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Gaseous Emissions from a Fattening Piggery and a Dairy Barn with an Automatic Milking System

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Abstract. *The concentrations of CH_4, N_2O, CO_2 and NH_3 were measured with a photoacoustic multi-gas analyser 1412 and a multiplexer 1309 (Lumasense Technologies A/S, Ballerup, Denmark) in a piggery over two fattening periods (spring and autumn) and in a dairy cow barn (spring). The aim was to quantify the emissions and to study factors affecting the emissions. The mechanically ventilated piggery was a slurry-based small scale research facility with a partly slatted floor and daily manure removal with scrapers. It housed 50 and 54 fattening pigs per batch in spring and in autumn, respectively, with a weight gain of 0.86–0.94 kg pig^{-1} day^{-1}. The dairy cow barn was naturally ventilated and had cubicles and a solid sloping floor with a central urine gutter. The floor was scraped once every hour during the daytime and once every two hours at night. It housed 108 Holstein dairy cows, which were milked by an automatic milking system (AMS). The average milk production was 31.5 kg milk cow^{-1} day^{-1}.*

The air flow in the piggery was in the range of 55–103 m^3 pig^{-1} h^{-1}. Emissions in the piggery were 2.3–4.9 g CH_4 LU^{-1} h^{-1} and 1.3–1.6 g NH_3 LU^{-1} h^{-1} (1 LU = 500 kg animal weight). The air flow in the dairy cow barn was calculated using CO_2 mass balance and corrected for cow activity. The average daily air flow was 268–917 m^3 LU^{-1} h^{-1} with a mean of 524 m^3 LU^{-1} h^{-1}. Emissions in the dairy cow barn were 10.9 g CH_4 LU^{-1} h^{-1} and 0.82 g NH_3 LU^{-1} h^{-1}. The cow activity correlated with CH_4 (coefficient of determination, R^2 = 0.91) and NH_3 (R^2 = 0.56) emissions. Diurnal emission patterns *were observed from both buildings. Mitigation strategies that target periods of emission spikes rather than an entire day might be more effective.*

Keywords. Livestock buildings, animal activity, ventilation rate, ammonia, greenhouse gases

Introduction

The influence of livestock to the environment has been of interest to researchers and to people living close to confined animal feeding operations. In a number of countries research concerning NH_3 and livestock has been going on for a long time, and in other countries research has moved from odour reduction to NH_3 mitigation (Groenestein and Van Faassen, 1996; Kuczynski et al., 2005). The contribution of greenhouse gases, especially CH_4 and N_2O from animal husbandry to global warming needs to be addressed in greater detail. The emission of N_2O is also of importance as it contributes to stratospheric ozone depletion (Crutzen, 1976).

Livestock management accounts for close to 75–80% of N_2O emission from agriculture and 65% of the global anthropogenic N_2O production (FAO, 2006). Enteric fermentation and manure management are the major sources of CH_4 production in animal husbandry, representing 80% of CH_4 release from agriculture and 35–40% of the total anthropogenic CH_4 emissions (FAO, 2006).

It is estimated that 94% of the global anthropogenic emissions of NH_3 originate from the agricultural sector, of which close to 64% comes from livestock management (FAO, 2006). Excessive levels of NH_3 emissions contribute to eutrophication and soil acidification.

A reliable emission inventory is needed for successful mitigation of these gases and high requirements have been set for reliable inventory collection (Jungbluth et al., 2001; Kuczynski et al., 2005). It is possible that a limited number of days with continuous measurements might generate reliable seasonal data (Ngwabie et al., 2009).

The aim of this experiment was to measure the concentrations of CH_4, N_2O, NH_3 and CO_2 in a mechanically ventilated fattening piggery over two seasons and in a slurry-based dairy cow barn with a concrete floor and a urine gutter. Emissions from both livestock buildings in live units (500 kg animal weight) were compared. The relationship between emissions to animal activity, ventilation rate and animal weight were also investigated.

Materials and Methods

The concentrations of CH_4, N_2O, NH_3, CO_2 and water vapour were measured in the livestock buildings using a photoacoustic multi-gas analyser 1412 and a multiplexer 1309 (Lumasense Technologies SA, Ballerup, Denmark).

Experimental building

Measurements were carried out in a fattening piggery. It had a central aisle with five pens on one side and four on the other side. The pens were partly slatted with a surface area of 8.75 m^2 each, and holding 5–7 pigs. The slatted section (40% of a total pen surface area) was over a manure duct which was 1 m deep and 1.3 m wide. The manure was mechanically scraped to external storage tanks once a day at about 8:30 a.m. Air was exhausted from the piggery by a fan in the manure duct or in the side-wall. The air inlet was through a breathing ceiling or adjustable flaps at the edge of the ceiling.

In spring, 50 pigs with an initial body weight of about 30 kg pig^{-1} were fattened for 92 days between March and June. In autumn, 54 pigs with a weight of about 40 kg pig^{-1} were fattened for 103 days between September and December (Table 1). The pigs were fed *ad libitum* with dry feed once everyday at 8 a.m.

Measurements were also carried out in a naturally ventilated dairy cow barn with cubicles, a solid sloping floor and a central urine gutter. The floor was scraped once every hour between 6 a.m. and 6 p.m., and once every two hours at night. The slurry was dumped into a pit at the end of the alley which was emptied daily at 6 a.m. and at 5 p.m. The barn had two integrated automatic milking parlours. There were 108 Holstein dairy cows in the barn with an average milk production of 31.5 kg day^{-1} cow^{-1} (Table 1). The average daily feed consumption per cow was estimated at: 7 kg grass silage, 4.5 kg corn silage, 1 kg straw, 5 kg wheat and 5.6 kg protein concentrate. With the exception of the wheat and protein concentrate that were given as a separate diet in the milking parlours and feeding stations, the cows were fed on a mixed ration twice a day at 8 a.m. and 4 p.m.

Table 1. Production data during the measurement periods.

Parameter	Fattening pigs		Dairy cows
Season	Spring, 2007	Autumn, 2007	Spring, 2008
Fattening period	26th March–26th June	9th Sept–18th Dec	-
Analysis period	4th April–9th June	10th Sept–15th Nov	26th Feb–9th May
Number of animals	50	54	108
Building volume	300 m^3	300 m^3	6747 m^3
Mean initial weight	30 kg on 27th March	40 kg on 7th Sept	600 kg
Mean final weight	94 kg on 9th June	105.5 kg on 15th Nov	600 kg
Feed intake	2.35 kg pig^{-1} day^{-1}	2.76 kg pig^{-1} day^{-1}	-
Weight gain	0.86 kg pig^{-1} day^{-1}	0.94 kg day^{-1}	-
Feed conversion	2.74 kg/kg	3.12 kg/kg	-
Milk production	-	-	31.5 kg day^{-1} cow^{-1}

Instrumental set-up

Air was drawn through polytetrafluoroethylene tubes to channels of the multiplexer and further to the analyser for concentration measurements.

In the piggery, one tube connected to a location outside the building was used for measuring outdoor concentrations. Another tube was moved with the air exhaust which was either the manure duct or the wall-fan.

Sampling tubes from five channels of the multiplexer were evenly distributed inside the dairy cow barn. Two sampling locations were chosen at either side of the aisle and one sampling location was at the centre of the aisle. The mean from all these five locations was used as the indoor concentration. The outdoor concentrations were measured at two locations, the mean of which was used as the outdoor concentration. Hourly concentration averages were used for analyses.

The effect of different sampling tube materials regarding adsorption and desorption of some gases such as NH_3 has been discussed by Shah et al., 2006 and Mukhtar et al., 2003. The multi-gas analyser's efficiency of tracking gas concentrations when switching channels or when measuring high concentrations differences is gas dependent and might affect the measured concentrations (Hinz & Linke, 1998; Rom & Zhang, 2008). These might not be limiting factors in our measurements as the emphasis was on the mean concentration levels.

The cow activity was measured using passive infrared detectors and an analogue signal interface (Pedersen & Pedersen, 1995). The temperature in the piggery was measured using Cu/CuNi thermocouples. The temperature in the dairy barn was measured using Tiny-tags (Gemini Data Loggers, Chichester, UK). Hourly averages were used for analyses.

The ventilation rate in the piggery was measured using a thermal anemometer (VelociCal 9545/9545-A, Minnesota, USA) at the exhaust fan. The ventilation rate in the dairy barn was calculated using CO_2 mass balance (CIGR, 2002; De Sousa and Pedersen, 2004) as presented in Equation 1:

$$\mathrm{VR\ per\ HPU} = \frac{0.185(\mathrm{Relative\ animal\ activity})}{(\mathrm{CO_2 indoors} - \mathrm{CO_2 outdoors})10^{-6}} \qquad (1)$$

where VR is the ventilation rate in $m^3\ h^{-1}$, 1 HPU (heat producing unit) is 1000 W of the total heat produced by the animals at 20 ^oC (CIGR, 2002), 0.185 is the CO_2 production in $m^3\ h^{-1}$ per heat producing unit and corresponds to a medium feeding level, $CO_2indoors$ is the CO_2 indoor concentration in ppm, and $CO_2outdoors$ is the CO_2 outdoor concentration in ppm. The CO_2 production was directly adjusted for animal activity.

The emission rate of a gas was calculated using the ventilation rate and the relative concentration of the gas in the building as shown in Equation 2.

$$\mathrm{ER} = \mathrm{VR}(C_{in} - C_{out}) \qquad (2)$$

where ER is the emission rate in mg h^{-1}, VR is the ventilation rate in $m^3\ h^{-1}$, C_{in} and C_{out} are the gas concentrations inside and outside the building respectively in mg m^{-3}.

Results

The minimum and maximum mean daily ventilation rates in the dairy cow barn were 268 $m^3\ LU^{-1}\ h^{-1}$ and 917 $m^3\ LU^{-1}\ h^{-1}$ respectively. The average ventilation rate was 524 $m^3\ LU^{-1}\ h^{-1}$. The ventilation rate in the piggery was 60 $m^3\ pig^{-1}\ h^{-1}$ and 55 $m^3\ pig^{-1}\ h^{-1}$ in spring and autumn respectively, when air was exhausted through the manure duct. When air was exhausted through the wall-fan, the ventilation rate was 103 $m^3\ pig^{-1}\ h^{-1}$ in spring and 96 $m^3\ pig^{-1}\ h^{-1}$ in autumn.

There was a diurnal variation in the mean hourly emissions of CH_4 and NH_3 from the dairy cow barn with high values in the daytime (Figure 1). Two daily emission peaks for CH_4 and NH_3 in the barn occurred at about 9 a.m. and 5 p.m. The lowest emissions during a day in the cow barn were measured at about 5 p.m. Mean emission values from the barn for the entire measurement period are presented in Table 2

Table 2. CH_4 and NH_3 emissions from the dairy cow barn.

	CH_4		NH_3	
Statistics	g $LU^{-1}\ h^{-1}$	g $cow^{-1}\ h^{-1}$	g $LU^{-1}\ h^{-1}$	g $cow^{-1}\ h^{-1}$
Mean	10.9	13.2	0.82	0.99
SD	2.6	3.1	0.4	0.5
Range	5.8–23.2	6.9–27.9	0.2–3.4	0.2–4.1

SD: Standard deviation

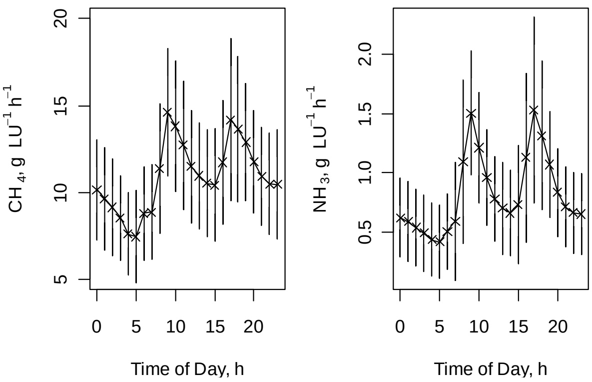

Figure 1. Diurnal variations in the emission rates of CH_4 and NH_3 measured in the dairy cow barn. The crosses in the undulating line represent the hourly averages for the entire sampling period (26th Feb–9th May, 2008). Vertical lines represent standard deviations.

There was a single daily emission peak for all the gases measured from both pig batches, which occurred at about 8 a.m. (Figure 2). Emissions values from the piggery are given in Table 3.

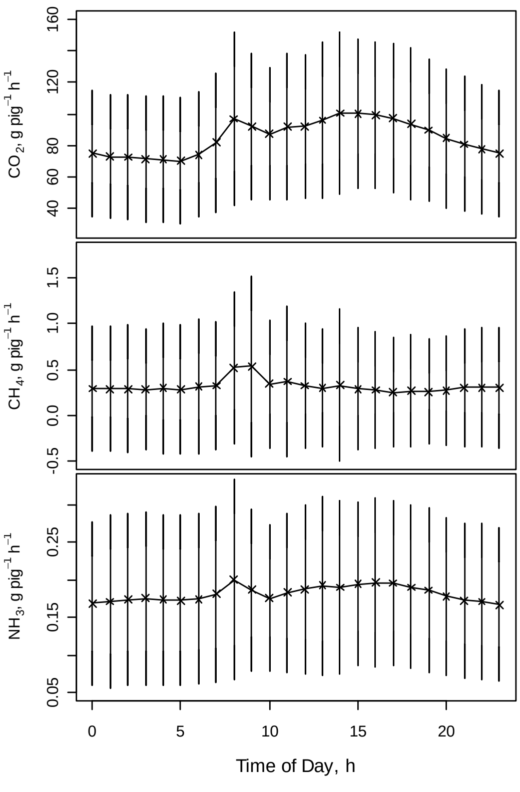

Figure 2. Diurnal variations in the emission rates of CO_2, CH_4 and NH_3 measured in the piggery in spring. Crosses in the undulating line represent the hourly averages for the entire sampling period (4th April–9th June, 2007), while the vertical lines represent standard deviations.

Table 3. Gaseous emissions from the piggery.

Season	Statistics	CO_2		CH_4		NH_3	
		g LU^{-1} h^{-1}	g pig^{-1} h^{-1}	g LU^{-1} h^{-1}	g pig^{-1} h^{-1}	g LU^{-1} h^{-1}	g pig^{-1} h^{-1}
Spring	Mean	778	85	2.3	0.32	1.6	0.18
4th April–9th June	SD	237	25	2.2	0.34	0.3	0.07
	Range	417–2028	25–191	0–20	0–3.1	0.63–2.8	0.04–0.43
Autumn	Mean	652	91	4.9	0.67	1.3	0.19
10th Sept–15th Nov	SD	171	20	6.5	0.83	0.3	0.06
	Range	351–1765	48–198	0–92	0–10	0.41–2.7	0.04–0.39

SD: Standard deviation

Discussions

Diurnal variations in emissions from the dairy cow barn were likely a consequence of feeding routines (carried out at 8 a.m. and 4 p.m.) when the activity of the cows was maximum. This is indicated in Figure 1 with emission peaks that were measured about an hour after feeding. During this time, there was likely an increase in faeces and urine deposition frequency as well as mixing of the manure on the floor. Manure removal was an hourly process and might not have accounted for the large variations in emissions. Emission variations in the piggery (Figure 2) were related to feeding that took place at 8 a.m. and manure removal (8:30 a.m.). At this time, there was mixing of the manure in the gutter as it was emptied.

An ANOVA model relating the emissions of CH_4 or NH_3 to the animal species and the measurement period (treated here as dairy cows, pigs in spring, and pigs in autumn) was used to investigate species and seasonal effects. The time in a day when emissions were estimated was treated as a block effect. The null hypothesis, that there was no effect of animal species or seasonal changes on the emissions was rejected ($p < 0.05$). Emissions depended on the animal species and the measurement period. A further analysis to rank the emissions showed that NH_3 had the same emission level in the piggery in spring and in autumn, which was all higher than NH_3 production in the dairy barn (based on equivalent emission units). On the other hand, CH_4 had its highest emission in the dairy barn, followed by the piggery in autumn and then in spring. Note should be taken that the ventilation rate in the piggery was constant and was not regulated by changes in the indoor climate.

It was interesting to observe that the emissions of NH_3 and CH_4 were more dependent on the activity of the cows rather than on the ventilation rate (Table 4). Variations in the cow activity accounted for 59% and 91% of the variations in the NH_3 and CH_4 emissions respectively in the cow barn (Figure 3). NH_3 in contrast to CH_4 had a better correlation to the weight of the pigs

Table 4. Coefficient of determination (R^2) between emission rates and the weight of the pigs (or the ventilation rate in the cow barn).

Piggery	NH_3, g pig^{-1} h^{-1}	CH_4, g pig^{-1} h^{-1}	N
Spring weight, kg pig^{-1}	0.67	0.38	748
Autumn weight, kg pig^{-1}	0.70	0.01	1259
Dairy barn	NH_3, g LU^{-1} h^{-1}	CH_4, g LU^{-1} h^{-1}	
Ventilation rate, m^3 LU^{-1} h^{-1}	0.09	0.05	1751

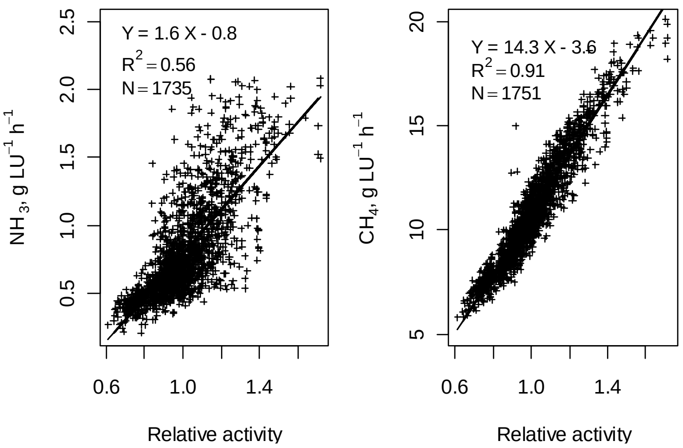

Figure 3. Relationship between NH_3 or CH_4 emissions and dairy cattle activity.

Conclusion

Emissions of CO_2, NH_3 and CH_4 were estimated in a dairy cow barn and in a piggery. Comparisons were made between emissions from both species. Emissions were analysed in relation to some climatic and animal parameters. The following conclusions could be drawn from this measurement.

- When equivalent animal weights were considered, the dairy cows produced more CH_4 while the fattening pigs produced more NH_3.
- NH_3 emissions had a better relationship to the weight of the pigs compared to CH_4 emission.
- Diurnal emission variations in the dairy barn were related to the activity of the cows, which was high during the feeding periods.
- Diurnal emission variations in the piggery were related to feeding and cleaning routines during which time there was mixing of the manure on the floor and especially in the gutter.
- Emission mitigation strategies that target specific periods of a day (such as when emission spikes occur) rather than the entire day might be more efficient and cost effective.

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