AMMONIA AND GREENHOUSE GASES CONCENTRATIONS AND EMISSIONS OF A NATURALLY VENTILATED LAYING HEN HOUSE IN NORTHEAST CHINA

Z. Zhu, H. Dong, Z. Zhou, H. Xin, Y. Chen

ABSTRACT. *This study quantifies concentrations and emission rates (ER) of ammonia (NH_3) and greenhouse gases (GHG) including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from a naturally ventilated cage layer (Hy-Line brown strain) house with daily manure removal, located in northeast China during four seasons of one year, with each monitoring episode lasting five consecutive days. Gaseous concentrations of background and exhaust air were measured using an infrared photoacoustic multi-gas monitor with a multi-channel sampler. Building ventilation rate (VR) was determined by CO_2 mass balance using literature metabolic rate data for modern laying hens. Both gas concentrations and ER showed considerable diurnal and seasonal variations. Annual mean (±SD) ER of NH_3, CO_2, CH_4, and N_2O for the monitored layer house were, in mg d^{-1} $bird^{-1}$, 129 ±40.3, 78,250 ±15,384, 112 ±56.5, and 9.4 ±2.5, respectively, or in g d^{-1} AU^{-1} (AU = 500 kg live body weight), 33.4 ±11.4, 19,975 ±3,071, 29.2 ±15.2, and 2.5 ±0.7, respectively. Ammonia ER from the current study was within the ranges of values reported for high-rise houses with annual manure removal and manure-belt houses with daily manure removal. Results of the study contribute to improving ammonia and GHG emissions inventory for animal feeding operations in China and worldwide.*

Keywords. *Ammonia, Greenhouse gases (GHG), Laying hens, Emission rate.*

Aerial ammonia (NH_3) is the predominant pollutant gas in animal, particularly poultry, production operations. Its generation is a result of microbial decomposition of uric acid in poultry feces. Ammonia emission is environmentally important because of its contribution to acidification of soils and increased nitrogen deposition in ecosystems (Liang et al., 2005). NH_3 is also a noxious gas and may cause respiratory ailment (e.g., coughing, upper respiratory tract bleeding, excessive secretions, and lung bleeding or inflammation) (Dong et al., 2009). Moreover, NH_3 has been reported to be a precursor to nitrous oxide (N_2O) (Clemens and Ahlgrimm, 2001). The indirect N_2O emission resulting from volatile nitrogen losses that occur primarily in the forms of NH_3 and NO_x is approximately 0.01 kg N_2O-N per kg NH_3-N + NO_x-N volatilized (IPCC, 2000). Methane (CH_4) is a reaction product of anaerobic bacterial decomposition of organic compounds, a digestive process by which carbohydrates are broken down by microorganisms from the decomposition of manure under anaerobic conditions, increasing with the volatile solids content of excreta. For laying hens, NH_3, CH_4, and N_2O generation or emissions are mainly from manure, whereas CO_2 generation or emission mostly comes from the animal's respiration. CH_4 emission mainly results from fermentation of animal waste under anaerobic conditions, while N_2O emission mainly results from aerobic nitrification.

A number of studies have been conducted to quantify NH_3 and GHG emissions from laying hen facilities in Europe and in the U.S. For instance, Wathes et al. (1997) measured NH_3 and GHG concentrations and emissions from U.K. laying hen houses. Groot Koerkamp et al. (1998) reported laying hen house NH_3 emissions from four European countries under different manure handling systems. Nicholson et al. (2004) measured NH_3 emission from different manure handling systems in the U.K. Fabbri et al. (2007) reported NH_3 and GHG emissions from two different laying hen houses in Italy. Keener et al. (2002) quantified, using N balance, NH_3 emission from a 1.6 million caged layer facility. Liang et al. (2005) reported NH_3 emissions for U.S. high-rise and manure-belt laying hen houses.

The objectives of this study were to characterize concentrations and emission rates (ERs) of NH_3, CO_2, CH_4, and N_2O gases during different seasons for a typical, naturally ventilated laying hen house located in Liaoning Province, northeast China. The results were expected to contribute to the baseline information on gas emissions from laying hen houses in China.

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MATERIALS AND METHODS

HOUSING DESCRIPTION AND MANAGEMENT

A cage layer farm in Heishan City, Liaoning Province, China, was selected for the study that monitored NH_3, CO_2, CH_4, and N_2O concentrations and emissions. Selection of the farm was based on its production scale and management practices being representative of the current and growing trend of egg production facilities in China. The farm had a total of 12 naturally ventilated houses that were grouped in three rows of four houses. Houses within each group had a 9 m separation distance. Each house had a dimension of 54 × 9 m (L × W) with an east-west orientation. Each house contained four cage rows and each cage row had three stair-step tiers, with a total holding capacity of approximate 8000 hens (fig. 1). Each house had 13 ventilation windows (0.9 × 1.2 m each) spaced at 2.5 m intervals along each south and north sidewall. There were 15 ridge vents (maximum opening of 1 × 2 m each) spaced at 3 m. House 3 was selected for the monitoring (with houses 1 and 2 to its south and house 4 to its north). The selection of house 3 (with houses on both sides) was to minimize the influence of wind on the flow of the natural ventilation air during mild/warm weather. Fresh air, via natural ventilation, entered the building through both sets of sidewall windows and exited the building through the ridge vents (fig. 1). This flow pattern was verified by observing the warm moist air exiting the ridge vents and comparing the temperatures near the ridge vents and the outside ambient air (air near the ridge vents being warmer than outside air). Operation of the ventilation windows and ridge vents was based on the target house temperature, which ranged from 15°C in winter to 25°C in summer and was adjusted manually.

The Hy-Line brown hens were fed commercial standard diets three times a day at 06:00, 11:00, and 17:00 h and had free access to drinking water. Feces dropped to the manure collection channel area and were scraped out daily. The removed manure was directly delivered to an on-site storage as composting raw material.

Five cages (four hens per cage, with a floor area of 50 cm × 35 cm = 1750 cm^2) were randomly selected to collect data on feed intake, egg production, and manure output for five consecutive days in each season. Bird performance data (feed consumption, bird age, and egg production) were collected during the experiment. Manure samples from each cage were taken after weighing and well mixing the collected manure, and their physical and chemical properties, including dry matter (DM) and total nitrogen (TN) contents, were analyzed following national or industrial standards (NY 525-2002) in a certified analytical lab in Beijing, China.

AIR SAMPLE COLLECTION AND ANALYSIS

For each of the four-season monitoring episodes, NH_3, CO_2, CH_4, and N_2O concentrations were measured for five consecutive days. The corresponding hen ages for the spring, summer, autumn, and winter measurement periods were, respectively, 32, 45, 56, and 67 weeks. A photoacoustic multi-gas analyzer (model 1312, Innova AirTech Instrument, Ballerup, Denmark) together with a multi-channel sampler (designed and built by the Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing, China) was used to successively take air samples at two exhaust sampling points near the ridge vents (one sampling point at the middle of the house and the other at 1/4 of the house length) and one outside sampling point as the background reading (fig. 1). Before each measurement episode, the multi-gas analyzer was checked and calibrated, as needed, using the respective (NH_3, CO_2, CH_4, N_2O, and N_2) standard calibration gases procured from the National Standard Material Center (Beijing, China). For each of the three (two exhaust and one inlet) air samplings, five 2 min measurement cycles were performed by the Innova gas analyzer, with the first four cycles for stabilization and the fifth (final) cycle reading taken as the measured value. Thus, 30 min was required to complete one sampling cycle.

Indoor air temperatures and relative humidity (RH) were measured at 30 min intervals throughout the experiment using portable temperature/RH loggers (Hobo Pro T/RH, Onset Computer Corp., Bourne, Mass.).

CALCULATION OF GASEOUS EMISSION RATE (ER)

Gaseous ER is defined as the amount of gas emissions from an animal or animal unit (AU = 500 kg live body weight) per unit time using equations of the following form:

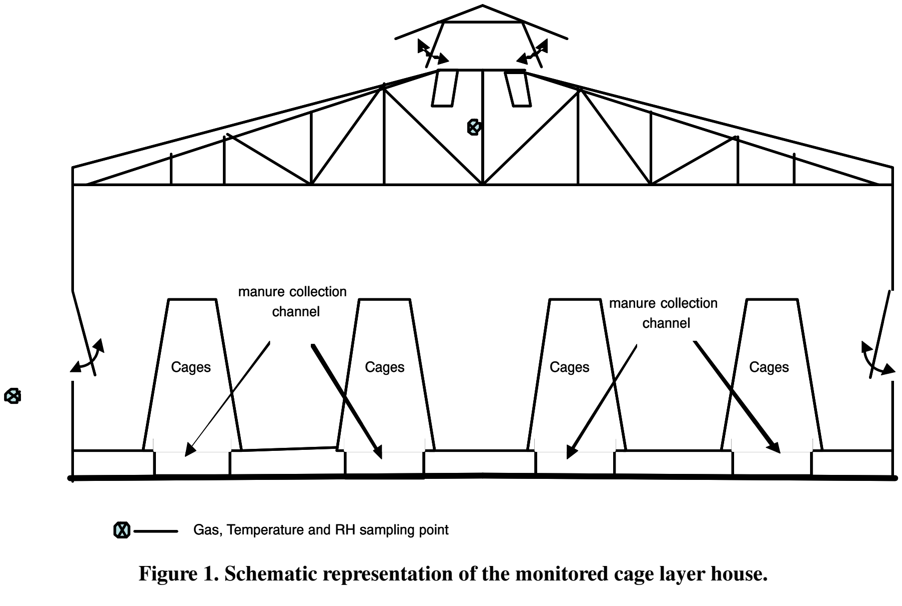

Figure 1. Schematic representation of the monitored cage layer house.

$$ER_h = VR_h \times \frac{\left(C_{e,h} - C_{i,h}\right)}{N} \qquad (1)$$

$$ER_{AU} = \sum_{h=1}^{24} ER_h \times \frac{500}{BW} \qquad (2)$$

where ER_h is emission rate per hen at the hth hour of the day (mg h^{-1} bird^{-1}), ER_{AU} is emission rate per AU in a day (g d^{-1} AU^{-1}), VR_h is house ventilation rate at the hth hour (m^3 h^{-1} house^{-1}), N is the number of laying hens in the house, $C_{e,h}$ and $C_{i,h}$ are concentrations of the gas under consideration at exhaust and inlet of the house, respectively (mg m^{-3}), and BW is average body weight of the hens during the monitoring period (kg).

The house ventilation rate was calculated using the CO_2 balance method of the following form:

$$VR = \frac{V_{CO2} \times 10^6}{C_{e,CO2} - C_{i,CO2}} \times \rho_{CO2} \qquad (3)$$

where V_{CO2} is CO_2 generation rate of the hen house (m^3 h^{-1} house^{-1}), $C_{e,\ CO2}$ and $C_{i,\ CO2}$ are exhaust and inlet CO_2 concentrations of the hen house at 20°C (mg m^{-3}), and ρ_{XO2} is CO_2 density (1.977 kg m^{-3} at 20°C).

Van Ouwerkerk and Pedersen (1994, as reported in CIGR, 2002), stated that the respiratory quotient (RQ) of hens is 0.86 to 0.92 (high to low quality feed). Using an indirect calorimetry relationship between total heat production, CO_2 production, and RQ, and adjusting for environmental temperature effects and CO_2 production from manure, the CO_2 production of the laying hen house could be expressed as follows (Van Ouwerkerk and Pedersen, 1994):

$$V_{CO2} = \frac{0.0036 \times f_c \times THP \times N \times 273}{\left(\frac{16.18}{RQ} + 5.02\right) \times (T_i + 273)} \times K_{m,CO2} \qquad (4)$$

where THP is total heat production (W hen^{-1}), f_c is a correction factor for diurnal CO_2 production, N is the number of hens in the house, RQ is respiratory quotient (RQ of 0.86 was chosen for the current study for high-quality feed; Van Ouwerkerk and Pedersen, 1994), $K_{m,CO2}$ is a multiplication factor representing the increase of CO_2 production from manure and other activities ($K_{m,CO2}$ of 1.0 was chosen for the current study based on the result from Li et al., 2005, who reported a negligible amount of CO_2 generation from manure when it was removed from the house every day), and T_i is the inside air temperature (°C).

The total heat production of the laying hens was derived from the recently updated CIGR (2002) equation:

$$THP = (6.28 \times M^{0.75} + 25 \times Y_2) \qquad (5)$$

where M is body mass of the hen (kg), and Y_2 is average egg production (kg d^{-1}).

When the ambient temperature deviated from 20°C, THP was adjusted by the following equation to account for ambient temperature effect for the birds (CIGR, 2002):

$$K_{t,THP} = 1 + 0.02 \times \left(20 - T_i\right) \qquad (6)$$

The value of f_c can be approximated by the following sinusoidal equation (CIGR, 2002):

$$f_c = 1 - a \times \sin\left[\left(2 \times \pi / 24\right) \times \left(h + 6 - h_{\min}\right)\right] \qquad (7)$$

where f_c is a correction factor for animal activity, a is constant (0.61 for layers), and h_{min} is time of the day with minimum activity (hours after midnight; -0.1 was chosen for this study).

RESULTS AND DISCUSSION

BIRD PERFORMANCE AND MANURE PROPERTIES

Body weight, age of the hens, feed intake, and CP content during the experiment for different seasons are listed in table 1. Feed intake increased with hen age from 32 to 67 weeks. The lowest feed intake was found in the summer season. Manure was sampled and analyzed, with the results shown in table 2. The lowest nitrogen content in the manure was found in the summer season, presumably arising from greater NH_3 volatilization from the manure driven by higher environmental temperature.

DAILY MEAN TEMPERATURE AND RH

The laying hen house used natural ventilation without supplemental heating or cooling. Consequently, its indoor environment was subject to the influence of outdoor climatic conditions. Figure 2 shows the variations of both indoor and outdoor temperatures in different seasons. It is apparent that the temperature profile of the hen house followed that of the outside in mild and warm seasons (spring and summer) but remained fairly constant in the cool and cold season (autumn and winter). Daily mean outside temperature during the one-year measurement period ranged from −16.7°C to 31.9°C, with an overall mean of 9.9°C. Outside RH ranged from 22% to 100% with a mean of 77%. The indoor temperature ranged from 12.9°C to 31.5°C with an overall mean of 21°C, whereas indoor RH ranged from 25% to 95% with a mean of 69%.

PROFILES OF NH_3 AND GHG CONCENTRATIONS

Figure 3 depicts the temporal variations in CO_2, NH_3, CH_4, and N_2O concentrations averaged from the two exhaust sampling points during the four seasons monitored. The N_2O concentrations during the winter season were mostly below the detection limit of the instrument and were omitted from the presentation. As shown by the data, all gaseous concentrations exhibited considerable diurnal variations. The higher concentrations of NH_3 and CO_2 occurred during the night, corresponding to cooler temperature and lower ventilation rate (VR). Similarly, colder weather in autumn and winter resulted in higher NH_3 and CO_2 concentrations due to the lower VR. However, the CH_4 concentration did not quite follow the same relationship with VR as did NH_3 or CO_2. The lower CH_4 concentration in winter than in the rest of the year presumably resulted from the less favorable fermentation conditions at the cooler temperature.

The NH_3, CO_2, CH_4, and N_2O concentrations and the calculated VR for the monitoring periods are summarized in table 3. Indoor CO_2 concentration is indicative of the barn VR, with lower CO_2 concentration corresponding to higher VR. As expected, the barn VR was higher in summer (mean CO_2 level of 1,392 mg m^{-3}) than in other seasons (mean CO_2 level of 1,617 to 5,197 mg m^{-3}) to maintain the target indoor temperature.

Table 1. Number, age, body weight, average daily feed intake, and egg production of laying hens (Hy-Line brown strain) monitored during different seasons.

Sampling Season	No. of Birds	Hen Age (weeks)	Avg. Body Weight (kg)	Avg. Daily Feed Intake (g hen^{-1})	Feed CP Content (%)
Spring	8112	32	1.94	119	16.9
Summer	7948	45	1.83	114	17.8
Autumn	7795	56	1.98	133	17.5
Winter	7741	67	2.04	134	18.3

Table 2. Characteristics of (Hy-Line brown) hen manure sampled in different seasons. Values are means of five daily samples and corresponding standard deviations.

Sampling Season	As-Is Fecal Production (g bird^{-1} d^{-1})	Moisture Content (%)	Total Nitrogen (% d.b.)
Spring	138 ±30	74.4 ±2.8	5.9 ±0.87
Summer	133 ±24	75.0 ±3.1	4.9 ±0.81
Autumn	145 ±17	77.0 ±2.5	6.0 ±0.21
Winter	146 ±10	76.1 ±2.1	5.7 ±0.25

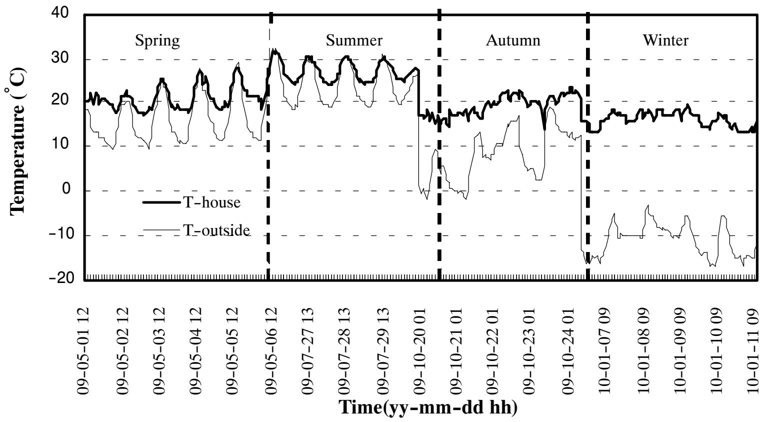

Figure 2. Outside and inside air temperature profiles during different seasons of monitoring the laying hen house.

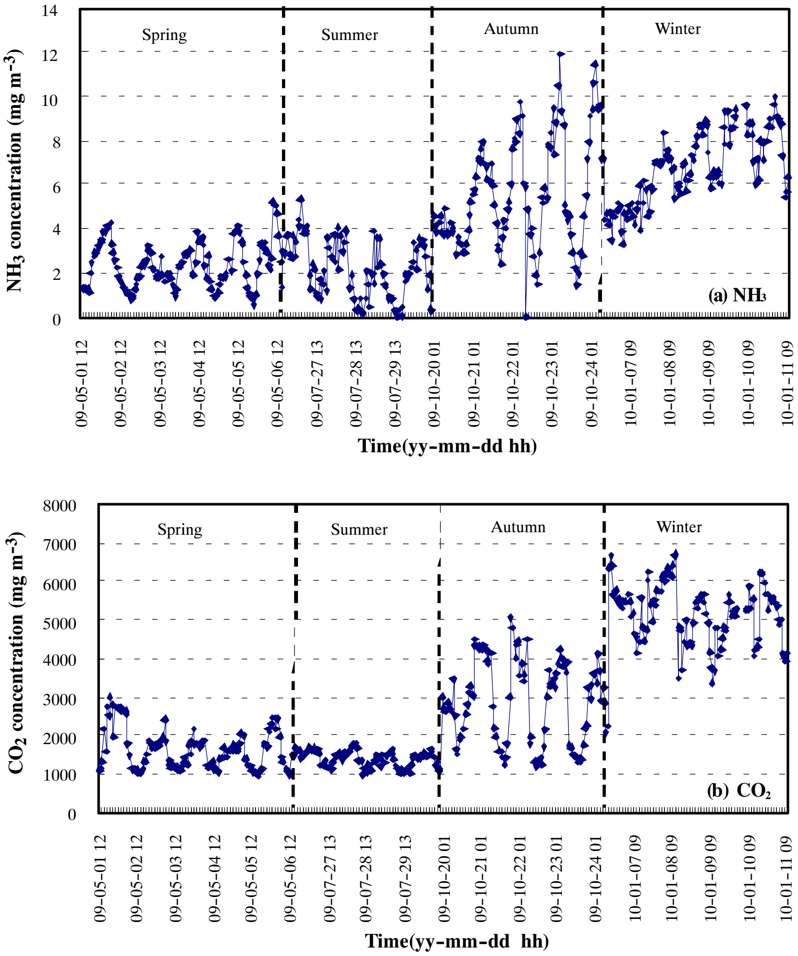

Figure 3. Diurnal NH_3 and GHG concentrations, and VR of the laying hen house during different seasons: (a) NH_3, (b) CO_2, (c) CH_4, (d) N_2O, and (e) VR (continued on next page).

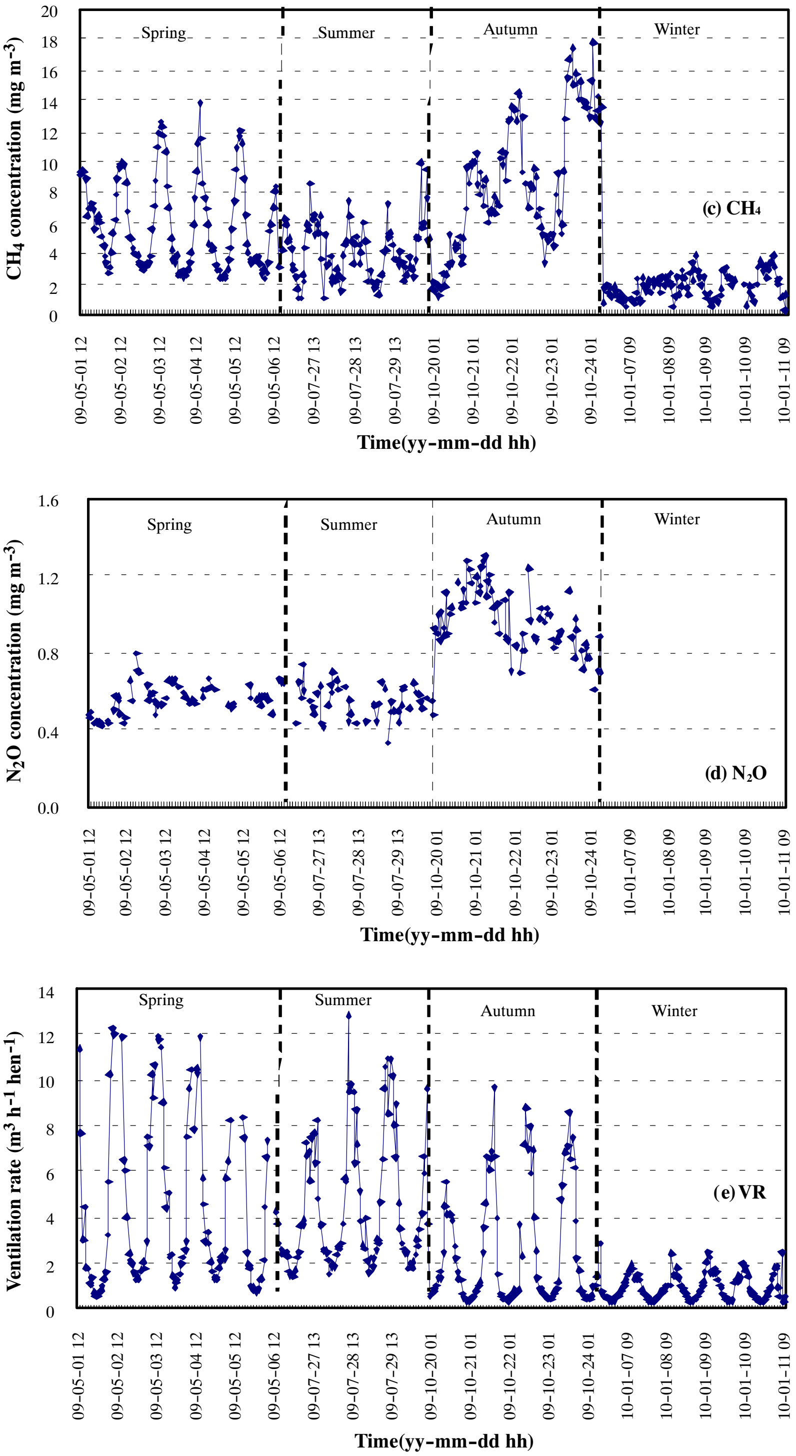

Figure 3 (continued from previous page). Diurnal NH_3 and GHG concentrations, and VR of the laying hen house during different seasons: (a) NH_3, (b) CO_2, (c) CH_4, (d) N_2O, and (e) VR.

NH_3, CO_2, CH_4, AND N_2O EMISSIONS

Table 4 summarizes the ER of NH_3, CO_2, CH_4, and N_2O for the laying hen house during different seasons. NH_3 emissions showed significant seasonal variations ($p < 0.05$), with summer emissions being the highest. This result was in agreement with the results of Nicholson et al. (2004) showing that NH_3 loss in summer more than doubled that in winter. Annual mean (±SD) NH_3 ER for the monitored layer house was 129 ±40.3 mg d^{-1} $bird^{-1}$ or 33.4 ±11.4 g d^{-1} AU^{-1}, which was comparable with literature values for a similar management system. In comparison, Nicholson et al. (2004) reported an NH_3 ER of 37.9 g d^{-1} AU^{-1} for a manure-belt house with daily manure removal. Groot Koerkamp et al. (1998) reported 39.1 g d^{-1} AU^{-1} for manure-belt houses (although manure removal frequency was not reported). Fabbri et al. (2007) reported NH_3 ER of 39.4 ±12 g d^{-1} AU^{-1} for manure-belt with manure drying on the belt and daily manure removal. However, compared with the NH_3 ER value of 17.5 g d^{-1} AU^{-1} reported by Liang et al. (2005) for manure-belt hen houses with

Table 3. Ammonia and greenhouse gas concentrations (mg m^{-3}) and ventilation rate (VR, $m^3\ h^{-1}\ hen^{-1}$) of the monitored laying hen house during different seasons.[a]

Gas	Statistic	Spring	Summer	Autumn	Winter	Annual
NH_3	Min	0.6	0.0	1.4	3.4	0
	Max	5.2	5.3	11.9	10.0	11.9
	Mean	2.3	2.2	5.6	6.8	4.2
	SD	1.0	1.3	2.5	1.6	2.3
	CV	43%	59%	44%	24%	55%
CO_2	Min	966	987	1,178	3342	966
	Max	2,973	1,804	5,036	6,707	6,707
	Mean	1,617	1,392	2,892	5,197	2,775
	SD	515	209	1,095	751	1,745
	CV	32%	15%	38%	14%	63%
CH_4	Min	2.4	1.2	1.2	0.3	0.3
	Max	13.9	9.9	17.8	4.0	17.8
	Mean	5.9	4.1	8.8	2.0	5.2
	SD	3.0	1.8	4.4	0.8	2.9
	CV	50%	43%	49%	42%	55%
N_2O	Min	0.42	0.33	0.61	N/D	0.33
	Max	0.80	0.74	1.31	N/D	1.31
	Mean	0.56	0.55	0.97	N/D	0.69
	SD	0.08	0.08	0.16	N/D	0.24
	CV	14%	15%	16%	N/D	35%
VR	Min	0.6	1.4	0.3	0.3	0.3
	Max	12.3	12.9	9.7	2.5	12.9
	Mean	4.3	4.5	2.6	1.0	3.1
	SD	3.6	2.8	2.6	0.5	1.6
	CV	85%	63%	100%	56%	53%

[a] SD = standard deviation, CV = coefficient of variation (SD/mean × 100%), and N/D = not detectable

daily manure removal in the Midwest U.S., the NH_3 ER value from the current study was about twice as high. The difference could have resulted from differences in manure moisture content, emitting surface area per hen (larger for our case), dietary composition (likely higher CP content for our diet because of brown bird vs. white leghorn, W36 strain, 17.6% vs. 13.7% to 16.9%), and ventilation system (natural vs. mechanical ventilation).

Emissions of CO_2 originate mostly from respiration of the hens. The CO_2 ER value of the current study was calculated using the CIGR metabolic heat production equation corrected for diurnal bird activity pattern and seasonal temperature effect. It showed significant seasonal variations ($p < 0.05$), with the annual mean (±SD) of 78.3 ±15.4 g d^{-1} $bird^{-1}$ or 20.0 ±3.1 kg d^{-1} AU^{-1}. The mean value was within the range of those given for laying hen facilities in the literature. Ning (2008) reported a CO_2 production rate of 70 g d^{-1} $bird^{-1}$ or 24.1 kg d^{-1} AU^{-1} for W-36 hens at thermoneutral condition. Green and Xin (2009) measured a CO_2 production rate of 68.3 g d^{-1} $bird^{-1}$ for W-36 laying hen under 24°C, and Chepete et al. (2004) reported a CO_2 production rate of 80.9 g d^{-1} $bird^{-1}$ for 37-week-old W-36 laying hens. The heat production-derived CO_2 ER provided the basis for indirect determination of the building VR in the current study.

CH_4 ER showed seasonal but non-significant variations, with the annual mean ±SD of 112 ±56.5 mg d^{-1} $bird^{-1}$ or 29.2 ±15.2 g d^{-1} AU^{-1}. The ER value observed in the current study was within the range of the limited literature values for laying hen facilities, i.e., 25 to 51.6 g d^{-1} AU^{-1} for Italian hen houses (Fabbri et al., 2007) and 21.6 g d^{-1} AU^{-1} for U.K. hen houses (Wathes et al., 1997).

Table 4. Emission rates of ammonia and GHG from a naturally ventilated laying hen house in northeast China.

Gas	Statistic	Spring	Summer	Autumn	Winter	Annual
NH_3	Statistics (mg d^{-1} $bird^{-1}$)					
	Max	315	579	651	298	651
	Min	2.3	12.3	18.8	11.2	2.3
	Mean[a]	79.4 a	172 b	149 c	116 d	129
	SD	70.7	89.8	120	67.0	40.3
	CV	89.1%	52.2%	80.8%	57.7%	31.2%
	ER (g d^{-1} AU^{-1})	20.5	47.0	37.5	28.4	33.4[b] ±11.4
CO_2	Statistics (g d^{-1} $bird^{-1}$)					
	Max	124	98.2	144	163	163
	Min	29.4	24.9	29.9	38.0	24.9
	Mean[a]	74.6 a	60.1 b	81.1 c	97.2 d	78.3
	SD	30.5	24.2	36.5	42.5	15.4
	CV	40.8%	40.3%	45.0%	43.8%	19.7%
	ER (kg d^{-1} AU^{-1})	19.2	16.4	20.5	23.8	20.0[b] ±3.1
CH_4	Statistics (mg d^{-1} $bird^{-1}$)					
	Max	579	538	582	77.2	582
	Min	38.7	6.9	8.5	3.8	3.8
	Mean[a]	153.3 a	144 a	121 b	29.7 c	112
	SD	133.5	125	105	15.8	56.5
	CV	87.1%	87.0%	86.4%	53.0%	50.5%
	ER (g d^{-1} AU^{-1})	39.5	39.3	30.7	7.3	29.2[b] ±15.2
N_2O	Statistics (mg d^{-1} $bird^{-1}$)					
	Max	22.6	43.2	99.8	N/A[c]	99.8
	Min	1.1	1.1	1.0	N/A	1.0
	Mean[a]	6.6 ab	10.3 bc	11.4 c	N/A	9 .4
	SD	5.1	9.1	14.2	N/A	2.5
	CV	77.6%	88.0%	125%	N/A	26.7%
	ER (g d^{-1} AU^{-1})	1.7	2.8	2.9	N/A	2.5[b] ±0.7

[a] Means in the same row followed by different letters are significantly different at $p < 0.05$.

[b] Mean ±SD (AU = animal unit = 500 kg live body weight).

[c] N/A = not available.

Very limited information is available on N_2O emission from laying hen houses, largely due to the low N_2O concentrations in the houses, which are often below the detection limits of the instrument. Fabbri et al. (2007) reported that no significant emissions were registered for N_2O in laying hen houses. Our study revealed undetectable N_2O emission from the hen house in winter and an annual N_2O ER of 9.4 ±2.5 mg d^{-1} $bird^{-1}$ or 2.5 ±0.7 g d^{-1} AU^{-1}, which is lower than that of deep pit (high-rise) laying hen house in summer (about 10.8 g d^{-1} AU^{-1}), as reported by Wathes et al. (1997).

SUMMARY AND CONCLUSIONS

Ammonia and GHG concentrations and emission rates (ER) from a typical, naturally ventilated laying hen house in northeast China were measured during four seasons of the year. Each monitoring episode lasted five consecutive days. The following observations and conclusions were made from this field monitoring. There exist diurnal and seasonal variations in ammonia and GHG concentrations and emissions for the laying hen house. Annual means ±SD of NH_3, CO_2, H_4, and N_2O ER in mg d^{-1} $bird^{-1}$ were 129 ±40.3, 78,250 ±15,384, 112 ±56.5, and 9.4 ±2.5, respectively. The respective ER in g d^{-1} AU^{-1} were 33.4 ±11.4, 19,975 ±3,071, 29.2 ±15.2, and 2.5 ±0.7. These results are within the ER ranges reported in the literature under different housing (high-rise and manure-belt) and manure handling (daily or annual manure removal) practices for laying hen houses.

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