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Greenhouse Gas (GHG) Emissions from Mechanically Ventilated Deep Pit Swine Gestation Operation

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Abstract

Emission of greenhouse gases (GHGs) from mechanically ventilated deep pit manure storage was monitored in a swine gestation operation. Air samples were collected from pit exhaust fans at different times of the year (fall, summer, and spring) using a vacuum chamber and Tedlar bags. GHGs concentrations were measured with a greenhouse gas chromatograph (GC) within 24 hours of collection. Air flow rates from exhaust fans were measured using a 160 mm bi-directional Gill propeller anemometer and the ventilation rate was determined as the summation of air flow rates from all fans.

The average methane (CH_4) concentration was 88±61 ppm and CH_4 concentration differences were statistically significant among sampling dates and seasons. The carbon dioxide (CO_2) concentration followed the same trend as CH_4. The average CO_2 concentration was 1105±1063 ppm. Nitrous oxide (N_2O) concentrations ranged from 0.02 to 0.66 ppm. Methane emissions varied between 115.94 to 572.18 g d^{-1} AU^{-1} and higher methane emission was observed during summer (480.28 g d^{-1} AU^{-1}). The average carbon dioxide emissions varied from 5.35 to 15.83 kg d^{-1} AU^{-1}, whereas average N_2O emissions varied from 0.06 to 7.30 g $d^{-1}AU^{-1}$. Significant variation of GHG concentrations and emissions were observed among fall, summer and spring seasons.

Keywords: Greenhouse gas; Concentration; Emission; Gestation; Deep pit manure storage

Introduction

The demand for animal products are expected to grow [1] and animal production will have a large impact on the world's natural resources and contributes significantly to environmental problems, such as pollution, climate change and loss of biodiversity [2]. Livestock production operation and manure storage generate greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) [3,4-6] and contribute to climate change by emission of these gases. Generation of GHGs from animal production facilities are from enteric fermentation, housing confinement, manure storage, manure treatment and land application of manure [7,8] and GHG emissions from animal production can vary with animal species, different diets, feed conversion mechanisms, manure management practices, and environmental conditions [7-12].

Swine production plays an important economic role in key hog producing states in the United States [13]. The growth of swine production in the United States, as well as in North Dakota, is expected to continue. The main environmental concerns with animal production facilities are soil, water, and air pollution (i.e. odor, ammonia, hydrogen sulfide, and greenhouse gases) [14,15]. However, little is known about the relative contributions to GHG emissions from mechanically ventilated deep pit manure storage barns under temperate climatic conditions.

Due to confined and intensive swine production in a concentrated area, there are many outdoor and indoor (i.e., deep pit and shallow pit) manure storage systems. Deep pit manure storage systems are commonly used for swine operation for long-term storage of manure. Manure in deep pit storages undergoes anaerobic decomposition and generates pollutant gases including ammonia, hydrogen sulfide, and GHGs [16]. Production of N_2O during storage can occur due to incomplete nitrification-denitrification of nitrogen contained in the wastes. Anaerobic decomposition of organic matter in manure generates methane. The amount of methane produced during decomposition is influenced by ambient temperature and manure management practices.

Many researchers have identified temperature as an important factor for CH_4 emissions from manure storage facilities. Low temperatures can suppress microbial activity and metabolism and therefore production of CH_4 [17]. High temperatures may expedite decomposition of organic matter in manure and increase CH_4 production. At the same time, high ambient temperatures require high ventilation rates and are correlated to high CH_4 emissions [18]. Despite the rather contrasting differences in operational practices, data on GHG emission rates under temperate climatic production conditions are inadequate. In order to address environmental concerns and to adapt a management practice, it is important to monitor GHG emissions under different climatic conditions and manure management practices. Therefore, the purpose of this study is to quantify GHG emissions from mechanically ventilated deep pit exhaust fans in swine gestation operation in temperate climatic conditions.

Materials and Methods

Description of facilities and management practices

This study was conducted at a commercial swine gestation operation in North Dakota, USA (Figure 1). The total capacity of this facility is 5000 animals. The facility has two gestation-barns (g-barn) and each g-barn (165 m×24 m) has 2100 gestation-stalls with deep manure pits for collection. The deep pit size is 165 m×24 m and the maximum operating depth is 3 m. The two g-barns are identical in size,

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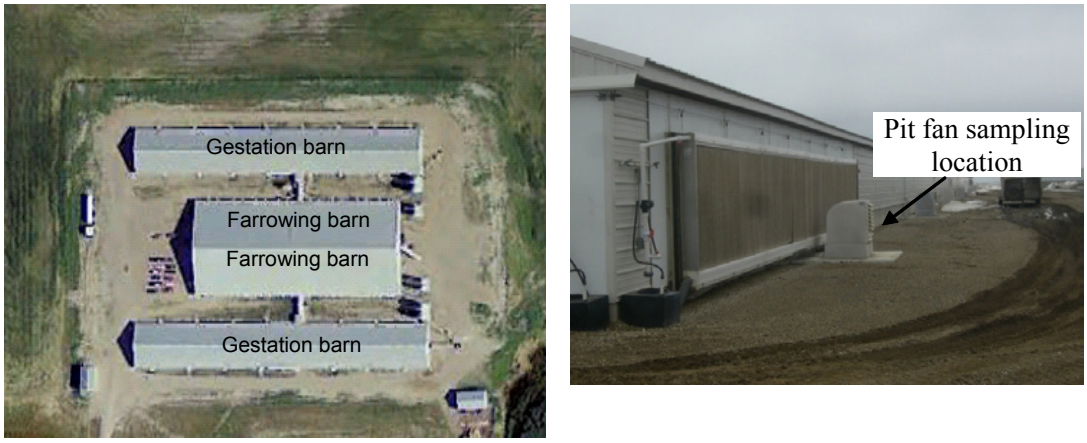
layout, and stocking density. This facility is cross ventilated via pit fans in the winter and tunnel vented with cooling pads at the end walls and fans in the center of the side walls in the summer. The deep pit manure storage systems are completely separated from each other. There are 16 pit ventilation fans and eight (8) wall ventilation fans in each g-barn. Typically, the producer empties the deep pit storage system twice per-year (fall and spring).

Air sample collection

Because of the large number of exhaust fans, only a limited number of samples (16 to 18) were collected during each sampling event for GHG analysis. Two ambient air samples were collected at the upwind site of the barn during each sampling event to obtain background concentrations. For sampling consistency, samples were collected in duplicate from the same pit fans and at the same time of a day (10 am-12 noon) each time. All air samples were collected in Tedlar bags using a vacuum chamber (SKC Inc., 863 Valley View Rd., Eighty Four, PA 15330) from the exhaust side of the fans for biosecurity reasons. Samples were collected from inside of an exhaust fan as shown in the Figure 1 to minimize dilution of sample with ambient air.

Measurement

Within 24 hours of collection, air samples were analyzed for CH_4, CO_2, and N_2O using a greenhouse gas chromatograph (GC) (Model No. 8610C, SRI Instruments, 20720 Earl St., Torrance, CA 90502) (Figure 2) equipped with a flame ionization detector (FID) and an electron captured detector (ECD). An air sample from the Tedlar bag was injected into a 1mL sample loop using the inbuilt vacuum pump interface (Figure 2) and the event program. Before injecting any sample into the sampling loop, the FID detector temperature was



(a) (b)

Figure 1: Study sites and description of facilities:
a) Showing two gestations (deep pit manure storage underneath) and two farrowing barns
b) One of the pit exhaust fans sampling location.

GHG	CAS[a] No.	Molecular weight, g gmol^{-1}	Retention time, min	Calibration gas equation	R^2	MDL[b] (ppbv)
Methane (CH_4)	74-82-8	16.04	1.56	y=0.1817(x)	0.99	120
Carbon dioxide (CO_2)	124-38-9	44.01	2.88	y=0.1877(x)	0.99	960
Nitrous oxide (N_2O)	10024-97-2	44.01	3.62	y=0.0019 (x)	0.99	16

[a]CAS No.- Chemical abstracts service number
[b]MDL – Minimum detection limit

Table 1: GHG properties and gas calibration information.

Date	No of observation (N)	Average air Temperature[a](°C)	Concentration, ppm CH_4	CO_2	N_2O
5/10/11	16	9	184.72a[b]±87.27	1580b±396	0.074c±0.089
5/31/11	16	13	105.48cb±83.35	1455b±279	0.015c±0.015
6/7/11	16	15	59.38c±35.21	660cd±104	0.036c±0.022
6/28/11	16	20	77.86cb±51.03	561d±105	
7/12/11	16	21	89.89cb±77.18	666cd±94	
8/16/11	16	20	60.55c±38.43	444d±102	0.458b±0.119
9/6/11	16	18	51.13c±22.90	941c±230	0.644a±0.129
9/27/11	16	14	47.05c±20.97	921c±237	0.659a±0.061
10/18/11	16	9	120.34b±103.62	2341a±447	0.531b±0.121

[a]Source: North Dakota Agriculture Weather Network (NDAWN)
[b]Averages within a column followed by different letters are significantly different at $p < 0.05$ according to Duncan multiple range tests

Table 2: Averages and standard deviation of greenhouse gas concentrations measured from a gestation barn measured from deep pit manure storage exhaust fans.

raised to 300°C and the ECD detector temperature was raised to 350°C. The system was operated on a nitrogen carrier at 20 PSI for the ECD, while hydrogen and air were supplied to the FID/methanizer using a built-in air compressor at 20 PSI. In this system, the ECD detector detects N_2O, while the FID/methanizer detector detects both CH_4 and CO_2. Gas chromatographs were recorded and analyzed with the Peak Simple Chromatography Data System Software (Version 3.72, SRI Instruments, 20720Earl St., Torrance, CA 90502). Before and after sample analysis, calibration gases were used to ensure that the GC was functioning properly. Blank samples were also run between samples using the same procedure to check any contamination from previous analysis. To generate calibration equations, three points calibration were conducted for CH_4 (20, 100, and 1000 ppmv), CO_2 (100, 1000, and 2500 ppmv), and N_2O (0, 1, and 10 ppmv) gases. Calibration equations and R^2 value of equations are listed in Table 1.

The average air velocity rates (ms^{-1}) from all running pit exhaust fans were measured continuously using a 160 mm bi-directional Gill propeller anemometer (Model 27106RS, RM Young Company, 2801 Aero Park Dr., Traverse City, MI 49686) (Figure 3) as also used by other researchers [18]. The average air velocity across the radius of an exhaust fan was measured in at least 10-15 locations (Figure 4). A single propeller was installed on the exhaust side of a fan and the output signal of the anemometer (0 to 1 VDC) was recorded with a CR10X data logger (Campbell Scientific, Inc., 815 West 1800 N., Logan, UT 84321). The air flow rate (m^3s^{-1}) of each running fan was calculated from the measured average air velocity and the fan cross-sectional area. The total ventilation rate from each gestation barn was determined as the summation of the air flow rates of all fans.

GHG Emission rates calculation The GHG emission rate from the building exhaust was calculated as [19]:

$$ER_{GHG} = (C_{GHG} - C_{GHG\text{-}BK}) \times VR \times \rho_{GHG} \times 3600 \times 24/AU/1000$$

Where: ER_{GHG} = GHG emission rate from building exhaust (g $day^{-1}AU^{-1}$)

C_{GHG} = GHG concentration of the sample (ppm)

$C_{GHG\text{-}BK}$ = background GHG concentration (ppm)

ρ_{GHG} = density of GHG (kg/m^3) (CH_4 = 0.65; CO_2 =1.72; N_2O = 1.72)

VR= ventilation rate through exhaust fan ($m^3\ s^{-1}$)

AU = Animal unit = $(N_{animal} \times M_{animal})/500$ (1 AU =500 kg of live animal weight)

N_{animal} = Number of animal

M_{animal}= Average mass of an animal, kg

Data analysis

Data were pooled and pair wise means were compared among sampling dates and seasons. Both concentration and emissions were analyzed at $P<0.05$ to quantify the seasonal effect. The significance of the differences in concentration and emissions were examined according to Duncan's multiple range tests [20].

Results and Discussion

Methane, carbon dioxide, and nitrous oxide concentrations from deep pit exhaust fans

Figure 5 illustrates the average CH_4 concentration during the monitoring period. The average CH_4 concentration of the deep pit

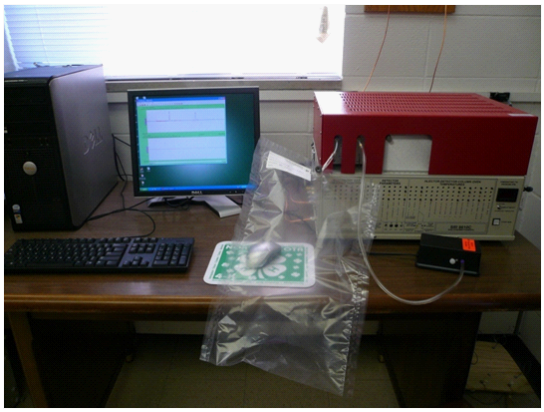


Figure 2: Gas chromatography (GC) set-up used in this study for sample analysis.

Figure 3: Set-up used for fan calibration using a bi-directional Gill propeller anemometer.

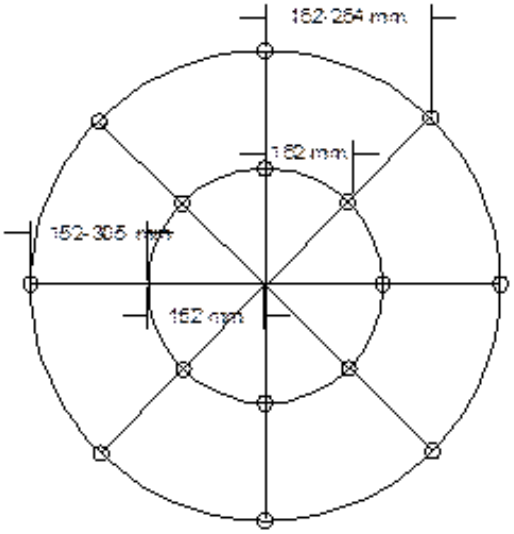


Figure 4: Schematic of air velocity measurement points (smaller circles) across the radius of an exhaust fan.

manure storage beneath the g-barn was 88±61 ppm, and the CH_4 concentration differences were statistically significant among sampling dates (Table 2). During spring, the CH_4 concentration was significantly higher than in the fall (September-October) and summer (June-August) (Table 3). Elevated CH_4 concentrations during the spring were likely due to the amount of manure stored in an anaerobic condition for an extended time (six-nine months) in the deep pit and when the ventilation rate was also low. Lower ventilation rates resulted in a greater concentration of CH_4. The longer the manure is stored in a deep pit under anaerobic conditions, the more methane will be produced. Also, a crust was observed on the manure surface, which might have also contributed to high CH_4 production as also reported by others [21]. In the month of July, a higher CH_4 concentration was observed (Figure 5), which was likely due to elevated anaerobic digestion of organic matter in the manure from higher ambient temperature. Methane generation and emissions are mainly depends on anaerobic digestion of organic matter in the manure [22,23] the duration of manure storage [23,24] and the manure removal frequency. In a deep pit manure storage system, it is common that bubbles rise from the liquid manure, which can carry methane and increase the concentration noticeably. The measured CH_4 concentration was higher than reported by Zhang et al. [19] but close to that reported by Lague [25]. This difference could be due to the manure storage system. The manure storage system in this study was deep pit storage under the g-barn, whereas in the Zhang et al. [19] study, it was an outdoor manure storage system and a shallow pit was used in the Lague [25] study.

Similarly, CO_2 concentrations are shown in Figure 6. The CO_2 concentration followed the same trend as CH_4 and the average CO_2 concentration was 1105±1063 ppm. During spring and fall, the CO_2 concentration was higher when the ventilation rate was low (Table 3, Figure 6). As the ventilation rate increased, the CO_2 concentration became lower. Carbon dioxide generation is mostly from animal respiration and from anaerobic digestion of organic matter in manure [26]. The variation of concentration is due to combination of management practices, animal activities, and ambient temperature during the study period. The methane and CO_2 concentrations followed a parallel trend (Figure 7) as also reported by others [27]. The measured CO_2 concentrations were within the range reported by Zhang et al. [19] and Lague [25].

The variation of N_2O concentrations are presented in Figure 8. Due to the malfunctioning of the ECD detector, no N_2O concentrations were measured during the 6/28 and 7/12 sampling events (Figure 8). The measured N_2O concentrations from the deep pit fans ranged from 0.02 to 0.66 ppm (Table 2). The highest N_2O concentration was observed during the summer and fall. This was likely due to the surface crust on the manure in storage, where N_2O production took place in the interface between manure and surface crust. A similar conclusion was also drawn by others [28]. Although a higher N_2O concentration was observed during summer and fall, the N_2O concentrations from the deep pit fans were found to be less than 1.0 ppm, averaging 0.35 ppm which was close to the background level (0.3-0.4 ppm). This means that under cold climatic conditions like North Dakota, manure storages would likely have lower N_2O emissions than in warmer climatic conditions.

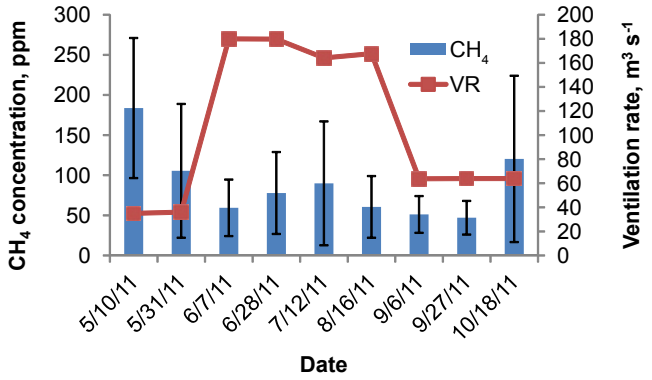


Figure 5: Variation of methane concentration from deep pit manure storage measured in deep pit exhaust fan. Error bars represent standard deviation.

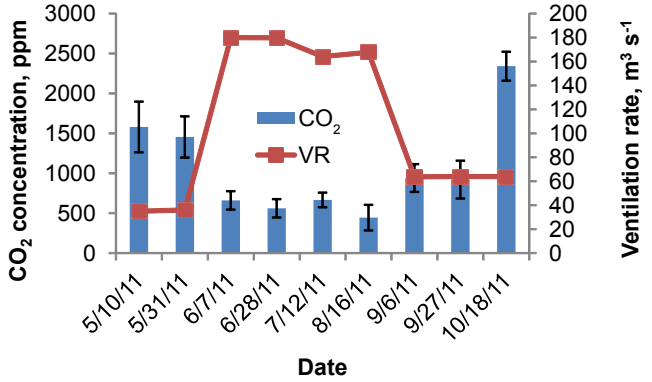


Figure 6: Variation of carbon dioxide (CO_2) concentration from deep pit manure storage measured in exhaust fan. Error bars represent standard deviation.

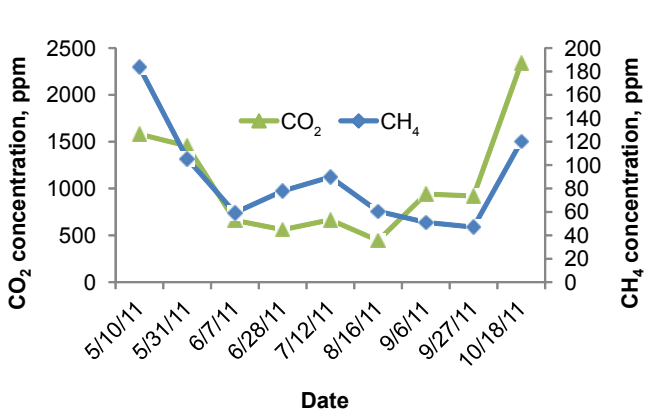


Figure 7: Average methane (CH_4) and carbon dioxide (CO_2) concentration from deep pit manure storage measured in exhaust fan.

Emissions of methane, carbon dioxide, and nitrous oxide from deep pit manure storage exhaust fans

Methane emissions varied from 115.94 to 572.18 g d^{-1} AU^{-1} (Figure 9).These values are comparable to those reported by Costa and Guarino [3] and Zhang et al. [19]. However due to manure storage differences, the variation was the same but magnitude was different. The higher methane emissions were observed during summer (Table 4) when ambient temperatures and the ventilation rates were high (Figure 9). Statistically significant differences were noticed between summer and fall and also between summer and spring methane emissions, but not between fall and spring emissions (Table 4). During June and July,

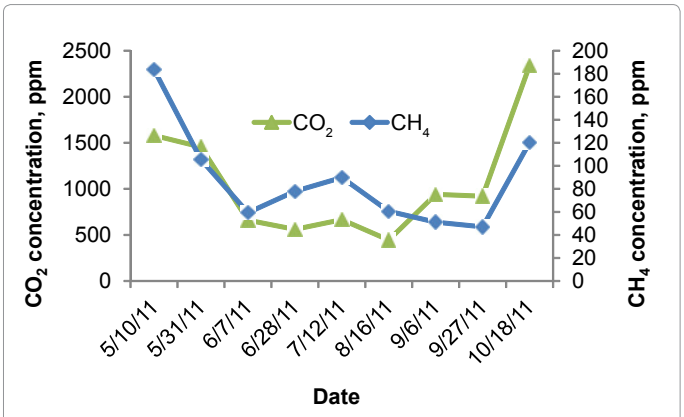


Figure 8: Variation of nitrous oxide (N_2O) concentration from deep pit manure storage measured in exhaust fan. Error bars represent standard deviation.

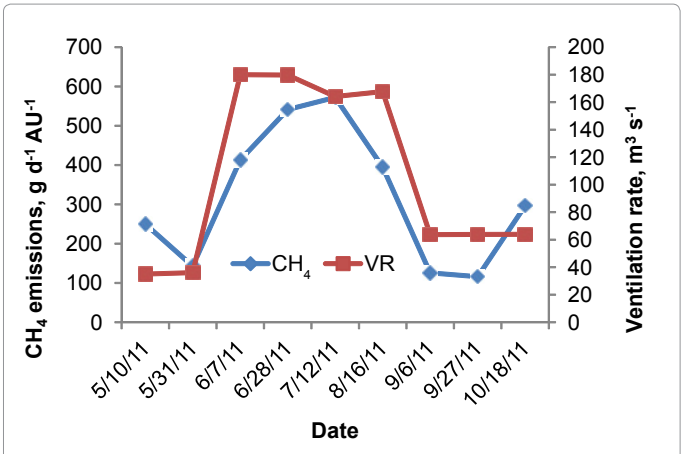


Figure 9: Variation of methane (CH_4) emissions from deep pit manure storage exhaust fan.

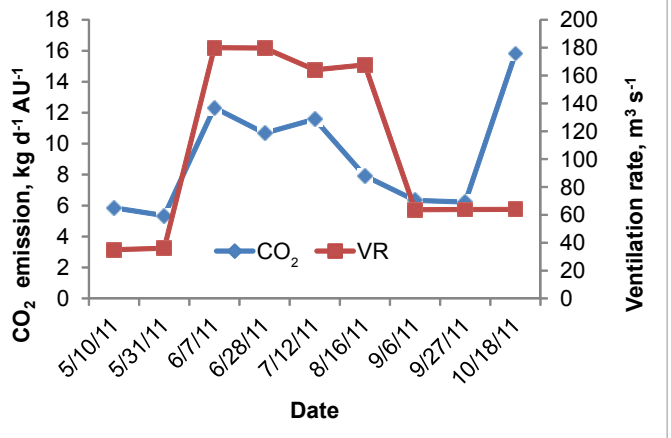


Figure 10: Variation of carbon dioxide (CO_2) emissions from deep pit manure storage exhaust fan.

accelerated microbial decomposition of organic matter in deep pit manure might occur and amplified the CH_4 production. In general, when the CH_4 concentrations were low, the emissions rates were high due to the high ventilation rates.

Carbon dioxide emissions followed a trend similar to the CH_4 emissions (Figure 10). As mentioned before, CO_2 generation is mostly from animal respiration and from anaerobic digestion of organic matter in manure. Additionally, a significant amount of CO_2 is also produced at the manure-air interface by the aerobic microbial degradation process [21,23]. As a result, higher CO_2 emissions were observed during the summer than in the fall and spring (Table 4), when anaerobic degradation of manure at high temperature resulted in higher CO_2 production, as well as aerobic decomposition at the manure-air interface [19,24]. However, no statistically significant differences were noticed between summer and fall emissions, but there was a clear difference between summer and spring emissions (Table 4). Higher ventilation rates contributed to higher CO_2 emissions during warm months. The average CO_2 emissions varied from 5.35 to 15.83 kg d^{-1} AU^{-1}. Results obtained in this study compare well with those of other studies [3,7,19].

The N_2O emissions trend is shown in Figure 11. As stated before, due to an ECD detector malfunction, no N_2O concentrations were measured during the 6/28 and 7/12 sampling times. As a result, no N_2O emissions were calculated for those days. Average N_2O emissions varied from 0.06 to 7.30 g d^{-1} AU^{-1}. Like other GHGs, significantly higher N_2O emissions were observed during the summer and fall as

Season	No of observation (N)	CH_4	N_2O	CO_2
Spring	32	144.60a [a]±96.31	0.05c±0.08	1517a±391
Summer	64	71.92b±60.21	0.25b±0.23	583b±148
Fall	48	72.85b±77.81	0.612a±0.14	1401a±788

[a]Averages within a column followed by different letters are significantly different at p <0.05 according to Duncan multiple range tests

Table 3: Averages and standard deviation of greenhouse gas concentrations measured during the spring, summer, and fall from deep pit manure storage exhaust fans.

Season	No. of observation (N)	CH_4 (g d^{-1} AU^{-1})	N_2O (g d^{-1} AU^{-1})	CO_2 (kg d^{-1} AU^{-1})
Spring	18	196.25b [a]±84.51	0.18b±0.17	5.60b±0.79
Summer	18	480.28a±203.82	4.42a±4.31	10.62a±2.26
Fall	18	179.36b±115.05	4.13a±0.54	9.46ab±5.22

[a]Averages within a column followed by different letters are significantly different at p <0.05 according to Duncan multiple range tests.

Table 4: Averages and standard deviation of greenhouse gas emissions measured during the spring, summer, and fall season in deep pit manure storage exhaust fans.

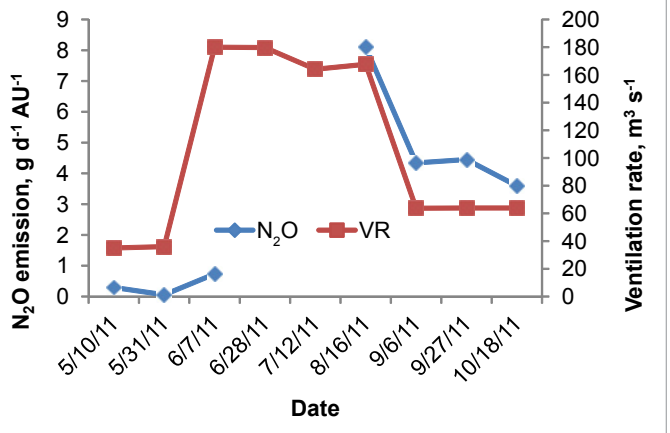


Figure 11: Variation of nitrous oxide (N_2O) emissions from deep pit manure storage exhaust fan.

compared to spring (Table 4). N_2O emissions occur due to incomplete nitrification and denitrification processes in manure and duration of manure storage [7]. True anaerobic condition in the deep pit manure storage system would produce low N_2O emissions. However, due to air exchange in the deep pit system, it is likely to generate N_2O [29] and that was the case in this study. Due to increased air exchange during summer months, increased N_2O emissions occurred. Overall, the contribution of N_2O to overall GHG emissions was less as compared to other gases.

GHG emissions (ER_{GHG}) were also expressed in terms of CO_2 equivalent (EQ_{CO2}) by lumping N_2O, CH_4, and CO_2 contribution together and expressed as kg $d^{-1}AU^{-1}$ using the following equation [6]:

$$EQ_{CO_2} = ER_{CO_2} + 23\ ER_{CH_4} + 296\ ER_{N_2O}$$

Where, EQ_{CO2} = CO_2 equivalent (kg $d^{-1}AU^{-1}$)

ER_{CO2} = CO_2 emission rate (kg $d^{-1}AU^{-1}$)

ER_{CH4} = CH_4 emission rate (kg $d^{-1}AU^{-1}$)

ER_{N2O} = N_2O emission rate (kg $d^{-1}AU^{-1}$)

It was estimated that from a gestation operation, 40.69% of the CO_2 equivalent was contributed from CH_4 and 6.27% from N_2O. Therefore, based on this study, the N_2O contribution from swine gestation barn to warming potential is much lower than methane. Better management practices and better feed efficiencies might reduce the CH_4 contribution to warming potential from swine gestation operations.

Conclusions

The following conclusions were drawn from this study:

1. Methane emissions varied between 115.94 to 572.18 g d^{-1} AU^{-1} and higher methane emissions were observed during summer (480.28 g d^{-1} AU^{-1}).
2. Carbon dioxide emissions varied from 5.35 to 15.83 kg d^{-1} AU^{-1}, whereas average N_2O emissions varied from 0.06 to 7.30 g d^{-1} AU^{-1}.
3. Significant variation of GHG concentrations and emissions were observed among fall, summer, and spring season.
4. About 40.69% of the carbon equivalent was contributed from methane, whereas nitrous oxide contributed 6.27% to the warming potential from swine gestation operation.
5. Better management practices and better feed efficiencies might reduce the CH_4 contribution to warming potential from swine gestation operations.

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References

1. Delgado C, Rosegrant M, Steinfeld H, Ehui S, Courbois C (1999) Livestock to 2020: The next food revolution. Food, Agriculture, and the Environment Discussion (Paper 28) Washington, DC: International Food Policy Research Institute.
2. van der Meer HG (2008) Optimizing manure management for GHG outcomes. Aust J Exp Agr 48: 38-45.
3. Costa A, Guarino M (2009) Definition of yearly emission factor of dust and greenhouse gases through continuous measurements in swine husbandry. Atmo Env 43: 1548-1556.
4. Nicks B, Laitat M, Farnir F, Vandenheede M, Desiron A, et al. (2004) Gaseous emissions from deep-litter pens with straw or sawdust for fattening pigs. Animal Science 78: 99-107.
5. Pain B (1998) Gaseous pollutants from organic waste use in agriculture. In: Ramiran (Ed.) Report of the Eighth International Conference of the European Cooperative Research Network on Recycling of Agricultural Municipal and Industrial Residuals in Agriculture 233–246.
6. Philippe FA, Laitat M, Canart B, Vandenheede M, Nicks B (2007) Comparison of ammonia and greenhouse gas emissions during the fattening of pigs, kept either on fully slatted floor or on deep litter. Livestock Science 111: 144-152.
7. Dong H, Zhu Z, Shang B, Kang G, Zhu H, et al. (2007) Greenhouse gas emissions from swine barns of various production stages in suburban Beijing, China. Atmo Env 41: 2391-2399.
8. Dong H, Zhu Z, Tao X, Shang B, Kang G, et al. (2006) Measurement and analysis of methane concentration and flux emitted from finishing pig house. Transactions of CSAE 26: 123–128.
9. Baudouin N, Laitat M, Vandenheede M, Désiron A, Verhaeghe C, et al. (2003) Emissions of ammonia, nitrous oxide, methane, carbon dioxide and water vapor in the raising of weaned pigs on straw-based and sawdust-based deep litters. Ani Res 52: 299–308.
10. Chadwick DR, Pain BF, Brookman SKE (2000) Nitrous oxide and methane emissions following application of animal manures to grassland. J Env Qua 29: 277-287.
11. Sharpe RR, Harper LA, Simmons JD (2001) Methane emissions from swine houses in North Carolina. Chemosphere - Global Change Science 3: 1–6.
12. Sneath R, Phillips VR, Demmers TGM, Burgess LR, Short JL, et al. (1997) Longterm measurement of greenhouse gas emission from UK livestock buildings. In: Proceedings of the 5th International Symposium on Livestock Environment 146–153.
13. Huang H, Miller GY, Ellis M, Funk T, Zhang Y, et al. (2004) Hollis G, Heber A J (2004) Odor management in swine finishing operations: Cost effectiveness. Food Agri Env 2: 130-135.
14. Kerr BJ, Ziemer CJ, Trabue SL, Crouse JD, Parkin TB (2006) Manure composition of swine as affected by dietary protein and cellulose concentrations. J Ani Sci 84: 1584-1592.
15. Thompson AG, Wagner-Riddle C, Fleming R (2004) Emissions of N_2O and CH_4 during the composting of liquid swine manure. Envi Monit Ass 91: 87-104.
16. Moody L, Burns R, Muhlbauer R (2009) Literature Review- Deep pit swine facility flash fires and explosions: Sources, occurrences, factors, and management. Report to National Pork Board.
17. Liu Z, Powers W (2011) Meta-analysis of greenhouse gas emissions from swine operations. ASABE.
18. Ni JQ, Heber AJ, Lim TT, Tao PC, Schmidt AM (2008) Methane and Carbon Dioxide Emission from Two Pig Finishing Barns. J Env Qua 37: 2001-2011.
19. Zhang Q, Zhou XJ, Cicek N, Tenuta M (2007) Measurement of odour and greenhouse gas emissions in two swine farrowing operations. Can Biosys Eng 49: 613-620.
20. Steel RGD, Torrie JH, Dickey DA (1997) Principles and Procedures of Statistics, A Biometrical Approach (3rd edn) McGraw-Hill Inc, NY, USA
21. Sommer SG, Petersen SO, Sorensen P, Poulsen HD, Moller HB (2007) Methane and carbon dioxide emissions and nitrogen turnover during liquid manure storage. Nutri Cycl Agro 78: 27-36.
22. Steed J, Hashimoto G (1994) Methane emissions from typical manure management systems. Biores Tech 50: 123-130
23. Moller HB, Sommer SG, Ahring BK (2004) Biological degradation and greenhouse gas emissions during pre-storage of liquid animal manure. J Env Qua 33: 27-36.
24. Hansen TL, Sommer SG, Gabriel S, Christensen TH (2006) Methane production during storage of anaerobically digested municipal organic waste. J Env Qua 35: 830-836
25. Laguë C (2003) Management practices to reduce greenhouse gas emissions from swine production systems. Adv Pork Produ 14: 287-300.

26. Dong H, Kang G, Zhu Z, Tao X, Chen Y, et al. (2009) Ammonia, methane, and carbon dioxide concentrations and emissions of a hoop grower-finisher swine barn. Trans ASABE 52: 1741-1747.

27. Jungbluth T, Hartung E, Brose G (2001) Greenhouse gas emissions from animal houses and manure stores. Nutr Cycl Agro 60: 133-145.

28. Sommer SG, Petersen SO, Sogaard HT (2000) Greenhouse gas emission from stored livestock slurry. J Env Qua 29: 744-751.

29. Sommer SG (2006) Emission of greenhouse gases from animal manure. Plantekongres 443-445.