour, following the pattern of NH_3 emissions. Hence, CO_2 emission behavior during dark hours may help elucidating NH_3 emissions. The specific relationship between NH_3 ER and CO_2 level remains further investigated. This increase in 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).

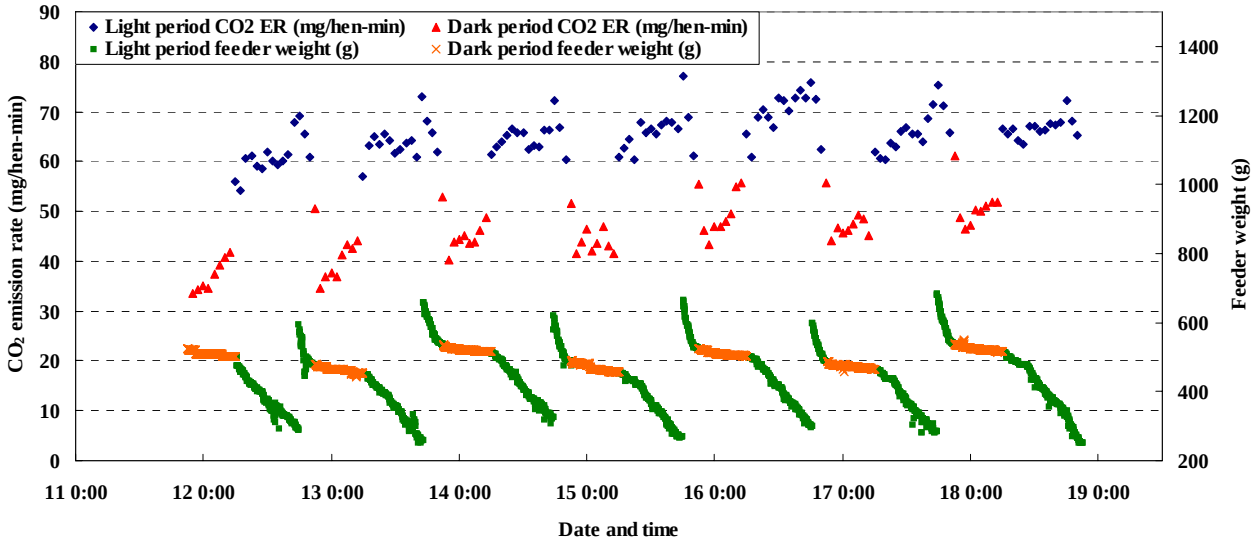

Figure 10. A sample of CO_2 emission rate of laying hens during an 8-day monitoring period.

Conclusions

This study investigates NH_3 and CO_2 emissions from W-36 laying hens as related to feeding and defecation events of the birds with manure accumulation period of 1 - 7 d. The hens were kept in 3-bird cages (500 cm^2/hen or 77 in^2/hen cage floor space) 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 103 g/hen-d and manure production of 125 g/hen-d (as-is basis). Daily feed use was partitioned as 95.5% during light period (L) and 4.5% during dark period (D). Similarly, daily manure production was partitioned into 81% L and 19% D.

- NH_3 emission ranged from 0.030 g/hen-d on the first day of manure accumulation to 0.22 g/hen-d after 7 d of manure accumulation. Daily NH_3 emission was partitioned into 66% L and 34% D.
- CO_2 emission was 68.7 g/hen-d on the first day of manure accumulation and 76.6 g/hen-d after 7 d of manure accumulation. Daily CO_2 emission was partitioned into 70% L and 30% 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 surface area may be useful to assess the impact of different production situations (e.g., cage-free) on NH_3 emissions.

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