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Odour and Greenhouse Gas Emission from Swine Farrowing Operations

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Abstract Odour and greenhouse gas (GHG) emissions were measured on two 3000-sow swine farrowing farms, one with open earthen manure storage (EMS) and other one with negative pressure covered (NPC) EMS. Air samples were taken in Tedlar bags with a vacuum chamber from exhaust fans of barns and the NPC EMS. A flux hood was used to collect air samples from the manure surface in the open EMS. Collected samples were analyzed for odour concentrations with a dynamic dilution olfactometer and for GHG concentrations with gas chromatography. The average odour emission rate of the two farms was 316 OU/s-AU (AU – animal unit) from farrowing rooms and 113 OU/s-AU from gestation rooms. Odour emission from the NPC EMS was negligible in comparison with the open EMS. The total odour emission from the farm with NCP EMS was 54% of that from farm with open EMS. The CO_2 emission rates from building exhaust ranged from 4.8 to 16.6 kg/day-AU and the rate from farrowing rooms was significantly higher than that from gestation rooms. The CH_4 emission rates from building exhaust ranged from 73 to 351 g/day-AU. Both CO_2 and CH_4 emissions from the secondary cell of the NPC EMS were negligible in comparison with the primary cell or with the open EMS. The CO_2 emission rate from the primary cell of the NPC EMS was significantly lower than that from the open EMS. Although the average CH_4 concentration in the primary cell of the NPC EMS was160 times higher than that in the open EMS, the total CH_4 emission from the NCP EMS was only 26% of that from the open EMS.

Keywords: swine operation, odour, greenhouse gases.

INTRODUCTION

Odour is one of the major concerns to the general public when considering the siting of new or the expansion of existing swine operations. Odour associated with swine operations are from three main sources: (1) building exhaust, (2) manure storage, and (3) land application. A shift to injection-spreading of manure seems to result in more odour complaints traceable to animal production facilities and manure storage units than to the land application of manure (Jacobson et al., 1998). In other words, odour from land application is becoming less of a concern as more and more producers are adopting manure injection. Odour emission from swine buildings is influenced by a number of factors, such as the type of operation (gestation, nursery, finishing, etc.), management practice, manure handling and storage, and ventilation. Odour emission rates reported in the literature vary widely among different facilities and within the same type of facilities (Zhang et al., 2002). Odour emission from manure storage also varies widely with the type of storage facilities. Little emission occurs if the storage is enclosed, such as covered concrete tanks. Odour emission from earthen manure storage is seasonal - very little emission in the winter and more in the spring, summer and fall.

Our understating of odour emissions from buildings and manure storage is still evolving. In particular, the relative contributions to odour from barns and the manure storage are not well known. The first objective of this study was to quantify these relative odour contributions by comparing odour emissions between two similar swine operations with different manure storage systems.

It is estimated that agricultural operations contribute approximately 10% of the total anthropogenic greenhouse gas (GHG) emissions in Canada, with about 40% of that originating from livestock production. However, little is known about the relative contributions to GHG emissions from barns and manure storage in different production systems. The second objective of this study was to determine greenhouse gas emissions from swine operations with open and covered manure storage.

MATERIALS AND METHOD

Site Description

Two farms (A and B) of 3000-sow farrowing operation, located in southern Manitoba, were selected for this study. The two farms were built from the same blueprint with slight medications - Farm A had an extra quarantine room at one end of the building. The major difference between the two farms was that Farm A had a two-cell earthen manure storage (EMS) with negative pressure covers (NPC); whereas Farm B had an open single cell EMS. The barns on both farms were mechanically ventilated with wall mounted exhaust fans. Farm A had 90 exhaust fans (including 6 in the quarantine room) and Farm B had 84. The manure handling system on the two farms were the same, both with liquid manure stored in under-floor shallow gutters and than removed to outdoor EMS once every week from gestation/breeding rooms and once every three weeks from farrowing rooms.

Air Sampling from Barns

There were 90 and 84 exhaust ventilation fans on Farms A and B, respectively. Due to the limit of the number of samples that could be handled in the olfactometry lab for odour analysis, taking samples from all exhaust fans was not feasible. Based on the production schedule, at least one room was sampled to represent other rooms at the same production stage. For each room, a

composite sample was collected by sampling from two or three exhaust fans in the center of the room. Air samples were collected in 10-L Tedlar bags using a vacuum chamber (AC'SCENT Vacuum chamber, St. Croix Sensory Inc., Stillwater, MN). When sampling, a bag was placed in the chamber and the inlet of the bag was connected to a Teflon probe which was placed in the mid stream of airflow from the exhaust fan. Each sample was taken in two steps: (i) fill the bag with 2 L of sample air and then evacuate to "coat" the bag, and (ii) draw odourous air into the bag at a rate of 1 to 2 L/minute until the bag was 3/4 full. For each sampling session, one reference sample was taken upwind from the facility to represent the background odour level.

To determine the ventilation rate for each room, air velocity was measured at five points across the radius of each and every running fan in the room with a hot wire anemometer. Air temperature was also recorded from the hot wire anemometer for each fan to estimate the indoor temperature of the room. The airflow rate for each fan was then estimated as the product of average air velocity and the fan diameter.

In each sampling session, a reference sample was taken upwind from the facility to represent the background condition.

Air Sampling from Manure Storage

A floating flux hood was used to collect air samples from the surface of manure storage (fig. 1). The hood covered a surface area of 0.3 m^2 (0.75 m x 0.4 m). Fresh air was drawn through a carbon filter, and introduced into the sample collection hood through a 100 mm diameter PVC duct. Airflow rates were measured inside the duct using a hot wire anemometer and were adjusted if necessary to maintain an air velocity of 0.3 m/s inside the hood (over the manure surface). For each sampling session, two odour samples were collected at the outlet of the hood, and one reference sample was collected after the carbon filter using a vacuum chamber and Tedlar bags (fig. 1). Manure temperature was measured at 10 cm below the manure surface using a digital thermocouple indicator.

For the NPC MES on Farm A, one composite sample was taken from the exhaust fans on each of the two cells, and airflow rate from the exhaust fans was measured in the same fashion as for building exhaust fans.

Sampling Dates

Air samples were taken on 19 different dates in September and October, 2003, and from June to September, 2004. On each sampling date, eight samples were taken from building exhaust and two from manure storage. Therefore, a total of 152 samples were taken from building exhaust and 38 from manure storage on the two farms. The majority (57%) of these samples were taken in afternoons, 31% in mornings, and 22% in evenings. The outdoor temperature ranged from 8 to 32°C on these sampling dates.

Odour and Greenhouse Gas Analysis

Collected samples (in Tedlar bags) were evaluated within 24 hours for odour concentrations. A single-port olfactometer (AC'SCENT, St. Croix Sensory Inc., Stillwater, MN) with six trained assessors was used for odour concentration measurement. The triangular forced-choice method was used to present samples to the assessors, with a 3-s sniff time. Assessors were selected and re-evaluated periodically following the procedure of CEN (1999). For each olfactometry session, data were retrospectively screened by comparing assessors' individual threshold estimates with the panel average (CEN, 1999). Odour concentration was expressed as odour units per unit volume (OU/m^3).

Fifteen (15) mL of gas was transferred from each sample collected in Tedlar bag to Exetainer vials for analysis of GHG concentrations by gas chromatography (Varian CP-3800, Varian Inc., Walnut Creek, CA). The gas chromatograph was equipped with electron capture, flame ionization, and thermal conductivity detectors for determination of N_2O, CH_4, and CO_2 concentrations in sample gas, respectively. The CP-3800 was also automated to sample GHG gases from Exetainer vials using a Varian Combi PAL sampler. All gas analyses were done following the Good Laboratory Practices with repeated standardization within sample runs and cross checking of calibration gases with several laboratories in Canada.

Calculation of Odour and Greenhouse Gas Emission Rates

The odour emission rate from buildings was calculated from the measured odour concentration and ventilation rate (airflow rate of exhaust fans) as follows:

$$Q_{od\text{-}B} = (C_{odour} - C_{od\text{-}BK}) \times V_B/AU \quad (1)$$

where: $Q_{od\text{-}B}$ = odour emission rate from building exhaust (OU/s-AU)
C_{odour} = odour concentration of the sample (OU/m^3)
$C_{od\text{-}BK}$ = background odour concentration (OU/m^3)
V_B = ventilation rate (m^3/s)
AU = animal units
$AU = (N_{pig} \times M_{pig})/500$
N_{pig} = number of pigs
M_{pig} = average mass of pigs (kg).

The GHG emission rate from building exhaust was calculated as:

$$Q_{GHG\text{-}B} = (C_{GHG} - C_{GHG\text{-}BK}) \times V_B \times \rho_{GHG} \times 3600 \times 24/AU/1000 \quad (2)$$

where: $Q_{GHG\text{-}B}$ = GHG emission rate from building exhaust (g/day-AU)
C_{GHG} = GHG concentration of the sample (ppm)
$C_{GHG\text{-}BK}$ = background GHG concentration (ppm)
ρ_{GHG} = GHG density (kg/m^3) (CH_4 = 0.65; CO_2 =1.72; N_2O = 1.72).

Odour and GHG emission rates from the open manure storage were determined as follows:

$$Q_{od\text{-}S} = (C_{odour} - C_{od\text{-}Ref})\, V_h/A_h \quad (3)$$

$$Q_{GHG\text{-}S} = (C_{GHG} - C_{GHG\text{-}Ref}) \times V_h \times \rho_{GHG} \times 3600 \times 24/A_h/1000 \quad (4)$$

where: $Q_{od\text{-}S}$ = odour emission rate from manure storage (OU/s-m^2)
$C_{od\text{-}Ref}$ = odour concentration of the reference sample (OU/m^3)
V_h = air flow rate through the flux hood (m^3/s)
A_h = manure surface area covered by the flux hood = 0.4 x 0.75 m^2
$Q_{GHG\text{-}S}$ = GHG emission rate from manure storage (g/day-m^2)
$C_{GHG\text{-}S}$ = GHG concentration of the sample (ppm)
$C_{GHG\text{-}Ref}$ = GHG concentration of the reference sample (ppm).

Odour and GHG emission rates from the NPC EMS were determined in a similar fashion as for building exhaust:

$$Q_{od\text{-}S} = (C_{odour} - C_{od\text{-}BK}) \times V_c / A_s \quad (5)$$

$$Q_{GHG\text{-}S} = (C_{GHG} - C_{GHG\text{-}Ref}) \times V_c \times \rho_{GHG} \times 3600 \times 24 / A_s / 1000 \quad (6)$$

where: V_c = air flow rate through the exhaust fans of NPC EMS (m^3/s)
A_s = total area of manure surface (m^2).

RESULTS AND DISCUSSION

Odour Emission from Building Exhaust

The odour emission rate is commonly expressed as odour unit per second per unit area of the building floor (OU/s-m^2) or per animal unit (OU/s-AU). Measured odour emission rates are summarized in Table 1. The mean odour emission rate from farrowing and gestation rooms were respectively 22.7 and 11.6 OU/s-m^2 on Farm A, and the corresponding values were 23.0 and 7.6 OU/s-m^2 on Farm B. There was no statistically significant ($P<0.05$) difference between the two facilities in emission rate from farrowing rooms; however, the emission rate from gestation rooms on Farm A was significantly higher than that on Farm B ($P<0.05$). The emission rate from farrowing rooms was 2.0 times higher than that from the gestation rooms on Farm A, and 3.2 times on Farm B. The differences in odour emission between the farrowing and gestation rooms were statistically significant ($P<0.05$) for both farms. Measured emission rates in this study were within the range reported by other researchers. For example, Zhang et al. (2002) reviewed odour emission data published in the literature and summarized that odour emission from swine farrowing buildings varied from 0.4 to 62 OU/s-m^2, and the published odour emission from gestation buildings ranged from 3 to 20 OU/s-m^2.

Large variations in measured odour emission, as indicate by large standard deviations, might be attributed to many factors, including sampling date and time, and outdoor temperature. Odour emission was lower in September than other months (June, July and August) (fig. 2), particularly for farrowing rooms. Low odour emission in September was probably attributed to the low outdoor temperature, which resulted in low ventilation. The average outdoor temperature in September was 12°C; whereas the average temperature was 22, 23, and 17°C in June, July and August, respectively (fig. 3). Although the odour concentration in September was slightly higher than that in other months (fig. 3), it did not compensate the effect of decreasing ventilation rate on the emission rate.

The odour emission rate increased with outdoor temperature (fig. 4). The rate of increase was higher in the lower temperature range than in the high temperature. The odour concentration in the temperature range of 10-14°C was slightly higher than that in other temperature ranges. The odour emission rate at the 10-14°C range was significantly ($P<0.05$) lower than that for other temperature ranges and there was no significant ($P>0.05$) change in odour emission rate when outdoor temperatures was above15-19°C range (fig. 4). Again, low odour emission at low outdoor temperature was attributed to low ventilation rates.

Odour emission was lower in the early morning (5:00 – 7:00) and evening (19:00 – 21:00) than other times of the day (fig. 5). The pattern of variation in odour emission followed the variation in outdoor temperature. In other words, the variation of odour emission during the day was more or less attributed to changes in outdoor temperature.

Odour Emission from Manure Storage

The flux hood did not provide reliable measurements of odour emission from the open EMS on Farm B. The problem was that the odour concentration measured at the reference point was sometimes higher than that at the exhaust (refer to fig. 1 for sampling locations). This was probably due to the failure of carbon filter in removing odour at the air intake. A total of 18 samples were collected from the open EMS on Farm B. Seven of the 18 samples had odour concentrations less than their corresponding reference samples. Those seven samples were excluded from the analysis because they would have produced negative emission rates. The average measured emission rate for the remaining five sessions was 22.4 OU/s-m^2 for the open EMS on Farm B. This value seems to be high in comparison with data reported in the literature. The reported odour emission rates from EMS for swine operations ranged from 3.1 to 17.6 OU/s-m^2 (Zhang et al., 2002). But these reported data were not specifically for farrowing facilities.

The odour concentration in the NPC EMS on Farm A was much higher than that in the open EMS on Farm B (Table 2). However, because only a small amount of air was exhausted from the NPC, the odour emission rate, determined as the product of the odour concentration and the airflow rate, was much lower from NPC EMS than from the open EMS. The emission rate from the primary cell of the NPC EMS ranged from 0.2 to 2.0 OU/s-m^2, with an average of 0.7 OU/s-m^2, which is only 3% of that of the open EMS on Farm B (Table 2). The emission rate from the secondary cell of the NPC EMS (0.2 OU/s-m^2) was less than 1% of that from the open EMS. The total manure surface area in the primary cell was about 40% of that in the secondary cell. Based on the area ratio between the primary and secondary cells, the weighted average emission rate from the entire NPC EMS was calculated as 0.3 OU/s-m^2, which is negligible in comparison with the open EMS.

Total Odour Emission (Building plus Manure Storage)

The total odour emission was determined as the sum of building emission and EMS emission as follows:

$$Q_{od\text{-}T} = Q_{od\text{-}B} \times AU + (Q_{od\text{-}S} \times A_S)_{primary\ cell} + (Q_{od\text{-}S} \times A_S)_{secondary\ cell} \qquad (7)$$

where: $Q_{od\text{-}T}$ = total (combined) odour emission rate (OU/s)

The total odour emission from Farm A with NCP EMS was 54% of that from Farm B with open EMS (17,4476 vs. 32,1190 OU/s) (Table 3). The open EMS contributed 60% to the total odour emission on Farm B; whereas the NPC EMS contributed only 2% to the total emission on Farm A. In other words, covering the EMS with NPC on Farm B would reduce the total odour emission by about 58%.

GHG Emission from Building Exhaust

The measured CO_2 concentrations in the building exhaust air ranged from 492 to 2787 ppm on Farm A and 413 to 1131 ppm on Farm B. The CO_2 concentration in farrowing rooms on Farm A were statistically ($P<0.05$) higher than that on Farm B (792 ppm vs. 669 ppm); whereas there was no significant ($P>0.05$) difference in CO_2 concentration between the two farms in

gestation rooms (1012 ppm vs. 691 ppm) (Table 4). The measured CO_2 concentrations were within the range reported in the literature for swine production buildings (e.g., Ni et al., 1999).

The CH_4 concentration in farrowing rooms on Farm A ranged from 2 to 42 ppm (average 14 ppm) and was significantly ($P<0.05$) lower than that on Farm B (ranged from 2 to 41 ppm and averaged at 20 ppm). For gestation rooms, the CH_4 concentration on Farm A (ranged from 3 to 39 ppm, averaged at 18 ppm) was not statistically ($P>0.05$) different from that on Farm B (ranged from 2 to 23 ppm, averaged at 12 ppm). The CH_4 concentrations measured in this study were within the range reported in the literature. Laguë (2003) reviewed the literature data on greenhouse gas emission from swine barns and reported that CH_4 concentrations ranged from 2.8 to 99.8 ppm in farrowing operations. Measured N_2O concentrations were 0.4 ppm on both farms (Table 4). This concentration was about the same as the measured ambient (background) level 0.34 – 0.4 ppm; therefore, the N_2O emission from building exhaust was considered to be zero.

CO_2 emission from farrowing rooms was significantly ($P<0.05$) higher than that from gestation rooms for both farms (Table 4). Measured CO_2 emission rates for both farrowing and gestation rooms on Farm A were significantly ($P<0.05$) higher than the corresponding rates on Farm B (Table 4). When the rates were expressed as per kg of animal mass (g/day-kg), the CO_2 emission was 33.2 and 23.2 g/day-kg from farrowing rooms for Farms A and B, respectively, and 23.0 and 9.6 g/day-kg from gestation rooms for the two farms, respectively. These rates were slightly lower than, but comparable to, those reported by Laguë et al. (2004) for two swine facilities in Saskatoon, SK. Their values were 42.9 and 36.8 g/day-kg for farrowing rooms, and 21.0 and 26.9 g/day-kg for gestation rooms.

CH_4 emission from farrowing rooms on Farm A was significantly ($P<0.05$) lower than that on Farm B; whereas there was no significant ($P>0.05$) difference in CH_4 emission from gestation rooms between the two farms (Table 4). The difference in CH_4 emission between farrowing and gestation rooms on Farm A was not significant ($P>0.05$); whereas emission from farrowing rooms was significantly ($P<0.05$) higher than that from gestation rooms on Farm B (Table 4).

The measured CH_4 emission rates were in good agreement with the study conducted by Laguë et al. (2004) for two swine facilities in Saskatoon, SK. They reported that the CH_4 emission rates in farrowing room were 0.63 and 0.10 g/day-kg in the two facilities, respectively. The rates measured in this study were 0.37 and 0.70 g/day-kg for the two farms, respectively. The CH_4 emission from gestation rooms in the Laguë et al. (2004) study was 0.27 and 0.07 g/day-kg for the two sites, respectively. Emission rates of 0.24 and 0.15 g/day-kg were measured in this study for gestation rooms on the two farms, respectively.

GHG Emission from Manure Storage

The CO_2 concentration in the NPC EMS on Farm A varied from 1404 to 7955 ppm in the primary cell and from 505 to 866 ppm in the secondary cell. In contrast, the CO_2 level in the open EMS on Farm B ranged from 385 to 583 ppm. The average CO_2 concentration in the primary cell of the NPC EMS on Farm A was 8.4 times higher than that in the open EMS on Farm B (3943 ppm vs. 452 ppm) (Table 5); whereas the CO_2 concentration in the secondary cell of the NPC EMS was in the same order of magnitude as that in the open EMS (Table 5).

The CH_4 concentration varied from 234 to 5556 ppm in the primary cell of the covered EMS and from 3 to 592 ppm in the secondary cell. The CH_4 concentration in the open EMS on Farm B was much lower than that in NPC EMS on Farm A (Table 5). The average CH_4

concentrations in the primary and secondary cells of the NPC EMS were 161 and 7.7 times higher than that in the open EMS, respectively.

The CO_2 emission rate from the open EMS was significantly ($P<0.05$) higher than that from both cells of the NPC EMS (Table 5). The CO_2 emission from the secondary cell was negligible in comparison with the primary cell or the open EMS. Although only a small amount of air was drawn from under the negative pressure cover, a large amount of CH_4 was produced in the primary cell of the NPC EMS under anaerobic conditions. The CH_4 emission rate from the primary cell of the NPC EMS was not significantly ($P>0.05$) different from that from the open EMS. The CH_4 emission from the secondary cell was negligible in comparison with the primary cell or the open EMS (Table 5).

Total GHG Emission (Building plus Manure Storage)

The total (combined) GHG emissions from each farm were calculated in the similar fashion to that for total odour emission (equation 7). Although the CO_2 emission rate from the NPC EMS on Farm A was much lower than that from the open EMS on Farm B, the total CO_2 emission from Farm A was 29% higher than that from Farm B because of higher emission from buildings on Farm A (Table 6). The CO_2 emission from the open EMS accounted for 41% of the total CO_2 emission on Farm B; whereas CO_2 emission from the NPC EMS was only 2% of the total emission on Farm A.

Although the CH_4 emission rate from primary cell of the NCP EMS on Farm A was not significantly different from the open EMS on Farm B, the total CH_4 emission from the NCP EMS was only 26% of that from the open EMS because the manure surface area in the primary cell of the EMS was relatively small (3,111 m^2) in comparison with the open EMS (10,500 m^2). The open EMS contributed 76% to the total emission on Farm B and the NPC EMS 43% on Farm A. The total CH_4 emission from Farm A with NPC EMS was 46% of that from Farm B (225 vs. 492 kg/day).

CONCLUSIONS

1. Odour emission from farrowing rooms was 2 to 3 times higher than that from gestation rooms. Outdoor temperature had the most influence on odour emission from building exhaust.

2. The average odour emission rate from the negative pressure covered (NPC) EMS (earthen manure storage) was negligible in comparison with the open EMS (0.3 vs. 22.4 OU/s-m^2).

3. The total odour emission (combined building and manure storage) from Farm A with NCP EMS was 54% of that from Farm B with open EMS (174,476 vs. 321,190 OU/s). The open EMS contributed 60% to the total odour emission on Farm B; whereas the NPC EMS contributed only 2% to the total emission on Farm A.

4. CO_2 emission from farrowing rooms was significantly higher than that from gestation rooms.

5. CH_4 emission from farrowing rooms was not significantly different from gestation rooms on Farm A (183 vs. 118 g/day-AU); whereas CH_4 emission from farrowing rooms was significantly higher than that from gestation rooms on Farm B (351 vs. 73 g/day-AU)

6. Both CO_2 and CH_4 emissions from the secondary cell of the NPC EMS were negligible in comparison with the primary cell or with the open EMS.

7. The average CO_2 concentration in the primary cell of the NPC EMS was 8.4 times higher than that in the open EMS (3943 ppm vs. 472 ppm). However, the CO_2 emission rate from the primary cell of the NPC EMS was significantly lower than that from open EMS (89 vs. 455 g/day-m^2).

8. A large amount of CH_4 was produced in the NPC EMS under anaerobic conditions. The average CH_4 concentration in the primary cell of the NPC EMS was160 times higher than that in the open EMS (3221 ppm vs. 20 ppm). Consequently, the NPC did not result in any significant reduction in CH_4 emission rate in comparison with the open EMS. However, the total CH_4 emission from the NCP EMS was only 26% of that from the open EMS because the manure surface area in the primary cell of the EMS was relatively small in comparison with the open EMS.

9. CO_2 emission from the open EMS accounted for 40% of the total CO_2 emission (combined building and EMS) on Farm B; whereas the CO_2 emission from the NPC EMS was only 2% of the total CO_2 emission on Farm A.

10. CH_4 emission from the open EMS contributed 76% to the total CH_4 emission on Farm B; whereas CH_4 emission from the NPC accounted for 43% of the total CH_4 emission on Farm A. The total CH_4 emission from Farm A with NPC EMS was 46% of that from Farm B with open EMS.

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Table 1. Measured odour concentrations and emission rates from barns

	Farrowing		Gestation	
	Farm A	Farm B	Farm A	Farm B
Odour emission (OU/s-m^2)	**22.7**	**23.0**	**11.6**	**7.6**
Standard deviation	15.2	14.4	6.0	3.4
Odour emission (OU/s-AU)	**314**	**317**	**136**	**90**
Standard deviation	214	198	71	40

Table 2. Measured odour concentrations and emission rates from manure storage

	NPC EMS on Farm A		Open EMS on Farm B)
	Primary cell	Secondary Cell	Farm A
Odour concentration (OU/m^3)	**4646**	**1991**	**769**
Standard deviation	3646	1568	356
Odour emission (OU/s-m^2)	**0.7**	**0.2**	**22.4**
Standard deviation	0.6	0.1	25.1

Table 3. Total odour emission and relative contributions of building and manure storage

	Farm A (covered EMS)			Farm B (open EMS)		
	Total	Building	EMS	Total	Building	EMS
Emission (OU/s)	**17,4476**	**17,0707**	**3,770**	**32,1190**	**12,9267**	**19,1923**
% contribution	--	98%	2%	--	40%	60%

Table 4. Greenhouse gas concentrations and emission rates from building exhaust

	Farrowing		Gestation	
	Farm A	Farm B	Farm A	Farm B
CO_2 concentration (ppm)	**792**	**669**	**1012**	**691**
Standard deviation	179	131	619	110
CO_2 emission (g/day-AU)	**16588**	**11576**	**11514**	**4808**
Standard deviation	10977	7073	7429	2996
CH_4 concentration (ppm)	**14**	**20**	**18**	**12**
Standard deviation	8	10	13	6
CH_4 emission (g/day-AU)	**184**	**351**	**118**	**73**
Standard deviation	170	204	119	51
N_2O concentration (ppm)	**0.4**	**0.4**	**0.4**	**0.4**
Standard deviation	0.1	0	0.1	0
N_2O emission (g/day-AU)	**0**	**0**	**0**	**0**
Standard deviation	0	0	0	0

Table 5. Greenhouse gas concentrations and emission rates from manure storage

	Farm A (NCP EMS)		Farm B
	Primary cell	Secondary cell	(open EMS)
CO_2 concentration (ppm)	**3943**	**619**	**472**
Standard deviation	2149	119	44
CO_2 emission (g/day-m^2)	**89**	**2**	**455**
Standard deviation	65	0.7	329
CH_4 concentration (ppm)	**3221**	**108**	**20**
Standard deviation	2491	215	14
CH_4 emission (g/day-m^2)	**30**	**0.3**	**44**
Standard deviation	25	0.5	27
N_2O concentration (ppm)	**0.4**	**0.4**	**0.4**
Standard deviation	0.1	0.1	0
N_2O emission (g/day-m^2)	**0**	**0**	**0**
Standard deviation	0	0	0

Table 6. Total greenhouse gas emissions and relative contributions of building and manure storage

	Farm A (covered EMS)			Farm B (open EMS)		
	Total	Building	EMS	Total	Building	EMS
CO_2 (kg/day)	**12,721**	**12,426**	**295**	**9,826**	**5,928**	**3,898**
% contribution	--	98%	2%	--	60%	40%
CH_4 (kg/day)	**225**	**129**	**96**	**492**	**118**	**374**
% contribution	--	57%	43%	--	24%	76%

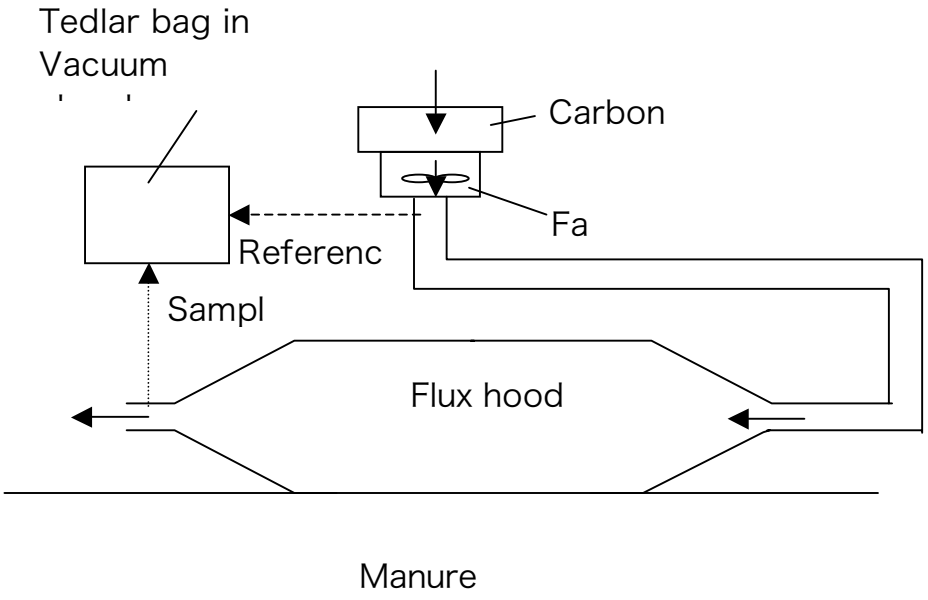

Figure 1. Floating flux hood for sampling from the manure surface in open earthen manure storage (EMS).

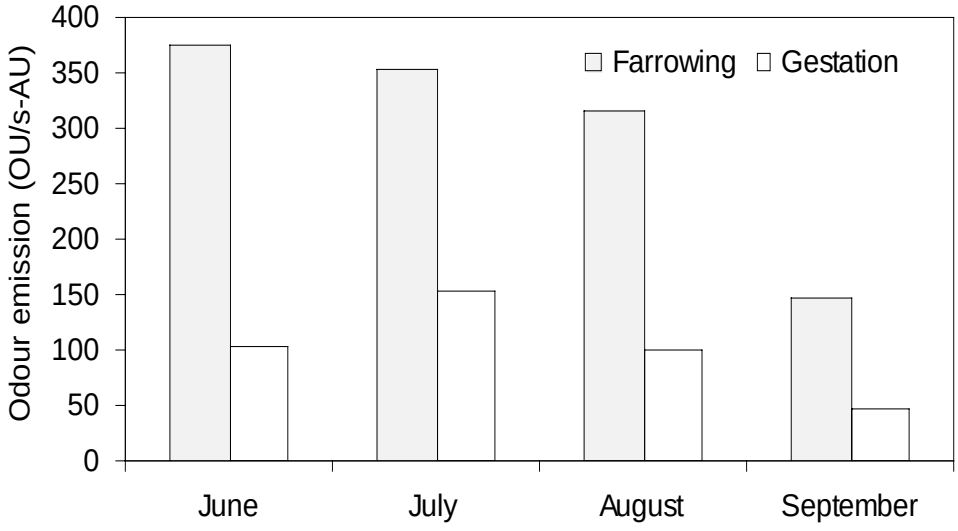

Figure 2. Average odour emission rates in four summer months.

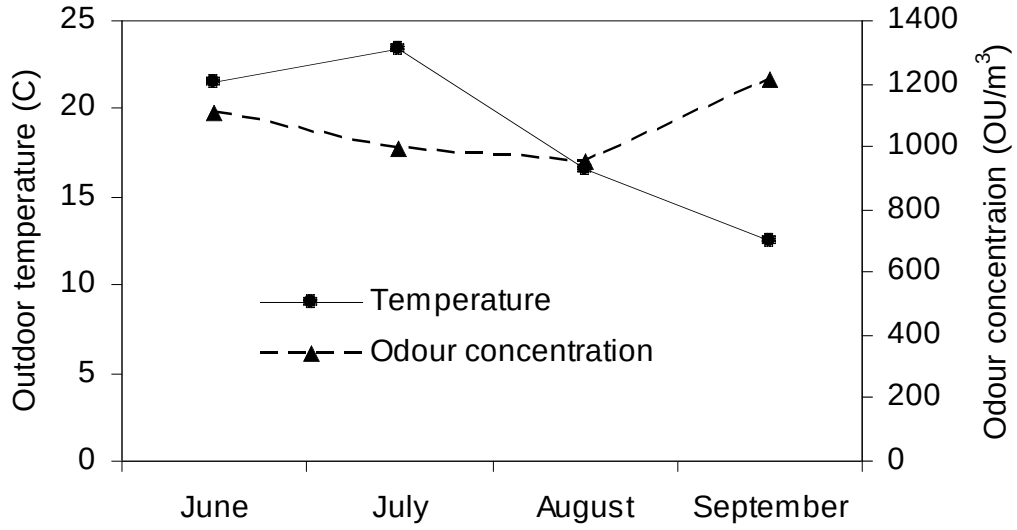

Figure 3. Average outdoor temperature and odour concentration in four summer months.

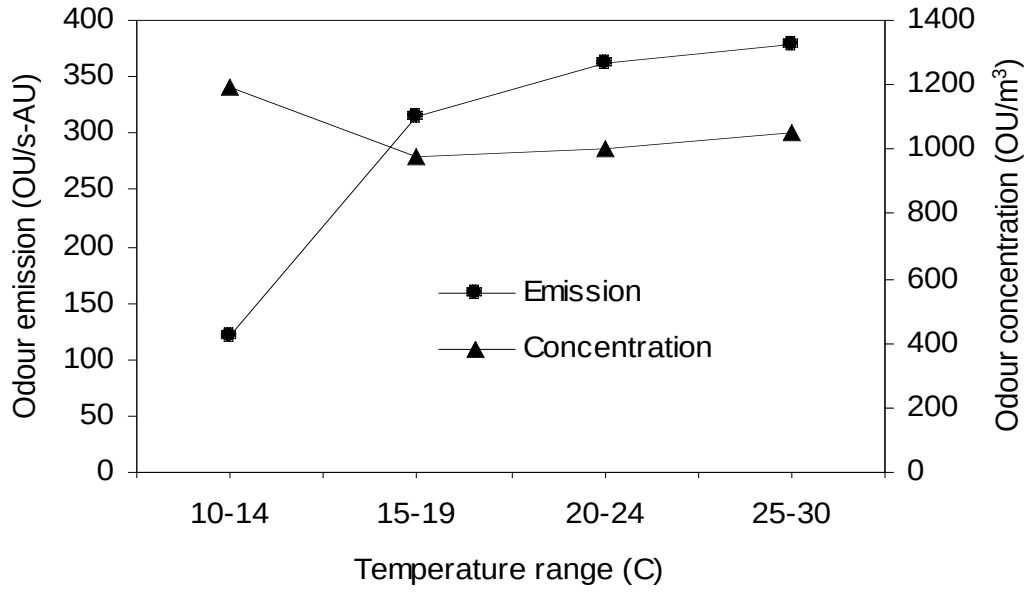

Figure 4. Variation of odour concentration and emission with outdoor temperature.

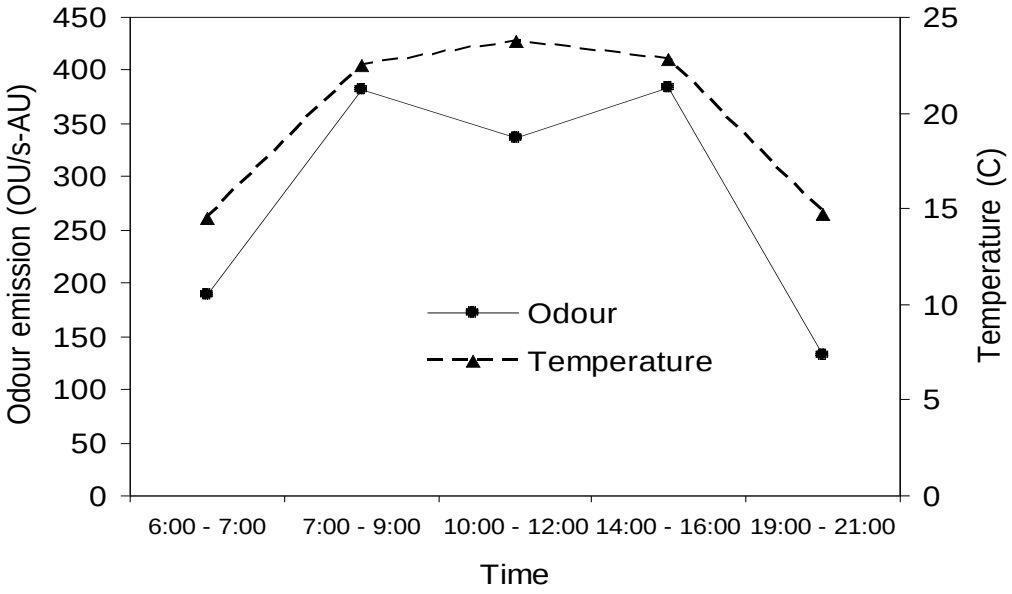

Figure 5. Variation of odour concentration and temperature during day.