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Quantification of Greenhouse Gas and Ammonia Emissions from a Midwestern Swine Breeding/Gestation/Farrowing Facility

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Abstract

Interest in greenhouse gas (GHG) emissions from animal feeding operations is increasing. However, information is meager concerning GHG emissions from swine operations, particularly from breeding, gestation, and farrowing facilities. The purpose of this study is to quantify GHG emissions from a breeding/gestation and farrowing facility located in Central Iowa. The monitored portion of the facility consists of a deep-pit breeding barn (1800 head), a deep-pit gestation barn (1800 head), and two shallow-pit farrowing rooms (40 farrowing crates per room). Monitoring began in January 2011 and will continue for one year to cover the seasonal effects on the emissions. This paper reports on data collected from January 12, 2011 to May 31, 2011. A mobile air emissions monitoring unit is dedicated to the extensive monitoring. At the time of this writing, results from the study show the following average daily emissions per animal unit (AU = 500 kg body mass): 31.9 g NH3, 8.82 kg CO2, 0.1 g N2O, and 283.1 g CH4 for sows in the breeding/early gestation barn; and 32.8 g NH3, 9.77 kg CO2, 0.1 g N2O, and 290.1 g CH4 for sows in the late gestation barn. For the farrowing rooms, results to date show the following average cumulative emissions per crate (sow and piglets): 1.02 kg NH3, 308 kg CO2, 0.0038 kg N2O, and 1.53 kg CH4. The 6 turns through each room had an average lactation period of 22 days, litter size of 10.5 piglets, and weaned piglet body weight of 5.59 kg.

Keywords

Swine, Aerial emissions, Greenhouse gas, Ammonia, Deep-pit

Disciplines

Bioresource and Agricultural Engineering

Comments

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Abstract. *Interest in greenhouse gas (GHG) emissions from animal feeding operations is increasing. However, information is meager concerning GHG emissions from swine operations, particularly from breeding, gestation, and farrowing facilities. The purpose of this study is to quantify GHG emissions from a breeding/gestation and farrowing facility located in Central Iowa. The monitored portion of the facility consists of a deep-pit breeding barn (1800 head), a deep-pit gestation barn (1800 head), and two shallow-pit farrowing rooms (40 farrowing crates per room). Monitoring began in January 2011 and will continue for one year to cover the seasonal effects on the emissions. This paper reports on data collected from January 12, 2011 to May 31, 2011. A mobile air emissions monitoring unit is dedicated to the extensive monitoring. At the time of this writing, results from the study show the following average daily emissions per animal unit (AU = 500 kg body mass): 31.9 g NH_3, 8.82 kg CO_2, 0.1 g N_2O, and 283.1 g CH_4 for sows in the breeding/early gestation barn; and 32.8 g NH_3, 9.77 kg CO_2, 0.1 g N_2O, and 290.1 g CH_4 for sows in the late gestation barn. For the farrowing rooms, results to date show the following average cumulative emissions per crate (sow and piglets): 1.02 kg*

NH_3, 308 kg CO_2, 0.0038 kg N_2O, and 1.53 kg CH_4. The 6 turns through each room had an average lactation period of 22 days, litter size of 10.5 piglets, and weaned piglet body weight of 5.59 kg.

Keywords. *Swine, Aerial emissions, Greenhouse gas, Ammonia, Deep-pit*

Introduction

Gaseous emissions from livestock production have received increasing attention as concern has grown over their environmental and health impacts. Local concerns over gaseous emissions are usually focused on the odor and environmental impacts. For example, ammonia (NH_3) is usually of concern for its potential negative impacts on local environments due to deposition. However, it is important to study these emissions to understand the quantity and composition of gasses being emitted to the atmosphere. The three biggest gasses of concern in terms of having potential to affect climate change are the greenhouse gasses (GHG): carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). In order to understand the magnitude of GHG emissions from livestock production, reliable emission factors for different livestock production systems in different geographic/climatic areas must be determined. Currently, there is a gap in the swine data for the breeding/gestation and farrowing stages of production.

The US breeding pig inventory was 5.97 million head as of March 1, 2011 and Iowa leads the US with over 17% of the breeding inventory (USDA NASS, 2011). The US EPA estimates that agriculture is responsible for 6.3% of the total GHG emissions in the US (2011 US Greenhouse Gas Inventory Report). As mitigation technologies are developed to reduce emissions, it is important to have accurate emission rates for accurate design and implementation of mitigation technologies, to evaluate the effectiveness of the technologies, and to direct technology development toward the areas of animal production that have the largest emissions footprint.

There is limited literature on GHG emissions from swine gestation and farrowing facilities. The gestation side is particularly sparse as many of the studies done are for shallow-pit or flush systems, not the deep-pit system common in the Midwest. Accumulation and storage of the manure in a deep-pit system increases the potential for NH_3, N_2O, and CH_4 emissions by providing a relatively stable environment for the chemical and biological processes that produce these gasses to occur. The literature for farrowing facility emissions is more comparable due to the common manure management practice of shallow-pit systems but is still meager. Additionally, many of these studies involved intermittent air sampling, which can struggle to capture the diurnal fluctuations of gaseous emissions and can be significantly impacted by short term weather conditions.

Therefore, the objective of this study was to quantify the emissions of GHG and ammonia from a Midwestern production scale breeding/gestation/farrowing facility over a one-year period. This study, when coupled with the results from a recent study by Pepple et al. (2011), will begin to establish the baseline GHG and NH_3 emissions data for the entire swine production cycle under Midwestern production conditions.

Methods and Materials

Site and Instrumentation Description

A 4300 sow capacity breeding/gestation/farrowing facility in central Iowa was used in this one-year monitoring study. The facility consisted of two farrowing buildings with 9 farrowing rooms each, a breeding/early gestation barn, and a late gestation barn. Two farrowing rooms, designated Room 1 and Room 2, were selected to be monitored. The farrowing rooms were each 15.5m x 13.9m (51ft x 45.5ft) with a shallow-pit system (0.61m deep) that was flushed out after every turn (approx. every 21 days). Each room utilized two 0.3m (12 in.) fans, two 0.6m (24 in.) variable speed fans, one 0.91m (36 in.) fan, and one 1.2m (48 in.) fan for ventilation with the inlet air drawn from a common hallway. Each room had 40 farrowing crates and one 66kW (225,000 BTU/h) space heater. Figure 1 shows the monitoring system layout for the farrowing rooms. Each room's exhaust air was sampled identically, with one composite sample from the shallow-pit fans and one composite sample from the lowest stage wall fans.

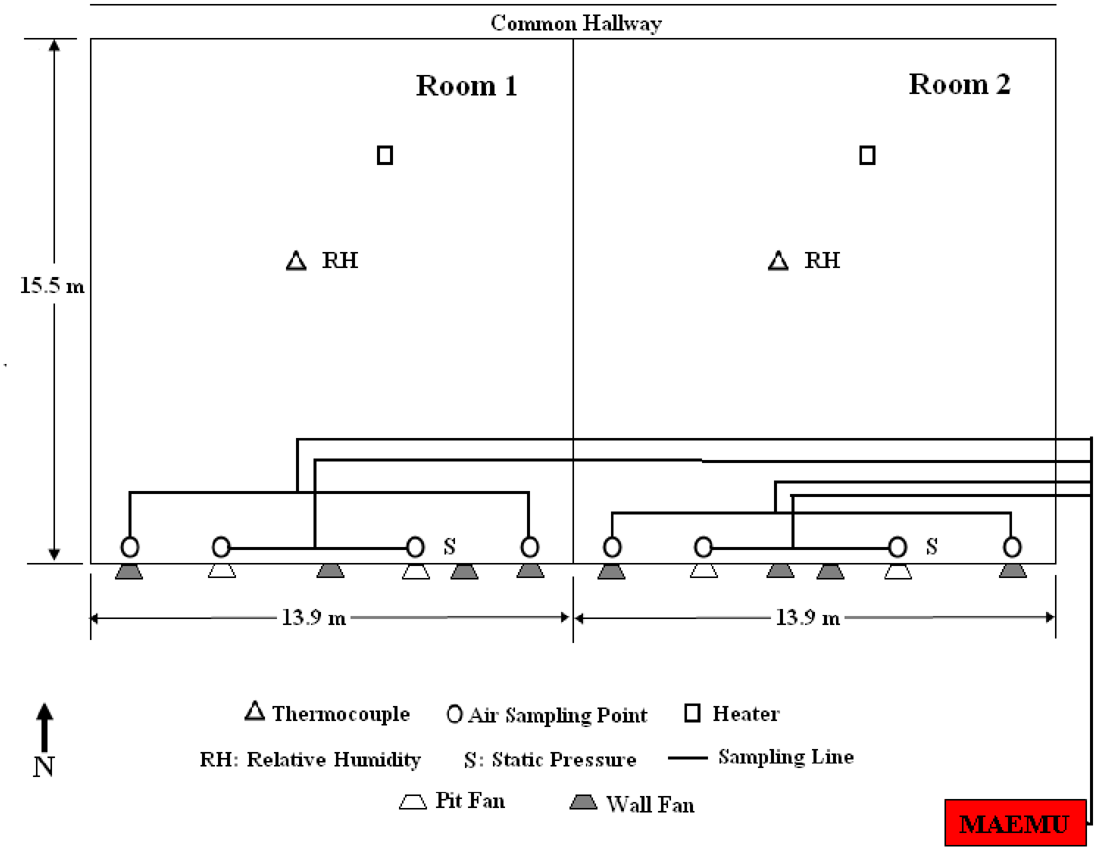

Figure 1. Diagram of Farrowing Rooms 1 and 2 showing air sampling, temperature, static pressure, and relative humidity measurement locations.

The breeding/early gestation barn and the late gestation barn, designated as Barns 1 and 2 respectively, had the same dimensions, ventilation design, and 1800 head capacity. The barns had dimensions of 121.9m x 30.5m (400ft x 100ft) and used mechanical ventilation year-round. Each barn had twelve 0.6m (24 in.) pit fans, fifteen 1.32m (52 in.) endwall fans, 55 bi-flow ceiling inlets, and ten 66 kW (225,000 BTU/hr) space heaters. When necessary, curtains on evaporative cooling pads located on the north, south, and east walls can be dropped to allow for tunnel ventilation with the cooling effect of the pads. Each barn had a deep-pit (3.05 m) and the manure was pumped out semi-annually, in the fall and spring. Figure 2 shows the monitoring system layout for Barns 1 and 2. Exhaust air samples from each barn were drawn as a composite from four of the lowest ventilation stage pit fans with a second sample from the lowest stage endwall fan. Barn 1, as the breeding/early gestation barn, contained both sows waiting to be bred and gestating sows up to day 40 of the gestation cycle. After day 40 the sows were moved to Barn 2 where they were held until ready to give birth at which time they were moved into a farrowing room. Barn 1 also received new breeding stock and held culled stock until they were hauled off. As a result, Barn 1's population fluxuated while Barn 2 was maintained at capacity.

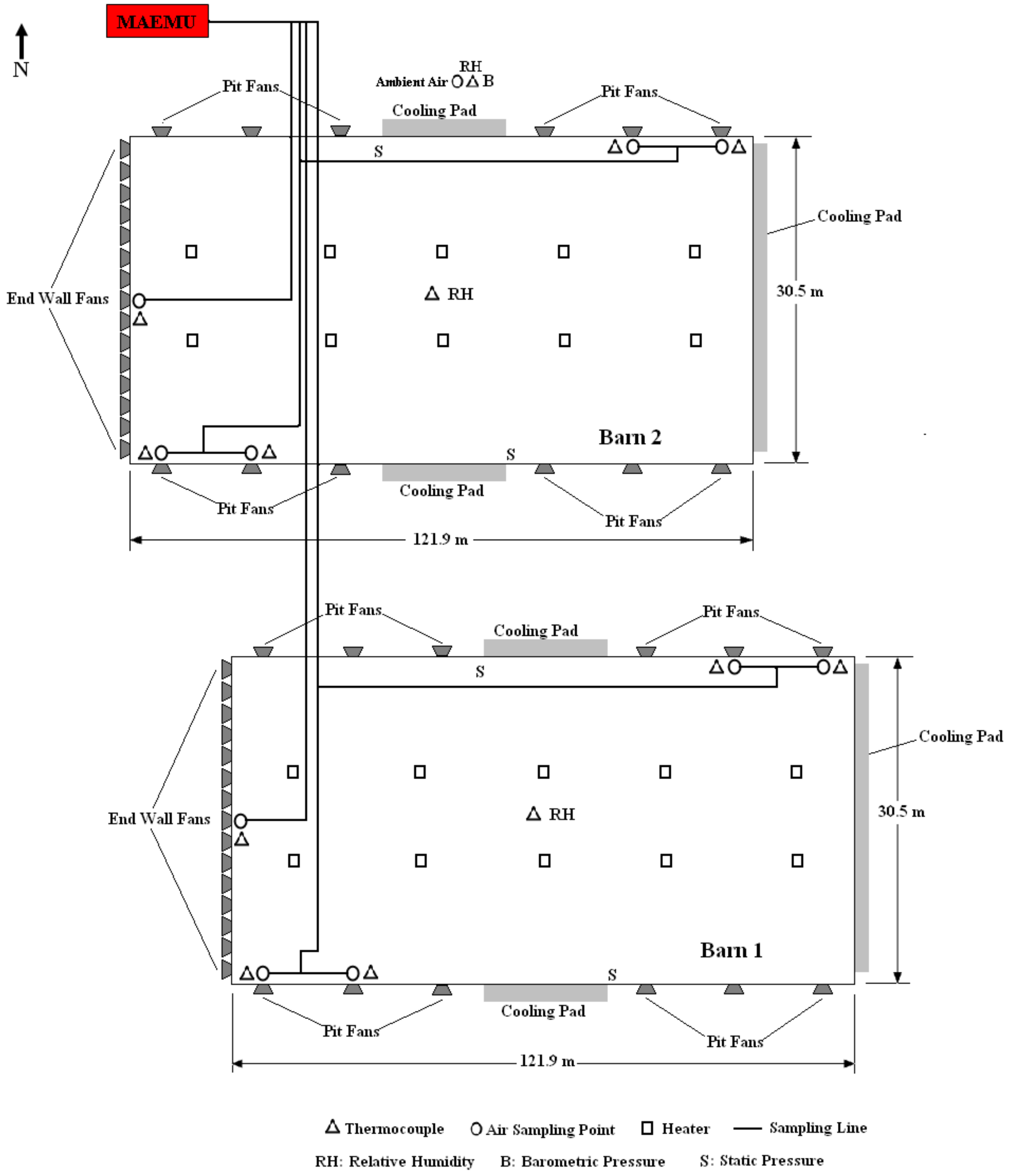

Figure 2. Diagram of Barns 1 and 2 showing air sampling, temperature, static pressure, relative humidity, and barometric pressure measurement locations.

A Mobile Air Emissions Monitoring Unit (MAEMU) was used to continuously collect emissions data from the previously described barns and farrowing rooms. A detailed description of the MAEMU and its operation can be found in Moody et al. (2008). The MAEMU housed, among other measurement and data acquisition equipment, a photoacoustic multi-gas analyzer (INNOVA Model 1412, INNOVA AirTech Instruments A/S, Ballerup Denmark) to measure NH_3, CO_2, N_2O, and CH_4 concentrations. The analyzer was challenged weekly with calibration gasses and recalibrated as needed.

Air samples were drawn for 120 s from each location. This corresponded to 4 measurement cycles by the analyzer. The fourth measurement value was taken as the exhaust air pollutant concentration. The 120 s sampling period corresponded to the T98 response time of 120 s for the analyzer. Samples were drawn from the 8 in-house locations and 1 outside location to provide ambient background data. Samples were drawn from each in-house location every 16 min (2 min per location) with the outside air being sampled every two hours for 6 min (12 samples). The outside location can be seen in Figure 2 on the north side of Barn 2. Pit fan sampling ports were located below the slats/floor directly under each fan. Wall fan sampling ports were located approximately 1.0 m (3.28 ft) in front of each wall fan. The sample port locations were chosen to best represent the exhaust air leaving each barn/room. Each sample line contained three consecutive in-line filters (60, 20, 5 µm) to prevent particulate matter from entering and plugging/damaging sample lines, pumps, valves, and the gas analyzer. The MAEMU utilized a positive-pressure gas sampling system to minimize potential infusion of unwanted air to the sample line. All pumps and sample lines were checked weekly for leaks and blockages.

All fans at the facility were fixed speed except for the 0.6m (24 in) wall fans in the farrowing rooms, which had variable speed. The fans were calibrated *in situ* at multiple operating points to develop a performance curve for each fan. This calibration was performed with a Fan Assessment Numeration System (FANS) (Gates et al. 2004). For the variable speed fans (0.6m wall fans in Room 1 and 2), the performance curve was derived as a function of static pressure and fan speed (revolutions per minute, RPM). For the fixed speed fans (all other fans) the performance curve was derived as a function of static pressure. The on/off status of each fan was monitored continuously by an inductive current switch on the each fan motor's power cord (Muhlbauer et al. 2011) with its analog output connected to the data acquisition system. The speed of the variable speed fans was measured by Hall Effect speed sensors (GS100701, Cherry Corp, Pleasant Prairie, WI). Static pressure sensors were located near the south wall of each farrowing room and near the middle of the north and south walls in Barns 1 and 2.

Gaseous Emission Rate Determination

Emission rates for each measured constituent were calculated as mass of the gas emitted per unit time using the following equation:

$$ER_G = \sum Q\left([G]_e - \frac{\rho_e}{\rho_i}[G]_i\right) \times 10^{-6} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}} \times \frac{W}{v} \qquad [1]$$

Where ER_G = Gas emission rate for the house, g hr^{-1} $house^{-1}$

Q = Incoming and exhaust ventilation rate of the house at field temperature and barometric pressure, respectively, m_3 hr^{-1} $house^{-1}$

$[G]_i$, $[G]_e$ = Gas concentration of incoming and exhaust ventilation air, respectively, ppmv

W = Molar weight of the gas, g $mole^{-1}$ (e.g., 17.031 for NH_3)

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

T_{std} = Standard temperature, 273.15 K

T_a = Ambient air temperature

ρ_i, ρ_e = Density of incoming and exhaust air, respectively, g cm^{-3}

P_{std} = Standard barometric pressure, 101.325 kPa

P_a = Atmospheric barometric pressure at the monitoring site, kPa

Results and Discussion

The results discussed below cover data collected from January 12, 2011 to May 31, 2011.

Figures 3 and 4 show the average daily ventilation rates for Barns 1 and 2 and Rooms 1 and 2, along with the outside temperature. The average ventilation rate for the monitoring period was 98,090 m^3/hr (59.7 m^3/hr-head) for Barn 1, 129,100 m^3/hr (71.7 m^3/hr-head) for Barn 2, 12,010 m^3/hr (300 m^3/hr-crate) for Room 1, and 11,790 m^3/hr (295 m^3/hr-crate) for Room 2.

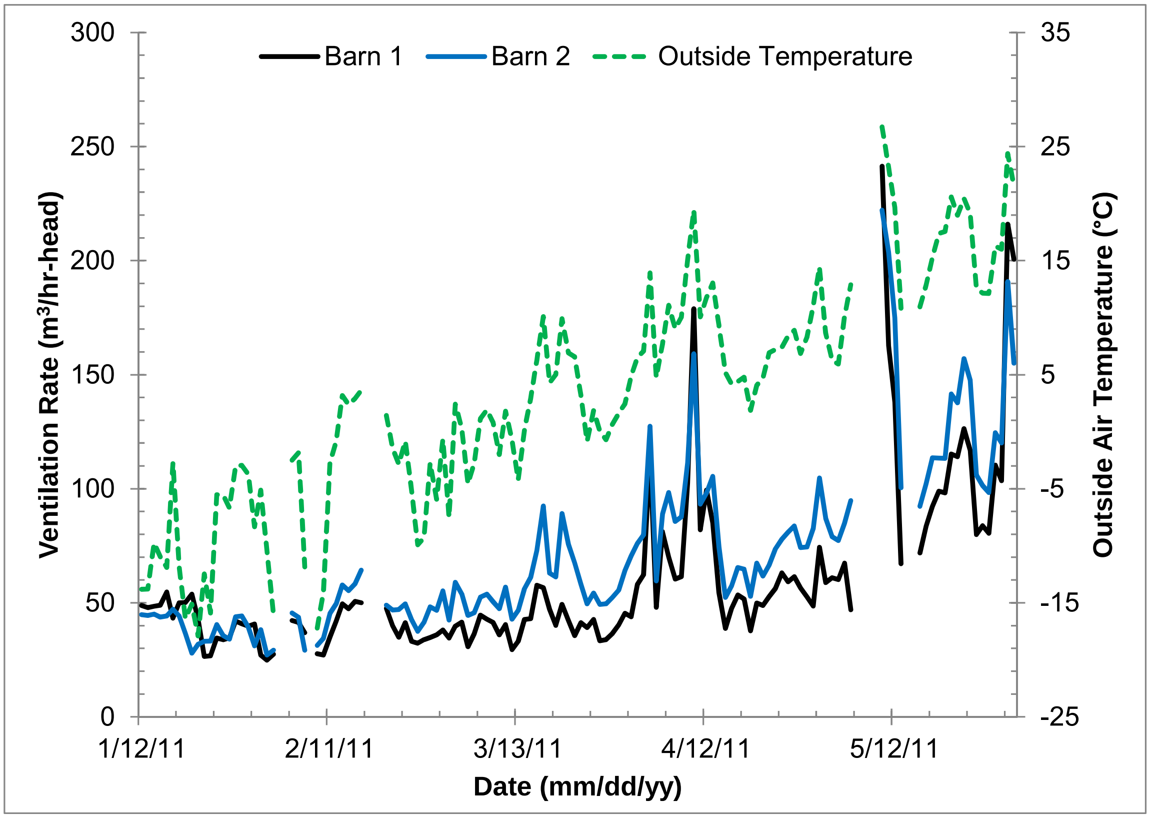

Figure 3. Average daily ventilation rate of barns 1 and 2 and outside temperature during monitored period. Barn 1 averaged 1625 head and barn 2 averaged 1800 head during the monitoring period.

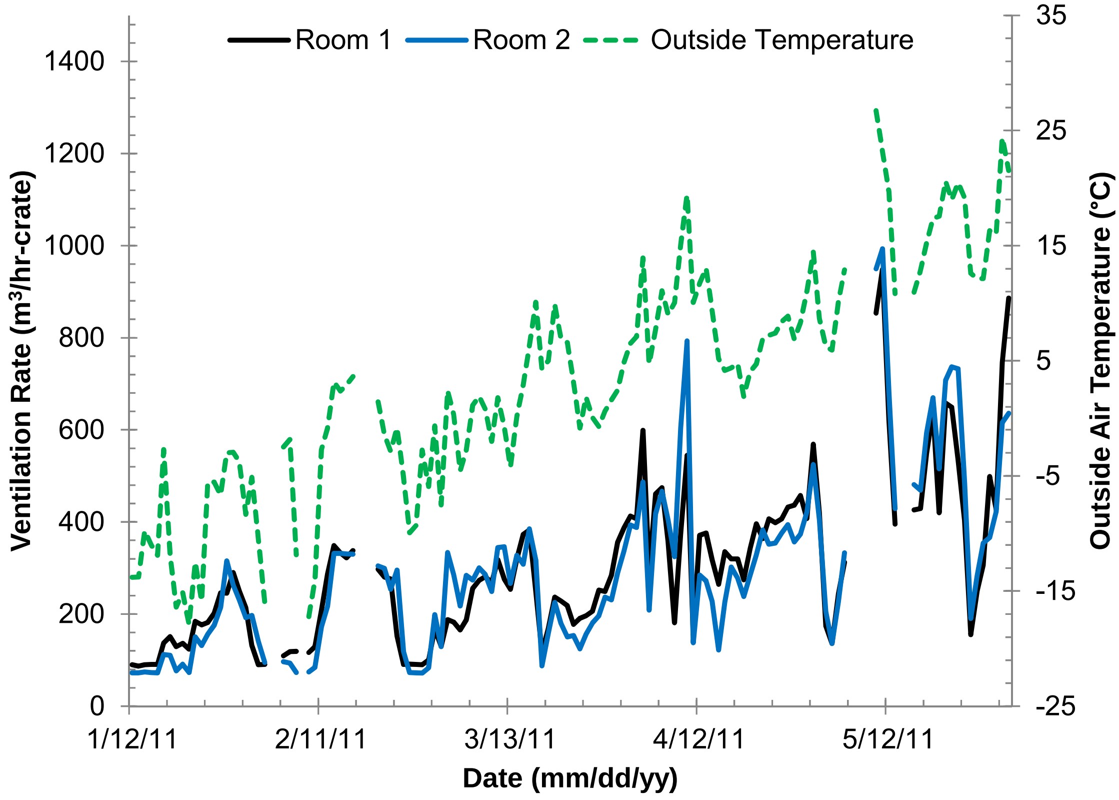

Figure 4. Average daily ventilation rate of rooms 1 and 2 and outside temperature during monitored period. Both rooms contain 40 farrowing crates.

Emission Rates

Emission rates were expressed in kg/d-house, g/d-AU (AU=animal unit, 500 kg live body mass), and kg/turn-crate. The kg/turn-crate is the cumulative emissions of each constituent over the lactation period (typically 21 days) divided by the number of sow/litter crates (40 per room).

Average daily emission rates for the monitored gasses are shown in Table 1. While Rooms 1 and 2 could be directly compared, it must be noted that Barns 1 and 2, although similar in design, were different in both number of pigs and production stage of the animals as discussed in the Methods and Materials section. To account for the differences in stocking, the emission rates are also expressed as g/day-AU in Table 2. The CO_2 emission rates included CO_2 production from the propane space heaters, which accounted for less than 3% of Barn 1 and Barn 2 emissions and less than 2% of Room 1 and Room 2 emissions.

Table 1. Average (SD) gaseous emission rates (kg/d-barn or room) of the two monitored breeding/gestation barns and two monitored farrowing rooms.

	# of Days Monitored	# Pigs or Crates	VR (m^3/hr-pig or crate)	NH_3	CO_2*	N_2O	CH_4
Barn 1	128	1625	59.66	18.4	5006	0.063	160.8
			(37.00)	(4.5)	(1250)	(0.3)	(55.9)
Barn 2	128	1800	71.72	21.3	6197	0.048	183.8
			(37.50)	(3.1)	(1224)	(0.3)	(50.4)
Room 1	128	40	300.12	1.9	549	0.018	2.6
			(171.32)	(0.7)	(226)	(0.03)	(0.9)
Room 2	128	40	244.44	1.7	542	(0.024)	3.2
			(184.01)	(0.55)	(223)	(0.03)	(1.04)

*Includes CO_2 production from propane heaters which is less than 3% of emissions from Barns 1 and 2 and less than 2% of emissions from Rooms 1 and 2.

Table 2. Average (SD) gaseous emission rates (g/d-AU) of the two monitored barns and two monitored farrowing rooms (AU = animal unit = 500 kg body mass).

Description	# of Days Monitored	# Pigs or Crates	VR (m^3/hr-pig)	NH_3	CO_2*	N_2O	CH_4
Barn 1	128	1625	59.66	31.6	8754	0.1	279.8
			(37.00)	(7.6)	(2382)	(0.4)	(95.4)
Barn 2	128	1800	71.72	32.7	9691	0.1	285.5
			(37.50)	(4.8)	(1879)	(0.3)	(77.4)
Room 1	128	40	300.12	101.3	28833	0.4	133.6
			(171.32)	(36.3)	(12016)	(1.0)	(49.4)
Room 2	128	40	244.44	88.2	28034	0.3	153.7
			(184.01)	(29.1)	(11740)	(0.7)	(54.8)

*Includes CO_2 production from propane heaters which is less than 3% of emissions from Barns 1 and 2 and less than 2% of emissions from Rooms 1 and 2.

Zhu et al. (2000) measured NH_3 emissions from several swine facilities in Minnesota, including a deep-pit gestation and deep-pit farrowing building. The gestation building had an emission rate of 0.007 to 0.014 g/h-m^2, which when scaled to Barns 1 and 2 gave a range of 0.757 to 1.516 kg/d-barn. This is far below the measured 18.6 and 21.3 kg/d-barn from Barns 1 and 2. For the farrowing barns, Zhu et al. reported a range of 0.01 to 0.18 g/h-m^2, which would scale to

0.362 to 0.931 kg/d-room. This was again lower than the measured 1.9 and 1.7 kg/d-room for Rooms 1 and 2.

Zhang et al. (2007) measured GHG emissions from two mechanically ventilated farrowing farms. The farrowing barns followed the same 3-week pit-flushing period as used for Rooms 1 and 2. Emission rates of CH_4 ranged from 73 to 351 g/d-AU, encompassing the measured emission rates of 134 and 154 g/d-AU of our current study. Zhang et al. also reported CO_2 emission rates of 16,588 and 11,576 g/d-AU, which were lower than the measured 28,833 and 28,034 g/d-AU emission rates in the current study. Zhang et al. did not measure any significant N_2O emissions, while the emissions from Rooms 1 and 2 averaged 0.4 and 0.3 g/d-AU.

Tables 3 and 4 show the cumulative emission of the constituents during each farrowing turn per crate (sow+litter). The tables also show the length of each farrowing turn, average litter size, and average weaned weight. Both rooms had comparable emissions for all constituents.

Table 3. Cumulative gaseous emissions for each farrowing turn in kg/turn-crate for Room 1.

Turn Dates	Length of Turn (days)	Average Litter Size	Average Weaned Weight (kg)	NH_3	CO_2*	N_2O	CH_4
1/12-2/1	21	10.1	5.81	0.74	317	0.018	1.48
2/2-2/23	22	10.0	5.62	1.18	356	0.008	1.47
2/24-3/17	22	10.4	5.45	1.21	325	0.0004	1.24
3/18-4/8	22	10.8	5.61	1.39	313	0.0004	1.12
4/9-4/29	21	10.3	5.68	1.00	327	0.0000	1.77
4/30-5/23	24	10.7	5.08	0.98	230	0.0001	1.42
Mean	22	10.4	5.54	1.08	311	0.004	1.42
SE	0.45	0.13	0.10	0.08	15.9	0.003	0.08

*Includes CO_2 production from propane heaters which is less than 2% of the cumulative emissions

Table 4. Cumulative gaseous emissions for each farrowing turn in kg/turn-crate for Room 2.

Turn Dates	Length of Turn (days)	Average Litter Size	Average Weaned Weight (kg)	NH_3	CO_2*	N_2O	CH_4
1/13-2/3	22	10.2	6.01	0.81	320	0.014	1.51
2/4-2/24	21	11.0	5.57	0.88	296	0.004	1.42
2/25-3/18	22	10.7	5.14	0.97	365	0.0007	1.87
3/19-4/11	24	10.3	5.46	1.15	316	0	1.40
4/12-5/2	21	10.9	5.89	0.94	310	0	1.95
5/3-5/24	22	10.7	5.75	0.96	225	0	1.65
Mean	22	10.6	5.63	0.95	305	0.003	1.63
SE	0.45	0.13	0.13	0.04	17.1	0.002	0.09

*Includes CO_2 production from propane heaters which is less than 2% of the cumulative emissions

As discussed previously, this study's NH_3, CO_2, and N_2O emissions were higher than literature values for comparable systems. One major difference between this study and previous studies is the sampling intervals used for both gas concentrations and ventilation rates. Zhang et al. (2007) collected one air sample per farrowing room per day for 19 different dates from September to October 2003 and from June to September 2004. At the time of each air sample, the ventilation rate was measured for each running fan using a hot-wire anemometer. Zhu et al. (2000) collected air samples every two hours for a single 12 hour period. Ventilation rate was estimated by measuring static pressure difference across each running fan and referring to fan rating tables. Neither of these studies accounted for both seasonal and diurnal variations in emission rates. Figures 5 and 6 show emission rates from Barn 1 for CO_2, CH_4, NH_3, and N_2O over a one day period. The dynamic emission rates are driven both by the changing ventilation rates and gas concentrations that are, in turn, driven by inside temperature, animal activity, and ambient weather conditions. Spot sampling or long intervals between samples can miss these fluxuations and underestimate or overestimate the daily emission. The more frequent sampling used in the current study at each location (every 16 min) and constant monitoring of building and environment conditions (fan statuses, static pressure, temperature, etc.) is expected to give a more accurate estimation of the daily emission rate.

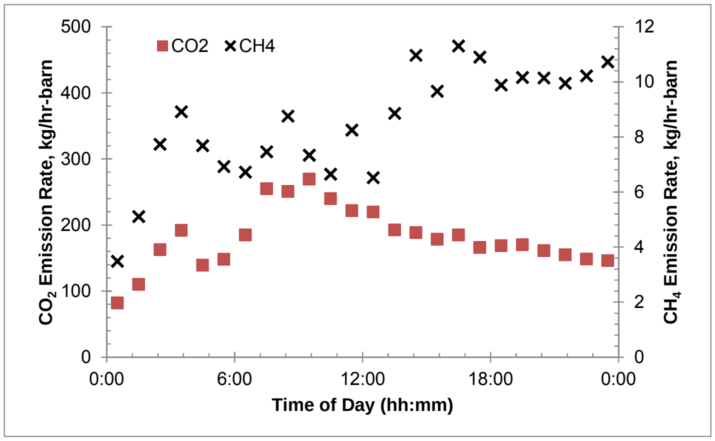

Figure 5. Diurnal variation of CO_2 and CH_4 emission rates (kg/hr-barn) for Barn 1.

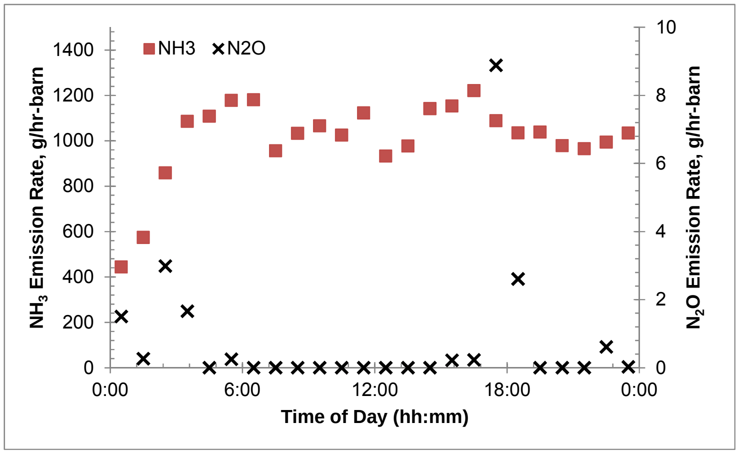

Figure 6. Diurnal variation of NH_3 and N_2O emission rates (g/hr-barn) for Barn 1.

Preliminary Conclusions

The results of this study to date indicate that gaseous emission rates from the Midwest swine breeding, gestation and farrowing facility are possibly higher than the current literature values in all cases except for CH_4 emissions from the farrowing rooms. The higher emission rates are likely due to this facility being a deep-pit system for Barns 1 (breeding and early gestation) and 2 (late gestation) and the nearly continuous sampling employed in this study as compared to the intermittent sampling used in the literature studies. More data collection is in progress and the one-year results will be available in summer 2012.

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References

EPA. 2011. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005. Washington, DC. United States Environmental Protection Agency.

Gates, R. S., D. K. Casey, H. Xin, E. F. Wheeler, J.D. Simmons. 2004. Fan Assessment Numeration System (FANS) design and calibration specifications. Transactions of the ASAE 47(6):1765-1778.

Moody, L., H. Li, R. Burns, H. Xin, R. Gates. 2008. A Quality Assurance Project Plan for Monitoring Gaseous and Particulate Matter Emissions from Broiler Housing. ASABE #913C08e. St. Joseph, Michigan.

Muhlbauer R.V., T.A. Shepherd, H. Li, R.T. Burns, H. Xin. 2011. Technical Note: Development and application of an induction-operated current switch for monitoring fan operation. Applied Engineering in Agriculture 27(2): 287-292.

Pepple, L.M., R.T. Burns, H. Xin, H. Li, J. Patience. 2011. Ammonia, Hydrogen Sulfide, and Greenhouse Gas Emissions from Wean-to-Finish Swine Barns Fed Traditional vs. a DDGS Based Diet. ASABE #1111201. St. Joseph, Michigan.

USDA, 2011. Quarterly Hogs and Pigs. USDA Reference No. 1949-1921. United States Department of Agriculture and National Agriculture Statistics Service.

Zhang, Q., X. Zhou, N.Cicek, M. Tenuta. 2007. Measurement of odor and greenhouse gas emissions in two swine farrowing operations. Canadian Biosystems Engineering 49: 6.13-6.20.

Zhu, T., L. Jacobson, D. Schmidt, R. Nicolai. 2000. Daily variations in odor and gas emissions from animal facilities. Applied Engineering in Agriculture 16(2): 153-158.