EMISSIONS OF GREENHOUSE GASES FROM A TYPICAL CHINESE SWINE FARROWING BARN

H. Dong, Z. Zhu, B. Shang, G. Kang, H. Zhu, H. Xin

ABSTRACT. *Emissions of greenhouse gases (GHGs) from animal feeding operations to the atmosphere are of environmental importance and concerns because of their impact on global warming. Gaseous concentrations and emission rates (ERs) of animal facilities can be affected by the animal production stages, animal species, dietary nutrition, housing types, manure handling schemes, and environmental conditions. This article reports ERs of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) for a typical, naturally ventilated 24-crate swine farrowing barn located in suburban Beijing, China, that was monitored over one-year period. The measurements were made at bi-monthly intervals (i.e., six measurement episodes total), with each measurement episode covering three consecutive days. Gaseous concentrations were monitored at bi-hourly intervals throughout each 3-day measurement episode. The ventilation rate of the barn was estimated using the CO_2 mass balance method. The GHG concentrations and ERs of the farrowing barn showed diurnal and seasonal variations. Specifically, the concentrations (monthly mean ±SD, mg m^{-3}) ranged from 2.3 (±0.3) to 9.3 (±2) for CH_4, from 0.6 (±0.02) to 1.2 (±0.16) for N_2O, and from 1,370 (±163) to 11,100 (±950) for CO_2, with the higher levels occurring in January and the lower levels in July. The specific ER ranged from 95.2 to 261.8 mg h^{-1} pig^{-1} for CH_4, from 6.4 to 12.9 mg h^{-1} pig^{-1} for N_2O, and from 122.9 to 127.3 g h^{-1} pig^{-1} for CO_2. On the basis of per animal unit (1 AU = 500 kg live body mass), the average daily ERs of the farrowing barn were 9.6 ±3.6 g AU^{-1} d^{-1} for CH_4, 0.54 ±0.15 g AU^{-1} d^{-1} for N_2O, and 7.5±0.1 kg AU^{-1} d^{-1} for CO_2. Results of the GHG ERs from this study differ markedly from the limited literature data collected primarily under European production systems and conditions. Results of the current study provide some baseline data on GHG ERs for swine farrowing operations, thus contributing to development or improvement of GHG emission inventory under the Chinese livestock production conditions.*

Keywords. *Carbon dioxide, CO_2 balance, Methane, Natural ventilation, Nitrous oxide.*

Global warming has been linked to the elevation in atmospheric levels of greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Agricultural operations play an important role in climate change in that 20% to 35% of the global GHG emissions are estimated to originate from agricultural sources. Of the GHG emissions, anthropogenic CH_4 emissions account for approximately 40%, while N_2O emissions account for more than 50% (IPCC, 2001). Animals and their manure are important sources of CH_4, N_2O, and CO_2 generation, resulting from enteric fermentation, housing confinement, manure storage, manure treatment, and land application.

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Previous studies have focused on GHG emissions from enteric fermentation and manure management, including manure storage, manure treatment, and manure application (IPCC, 1996, 2000; Dong et al., 2004). Studies have also been conducted to evaluate the effects of different housing types at various swine production stages on emission rate (Gallmann et al., 2000, 2003; Guarino et al., 2003; Dong et al., 2006). Sneath et al. (1997) measured CH_4 and N_2O continuously over seven weeks from a swine fattening barn, a broiler house, and a dairy cow barn. Osada et al. (1998) measured CH_4, CO_2, and N_2O emission rates during a pig fattening period. Groot Koerkamp and Uenk (1997) reported GHG emissions from three different types of swine housing. Baudouin et al. (2003) reported GHG emissions for weaned pigs. Methane emission rates for farrow-to-finish and farrow-to-wean operations were reported by Sharpe et al. (2001). A summary of GHG (CO_2, CH_4, and N_2O) emission rates in the literature, mostly collected under European production conditions, is presented in table 1. It is clear from the previous studies that remarkable variations exist in gaseous emissions among different pig production systems due to different animal production stages, animal strains, dietary nutrition, housing types, manure handling schemes, and geographical locations.

China is the largest pig production nation in the world, producing approximately 50% of the world's market pigs in 2004. However, information on GHG emissions under Chinese production conditions (i.e., natural ventilation, frequent manure collection and removal) is meager. Hence,

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Table 1. Summary of literature information on greenhouse gas (GHG) emission rates of swine operations with different housing and management schemes (AU = animal unit = 500 kg live weight).

Country	Production Stage	Housing and/or Manure Handling Type	Emission Factor Unit	CO_2	CH_4	N_2O	Reference
Germany	Fattening	Fully slatted floor	g d^{-1} AU^{-1}	17,000-23,000	69-135	N/A	Gallmann et al. (2003)
		Kennel housing	g d^{-1} AU^{-1}	11,000-13,000	18-36	N/A	
Germany	Fattening	N/A	g h^{-1} AU^{-1}	N/A	0.5-1	N/A	Gallmann et al (2000)
Holland	Sows	N/A	mg h^{-1} pig^{-1}	N/A	2,406	N/A	Groot Koerkamp and Uenk (1997)
	Weaner	N/A	mg h^{-1} pig^{-1}	N/A	445	N/A	
	Finisher	N/A	mg h^{-1} pig^{-1}	N/A	1,269	N/A	
Italy	Fattening	Fully slatted floor	g h^{-1} AU^{-1}	N/A	7.9 ±1.6	0.02 ±0.15	Guarino et al. (2003)
		Vacuum system	g h^{-1} AU^{-1}	N/A	6.4 ±2.0	0.05 ±0.03	
Belgium	Weaned pigs	Straw litters	g d^{-1} pig^{-1}	463	1.58	0.35	Baudouin et al. (2003)
		Sawdust litters	g d^{-1} pig^{-1}	481	0.77	1.4	
Demark	Finishing	Partly slatted floor	g fattening period^{-1} pig^{-1}	5,540	302	9.1	Osada et al. (1998)
U.S.	Farrow-to-finish	N/A	g d^{-1} pig^{-1}	N/A	6.9-29.2	N/A	Sharpe et al. (2001)
	Farrow-to-wean	N/A	g d^{-1} pig^{-1}	N/A	46.2	N/A	
U.K.	Fattening	Slurry	g d^{-1} AU^{-1}	N/A	85	0.4	Sneath et al. (1997)
China	Fattening	Natural ventilation, solid manure removed twice a day	mg h^{-1} pig^{-1}	N/A	68-207	N/A	Dong et al. (2006)

studies on GHG emissions under Chinese production conditions will be conducive to the improvement of the global GHG emissions inventory. The objectives of this study were to characterize diurnal and seasonal concentrations and emission rates of CO_2, CH_4, and N_2O gases for a typical, naturally ventilated swine farrowing barn located in suburban Beijing, China, and compare the GHG ER data of the current study with those reported in the literature.

Materials and Methods

Housing Characteristics and Management Practices

The swine farrowing farm used in this study was located in the Shunyi District of Beijing, China. The monitored farrowing barn measured 8 m wide × 26 m long, with an eave height of 2.4 m and an east-west orientation. The barn had eight large ventilation windows (1.5 × 3.0 m each) spaced at 0.3 m along the south side wall and eight small windows (0.8 × 1.0 m each) spaced at 3 m along the north sidewall. There were 24 farrowing crates in the barn, arranged in two rows of 12 crates each (i.e., three aisles) and raised 30 cm above the concrete floor (fig. 1).

The sows averaged 200 kg in body weight and were kept in the farrowing barn for seven weeks (to ensure all in / all out operation). During this period, the sows received a daily feed of 4 kg: 2 kg at 8:00 a.m. and another 2 kg at 4:00 p.m. The sows had free access to drinking water via nipple drinkers. Freshly excreted (solid) manure was collected and removed either immediately or within a short period of time after defecation during the day. Spilled drinking water and urine were swept into the gutter under the farrowing crates and discharged to the outside waste water treatment unit through the gutter. The entire farrowing barn was flushed twice a day, following the respective feeding times.

The farrowing barn was ventilated naturally through operation of the ventilation windows on both side walls, which were fully open during summer and partially open during winter to maintain the target inside air temperature of 25°C. Supplemental heat was provided with a coal-fired water heating system for the room, coupled with infrared heat lamps for the creep area (one lamp per crate).

Measurement Protocols and Instruments

Air samples for measurement of CH_4, N_2O, and CO_2 concentrations were collected using 100 mL glass syringes and stored in aluminized polyethylene air sampling bags of 1 L capacity (Dalian Guangming Chemical Research Institute, Dalian, Liaoning, China). Inside air sampling was

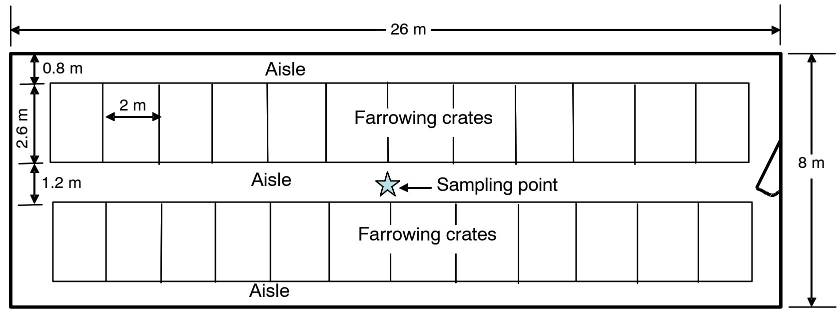

Figure 1. Plan view of two-row, raised-crate farrowing barn.

done at the central location of the barn, 0.3 m above the floor of the aisle. Selection of the central sampling location to represent the barn gas concentration was based on the results of a preliminary test on spatial distribution of gaseous concentrations inside the barn. During the test, air samples were taken at 4 h intervals throughout the day (25-26 November 2004) from five locations in the barn, i.e., near four corners and at the center. The results revealed that the disparity in GHG concentrations between the center location and any of the corner locations was less than 10%. Since the spatial uniformity test was done in winter, it was speculated that the disparity would be smaller during the warmer season due to increased ventilation and better mixing. A total of 144 gas samples were taken in duplicates at 2 h intervals for each of the three-day collection episodes in May, July, September, and November of 2004 and January and March of 2005. The outside air samples were taken once every 24 h at the same location 2 m away from the sidewall on the upwind side.

The collected air samples were transported, within one week of collection, to the Gas Analytical Laboratory of the Chinese Academy of Agricultural Sciences (CAAS) (Beijing, China), where they were analyzed for CH_4, N_2O, and CO_2 concentrations. Previous investigation by our group showed that up to two-week storage of air samples in this particular type of air sampling bag would have no effect on measurement integrity of the GHG concentrations (Hao et al., 2005). Quantification of the gas concentrations were performed using a GC (HP 6890, Agilent Technologies, Inc., Santa Clara, Cal.) with a flame ionization detector (FID) for CH_4 and CO_2 and with an electron capture detector (ECD) for N_2O. Table 2 lists the GC operational conditions used in the study, with an expected measurement accuracy of 2%. Calibration of the GC was done using standard gases, i.e., 1.79 and 9.8 μL L^{-1} for CH_4 (with N_2 balance), 310 and 740 μL L^{-1} for CO_2 (with N_2 balance), and 0.139 and 0.418 μL L^{-1} for N_2O (with N_2 balance) according to the National Research Center for Standard Materials, Beijing, China.

The indoor and outdoor temperature and relative humidity (RH) were recorded at 1 h intervals using programmable, battery-powered portable temperature and RH loggers with a 2% accuracy for temperature and 3% accuracy for RH (Hobo Pro T/RH, Onset Computer Corp., Bourne, Mass.). The inside air temperature was measured at 1.5 m above the floor to avoid destruction of the sensors by the pigs, at the same location as that of air sampling. The temperature data were used to adjust for temperature effect on total heat production (THP) in the indirect (CO_2 balance) determination of barn ventilation rate and thus gaseous emissions. The RH data provided a supplemental indicator to the environmental conditions of the barn.

Table 2. Operational conditions of the GC for analysis of CH_4, CO_2, and N_2O concentrations in the air samples from the monitored swine farrowing barn.

	Detector		Column				Flow
Gas	Type	Temp. (°C)	Type	Length (m)	Temp. (°C)	Carrier Gas	Rate (mL/min)
CH_4	FID	200	Porapak Q	3.0	70	N_2	35
CO_2	FID	200	Porapak Q	2.0	70	N_2	10
N_2O	ECD	330	Porapak Q	3.0	70	N_2	70

Determination of Ventilation Rate (VR)

Pedersen et al. (1998) compared three balance methods for determining ventilation rate (VR) in livestock buildings. For uninsulated livestock buildings, only the CO_2 balance method was recommended because of the difficulties in estimating the heat transmission loss from the building. Li et al. (2005) further demonstrated and confirmed the use of the CO_2 balance method for estimating VR of manure-belt layer houses by comparing the indirectly determined VR with the directly measured VR.

Because of the natural ventilation involved, the ventilation rate (VR, m^3 h^{-1}) of the farrowing barn in the current study was estimated using the CO_2 balance method in the following form:

$$\mathrm{VR} = \frac{V_{\mathrm{CO_2}} \times 10^6}{[\mathrm{CO_2}]_e - [\mathrm{CO_2}]_i} \times \rho_{\mathrm{CO_2}} \quad (1)$$

where
- V_{CO_2} = specific CO_2 production rate of the pigs (m^3 h^{-1})
- $[CO_2]_e$, $[CO_2]_i$ = CO_2 concentrations of the exhaust and inlet air, respectively (mg m^{-3}). All the CO_2 concentration differences between exhaust air and inlet air were greater than 300 ppm.
- ρ_{CO_2} = density of CO_2 (1.977 kg m^{-3})
- 10^6 = conversion of kg to mg.

Van Ouwerkerk and Pedersen (1994, as reported in CIGR, 2002) stated that when the respiratory quotient (RQ) of the pigs is 1.0 to 1.2, the pigs have a CO_2 production rate of 0.17 to 0.20 L h^{-1} W^{-1} (where W stands for watt of heat production), and CO_2 production from manure accounts for 4% of the total production. Using the indirect calorimetry relationship between total heat production (THP), CO_2 production, and RQ, and adjusting for environmental temperature effects and CO_2 production from manure, the CO_2 production of the farrowing barn could be expressed as follows:

$$V_{\mathrm{CO_2}} = \frac{0.0036 \times f_c \times \mathrm{THP} \times N \times 273}{\left(\frac{16.18}{\mathrm{RQ}} + 5.02\right) \times (T_i + 273)} \times K_{m,\mathrm{CO_2}} \quad (2)$$

where
- THP = total heat production rate of the pig (W pig^{-1})
- f_c = correction factor for diurnal CO_2 production (f_c = 1 for this study)
- N = number of sows and litters in the house (N = 24)
- RQ = respiratory quotient (RQ = 1 for this study)
- K_{m,CO_2} = multiplication factor representing the increase of CO_2 production from manure and other activities (K_{m,CO_2} = 1.04 for this study)
- T_i = inside air temperature (°C)

THP of the farrowing pig was derived from the recently updated CIGR (2002) equation:

$$\mathrm{THP} = (4.85 \times M^{0.75} + 28 \times Y_1) \quad (3)$$

where
- M = body mass of the farrowing pigs (kg; M = 200 for this study)
- Y_1 = milk production (kg day^{-1}; Y_1 = 6 for this study).

When the environmental temperature deviated from the reference temperature of 20°C, the THP was adjusted by the following equation to account for the temperature effect:

$$K_{t,\text{THP}} = 12 \times 10^{-3} \times (20 - T_i) + 1 \quad (4)$$

Determination of GHG Emission Rate (ER)

The CO_2, CH_4, and N_2O emission rates reported here represent the mass of GHG gas emitted from the farrowing barn to the atmosphere per unit time. The ER was calculated using the bi-hourly average gaseous concentrations and the corresponding indirectly derived VR (as described above) in the following form:

$$\text{ER} = \text{VR} \times \frac{[\text{C}]_e - [\text{C}]_i}{N} \quad (5)$$

where

ER = emission rate of the GHG (mg h^{-1} pig^{-1})

N = number of sows in the barn

$[\text{C}]_e$, $[\text{C}]_i$ = GHG concentration in the barn exhaust and inlet air (mg m^{-3}).

Results and Discussion

Environmental Conditions

Daily mean outside temperature during the one-year measurement period ranged from −2.8°C to 24.9°C with an overall mean of 11.5°C. Outside RH ranged from 16% to 75% with a mean of 39%. The indoor temperature remained relatively constant, ranging from 25.5°C to 27.5°C with a mean of 26.5°C. The inside and outside daily temperature profiles throughout the monitoring period are shown in figure 2. During the warm season or hours of the day when all windows were open, the inside temperature followed the outside temperature closely. However, during the cold season or hours of the day, the inside temperature was fairly constant as a result of the supplemental heat and adjustment of the windows.

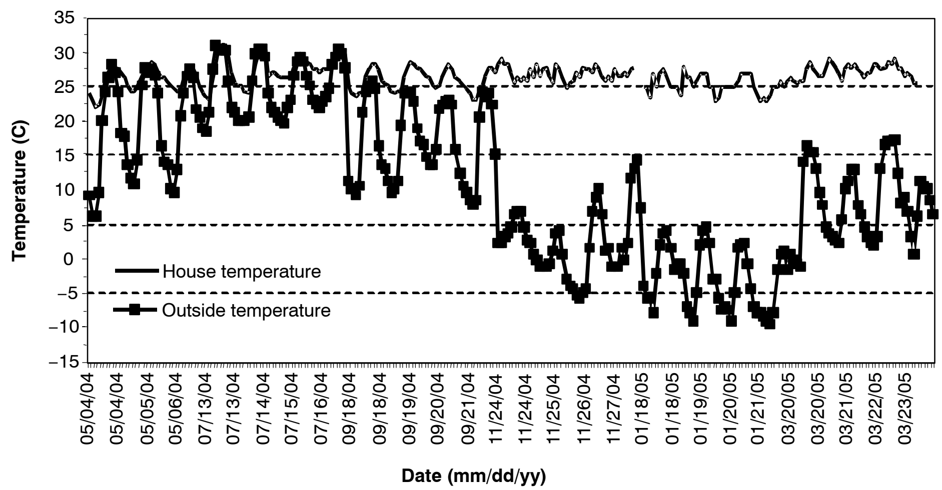

Figure 2. Air temperature profiles during the monitoring period of the swine farrowing barn.

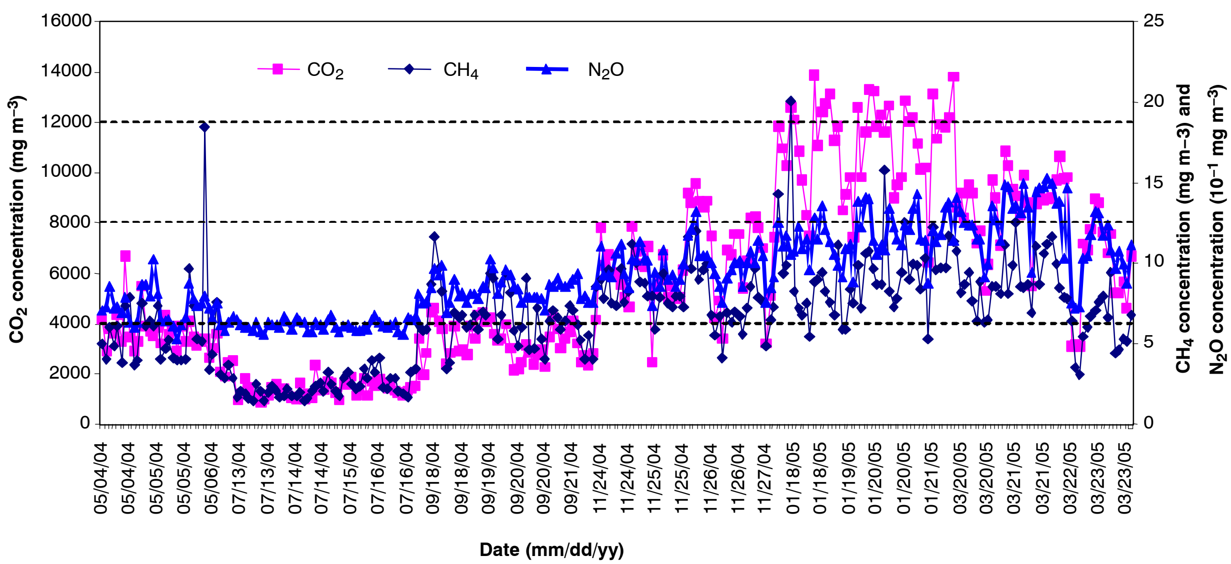

Figure 3. Profiles of CO_2, CH_4, and N_2O concentration inside the swine farrowing barn.

Table 3. Greenhouse gas (GHG) concentrations (mg m^{-3}) of the monitored swine farrowing barn in suburban Beijing, China, during the monitoring period (*n* = 36 for each mean value).

GHG	Statistic[a]	May 2004	July 2004	Sept. 2004	Nov. 2004	Jan. 2005	Mar. 2005	Annual
CO_2	Maximum	6,655	2,313	4,617	9,565	13,855	10,859	13,855
	Minimum	1,879	900	1,983	2,431	6,441	3,059	900
	Mean	3,557	1,370	3,300	6,427	11,100	7,824	5,956
	SD	568	163	447	1,111	950	1,507	3,556
	CV	16%	12%	14%	17%	9%	19%	64%
CH_4	Maximum	18.4	4.1	11.6	12.0	20.1	12.5	20.1
	Minimum	2.8	1.5	3.4	4.2	5.3	3.1	1.5
	Mean	5.4	2.3	6.6	8	9.3	7.8	6.6
	SD	1.4	0.3	1	0.8	2	1.5	2.5
	CV	26%	13%	15%	10%	22%	19%	38%
N_2O	Maximum	1.0	0.7	1.0	1.3	1.4	1.5	1.5
	Minimum	0.5	0.6	0.7	0.7	0.9	0.7	0.5
	Mean	0.7	0.6	0.8	1.0	1.2	1.2	0.9
	SD	0.09	0.02	0.04	0.09	0.07	0.16	0.26
	CV	13%	3%	5%	9%	6%	13%	28%

[a] CV = coefficient of variation, SD = standard deviation.

Gaseous Concentrations

Concentrations of the monitored GHG gases were affected by indoor temperature, which in turn affected VR of the barn. Figure 3 depicts variations of gaseous concentrations throughout the monitoring period. The gaseous concentra tions remained relatively constant throughout the day during the warm weather (July), presumably resulting from the consistently high VR of the barn. In comparison, the concentrations varied considerably between day and night during the cold weather as a result of changing the window openings and thus VR (more during the day and less at night). The inverse relationship between gas concentration and ambient temperature or season can also be seen from the data in table 3, with concentrations being lowest in July and highest in January. The elevated CO_2 concentrations, especially during the mild and cold months of the year (November, January, and March) were indicative of lack of ventilation for the barn, although assessment of ventilation performance or indoor air quality was not the direct objective of the study.

Emission Rates of the Greenhouse Gases

Table 4 summarizes the ERs of CO_2, CH_4, and N_2O for the farrowing barn during different months of the monitoring period. Emissions of CH_4 can originate not only directly from the digestive tract of the pigs but also from the anaerobic decomposition of the waste. Hence, the ER depends on animal type and size, feed intake and digestibility, indoor temperature, and manure handling practice. Compared with the literature data for CH_4 ER of 46.2 g d^{-1} pig^{-1} for a farrow-to-wean operation as reported by Sharpe et al. (2001), the annual mean ER found in the current study (9.6 g d^{-1} AU^{-1} or 3.04 g d^{-1} sow^{-1}) was substantially lower. This substantial difference was speculated to arise from the difference in manure handling practices. In the current study and as a general manure management practice in China, freshly excreted manure of the pigs was/is removed as promptly as possible from the barn (except at night). Hence, CH_4 generation from manure decomposition was/is essentially eliminated in the farrowing barn for the current study and in

Table 4. Emission rates of greenhouse gases from a naturally ventilated 24-crate swine farrowing barn in suburban Beijing, China.

GHG	ER[a]	Statistic[b]	May 2004	July 2004	Sept. 2004	Nov. 2004	Jan. 2005	Mar. 2005	Annual
CO_2	g h^{-1} sow^{-1}	Maximum	130.6	127.5	130.1	126.9	130.5	125.0	130.6
		Minimum	121.6	117.1	121.3	122.3	124.2	120.8	117.1
		Mean	126.0	122.9	126.0	124.1	127.3	123.2	124.9
		SD	3.3	3.8	3.1	1.5	1.9	1.3	1.8
		CV	3%	3%	2%	1%	1%	1%	1%
	kg d^{-1} AU^{-1}		7.6	7.4	7.6	7.4	7.4	7.4	7.5 ±0.1
CH_4	mg h^{-1} sow^{-1}	Maximum	237.9	278.6	293.9	172.9	147.3	127.5	293.9
		Minimum	117.4	107.0	174.7	125.2	77.6	95.7	77.6
		Mean	176.2	174.8	261.8	142.6	95.2	113.5	160.7
		SD	44.34	43.3	31.3	15.6	18.9	10.4	59.2
		CV	25%	25%	12%	11%	20%	9%	37%
	g d^{-1} AU^{-1}		10.6	10.5	15.7	8.6	5.7	6.8	9.6 ±3.6
N_2O	mg h^{-1} sow^{-1}	Maximum	13.6	15.6	15.1	10.7	8.8	12.1	15.6
		Minimum	0.3	1.1	9.8	6.6	5.6	8.6	0.3
		Mean	6.4	8.6	12.9	8.3	6.8	10.7	9.0
		SD	4.0	3.7	1.7	1.2	1.1	1.1	2.5
		CV	63%	43%	13%	14%	16%	10%	28%
	g d^{-1} AU^{-1}		0.39	0.51	0.78	0.49	0.41	0.64	0.54 ±0.15

[a] AU = animal unit = 500 kg live weight. The sows were assumed to have a body weight of 200 kg.
[b] CV = coefficient of variation, SD = standard deviation.

the Chinese swine production systems as represented by the study.

Unlike CH_4, N_2O results from both the nitrification and denitrification of waste. Hence, its emission magnitude largely depends on the microenvironment and manure management system. However, very limited information is available on N_2O emission from swine houses, largely due to the low N_2O concentrations present in swine houses, which makes measurement difficult. The annual mean N_2O emission rate (0.54 g d^{-1} AU^{-1}) found in the current study was higher than that of fattening pigs with a fully slatted floor and slurry manure system (0.4 g d^{-1} AU^{-1}), as reported by Sneath et al. (1997).

Carbon dioxide ER remained relatively constant in the current study, with an annual mean of 7.5 $\pm$0.1 kg d^{-1} AU^{-1}. No CO_2 ER data were available in the literature for comparison with the swine farrowing operation. The closest comparative value was the CO_2 ER of fattening pigs with kennel housing in Germany (11 to 13 kg d^{-1} AU^{-1}), as reported by Gallmann et al. (2003). The sows in the current study emitted much less CO_2 than the fattening pigs in the study by Gallmann et al. (2003). This outcome seems logical because one animal unit (500 kg) of sows involves less surface area than one animal unit of fattening pigs. Lower surface area translates to less metabolism (less metabolic heat dissipation) and thus lower respiratory CO_2 production. The restricted feeding of the sows, as compared to ad-lib feeding for the fattening pigs, would be another contributing factor to the lower CO_2 production/emission for the sows.

Variations in GHG Emission Rates

The diurnal bi-hourly CH_4 and N_2O emission rates during different months are plotted in figures 4 and 5, respectively. It can be seen that variations in the GHG emission rates tended to be greater during the warmer months, notably during July and September. This outcome presumably resulted from the larger temperature fluctuations during the warmer months, as compared to the cool/cold periods. The variations might have been further caused by differences in the timing of manure removal and animal activities. The nature of the diurnal variations in the gaseous emission rate makes it necessary to monitor the emissions throughout the day to ensure representative daily emission values. Similarly, the nature of the seasonal variations in the gaseous emission rate makes it necessary to monitor the emissions throughout the year to ensure representative annual emission values.

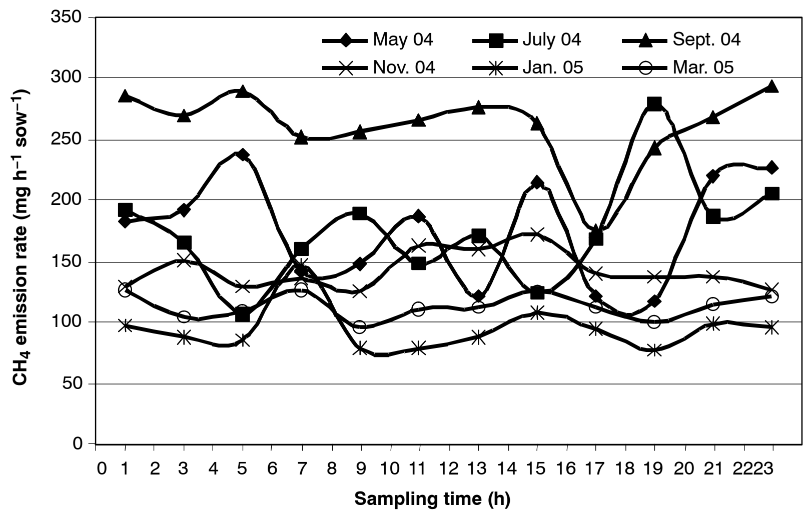

Figure 4. Diurnal variations of CH_4 emission rates of the swine farrowing barn during different months.

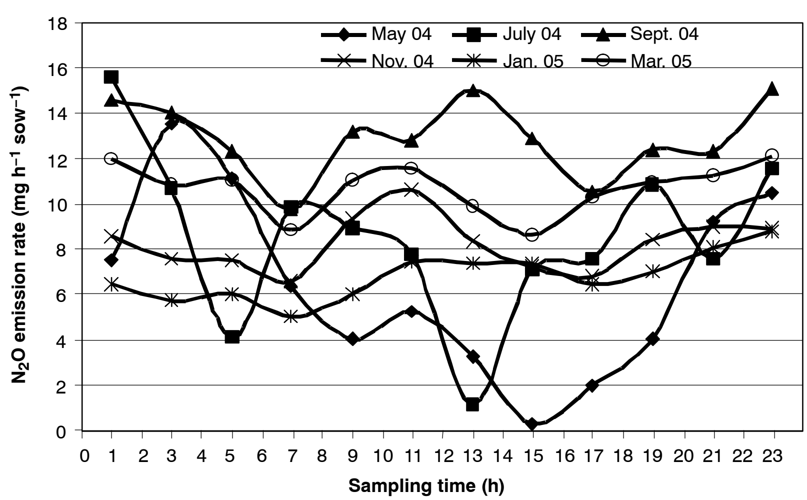

Figure 5. Diurnal variation of N_2O emission rates of the swine farrowing barn during different months.

The relationships of the GHG emission rates to indoor temperature are illustrated in figures 6, 7, and 8, respectively, for CH_4, N_2O, and CO_2. As shown in figures 6 and 7, CH_4 and N_2O emissions from the swine farrowing barn were rather independent of the indoor temperature. This outcome contradicts the general intuition of elevated emissions at higher environmental temperatures for most housing or manure storage systems. However, with manure being the source of CH_4 and N_2O emissions and with the unique manure handling practice used in this study (i.e., prompt removal from the barn), this outcome seems quite logical. It should be noted that prompt manure removal from swine barns is typical of commercial swine operation in northern China. Hence, direct application of GHG emission factors from other countries (e.g., Europe or America) to the estimation of GHG emissions for animal feeding operations in China would likely lead to gross errors. Carbon dioxide ER followed a linear, inverse relationship with inside temperature, a result of the negative linear relationship between THP and ambient temperature.

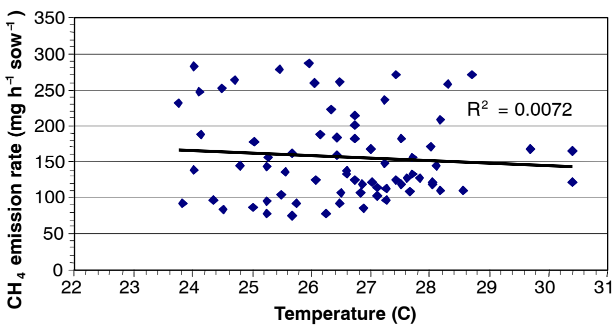

Figure 6. Methane (CH_4) emission rates vs. inside temperature of the swine farrowing barn.

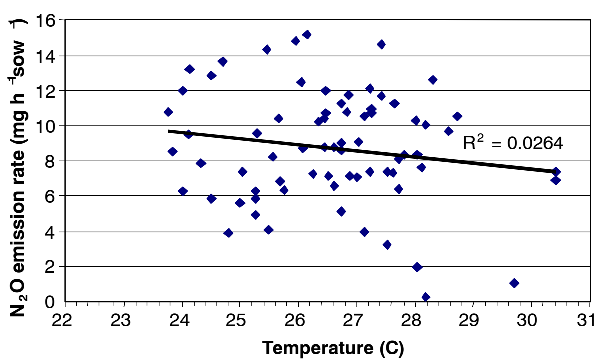

Figure 7. Nitrous oxide (N_2O) emission rate vs. inside temperature of the swine farrowing barn.

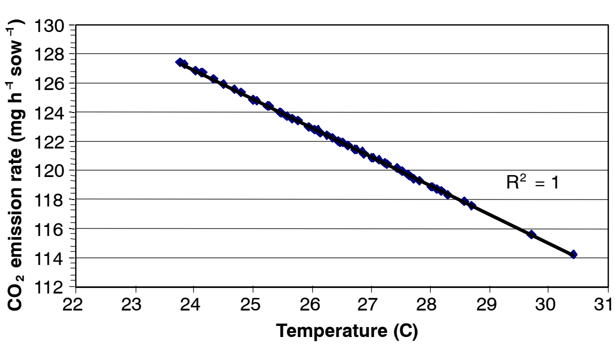

Figure 8. Carbon dioxide (CO_2) emission rate vs. inside temperature of the swine farrowing barn.

Conclusions

Emission rates of greenhouse gases (CO_2, CH_4, and N_2O) from a naturally ventilated 24-crate swine farrowing barn in suburban Beijing, China, were monitored at bi-monthly intervals for one year, with each measurement episode lasting three days. The annual ranges and means of GHG emission rates were:

- 7.4 to 7.6 and 7.5 ±0.1 kg d^{-1} AU^{-1} for CO_2
- 5.7 to 15.7 and 9.6 ±3.6 g d^{-1} AU^{-1} for CH_4
- 0.39 to 0.78 and 0.54 ±0.15 g d^{-1} AU^{-1} for N_2O.

The GHG ERs from the current study tended to differ substantially from the limited literature data, presumably resulting from the unique production and manure handling practices associated with typical swine operations in northern China.

There existed both diurnal and seasonal variations in the GHG emission rates, with more marked diurnal fluctuation during the warm months, making it necessary to take measurements throughout the day and the year to ensure representative annual GHG emission values.

The GHG emissions data from the study will contribute to the development or improvement of GHG emissions inventories for better assessment of the animal production impact on the environment, locally and globally.

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