Methane, ammonia and nitrous oxide emissions from a naturally ventilated dairy cattle building

N. M. Ngwabie, G. Gustafsson, K.-H. Jeppsson

Department of Rural Buildings and Animal Husbandry, Swedish University of Agricultural Sciences, P.O. Box 86, S-230 53 Alnarp, Sweden, E-mail: Ngwa.Martin.Ngwabie@ltj.slu.se

Abstract

Methane, ammonia, nitrous oxide and carbon dioxide concentrations were measured in a naturally ventilated dairy cattle building using a photoacoustic multigas analyser 1412 and a multiplexer 1309. Concentrations were continuously measured from December 2006 to March 2007 when the cows were permanently indoors. This was complimented with one week of warm weather measurement in May.

Ten sampling locations were chosen inside the building and two outside for background concentrations. The building had a liquid manure system with channel scrapers operating twice a day. It had on average, 180 dairy cattle with a mean mass of 600 kg cow^{-1} and milk production of 32 kg d^{-1} cow^{-1}. An average ventilation rate of 63400 m^3 h^{-1} with a variation of 26000 m^3 h^{-1} was measured through out the sampling period using the carbon dioxide mass balance method.

Emission rate values during cold weather from December to March ranged from 10.9–12.5 g CH_4 h^{-1} per 500 kg live weight and 0.97–1.10 g NH_3 h^{-1} per 500 kg live weight. Lower emissions were recorded in May with a value of 8.90 g CH_4 h^{-1} per 500 kg live weight and 0.88 g NH_3 h^{-1} per 500 kg live weight.

Introduction

Animal husbandry is a source of volatile organic compounds, organic dust production and other gaseous emissions into the atmosphere, which have an adverse affect on human health (Zhang et al., 1998). Due to the climatic and environmental effects of these emissions, measures have been taken to cut down on the level produced from livestock (Hill and Barth, 1976; Chiba, 1987; Hayes et al., 2004; Luo et al., 2004; Nimmermark and Gustafsson, 2005; Varel et al., 2007). However, effective mitigation methods rely on precise and updated emission inventory. It might be difficult to achieve such an inventory as it is not only dependent on animal type, but also on the management system in place and on the regional climate. An up to date data base is therefore necessary to keep tract of regional and global emissions, check if emission targets are met, and work out better emission control methods. Examples of inventory data from livestock emissions is available in Snell et al., 2003 Zhang et al., 2005 and Starmans and Hoek, 2007.

Dairy cattle are of particular importance with regards to ammonia and methane emissions. In mechanically ventilated buildings is it easier to estimate the emission rates of gases. This is not the case with naturally ventilated buildings due to difficulties in air exchange rate measurements. This type of building is common for cattle as it requires no extra heating, relying mainly on a temperature gradient and the wind for air exchange.

This paper contains preliminary results in an investigation that was aimed at measuring the concentrations of carbon dioxide, methane, ammonia and nitrous oxide in a naturally ventilated dairy cattle building. Ventilation rate, calculated from carbon dioxide mass balance (CIGR, 2002) was used to estimate the emission rates of ammonia and methane.

Methodology

The concentrations of methane, ammonia, nitrous oxide, carbon dioxide, and water content in the air were measured in a free stall dairy cattle building using a photoacoustic multigas analyser 1412 coupled with a multiplexer 1309 (INNOVA 2003, 2005). The building was naturally ventilated through flaps on side walls and the ridge and occasionally through side doors. The floor had a raised platform with cubicles where the cows slept and a lower walkway made of concrete slats over a manure channel. The manure in the channel was mechanically scraped out twice a day to external storage tanks. Animal number was in the range 164–195 with an average mass of 600 kg and a milk production rate of 31–33 kg d^{-1} cow^{-1}.

Measurements were carried out from December 2006 to March 2007 when the cows were indoors and for a week in May 2007 when they were out grazing during the day (10 am–4 pm). Ten measurement positions were chosen inside the building of volume 13148 m^3 with nine placed at a height of 2.5 m from the floor, and one in the manure channel. The indoor concentrations of the gases were taken as the means of all the indoor readings. There were two positions outside with the lower reading used as the background concentrations. The response time for the five gases including water vapour was one minute and it took twelve minutes to sample through all the locations.

Results

Daily fluctuations were observed in the concentrations of ammonia, carbon dioxide, methane and nitrous oxide. The mean values for these gases varied less during the cold months of winter; December to March when the cows were indoors (Table 1). Methane and ammonia concentrations in May when the cows were temporally in the building were lower than the values of the winter months when they were permanently indoors. This was due to a lower animal activity as the cows were outside during the day. Gaseous release from microbial processes in the manure was also lower due to less manure inside the building during this period. Subtracting a methane background level of 1.31 ppm from the shed concentration of 4 ppm when the cows were outside and 35 ppm when they were inside gave a production of about 8% from sources other than animal respiration. This resulted in 92% methane coming directly from the cows (enteric fermentation).

Table 1: Average concentrations in ppm of nitrous oxide, ammonia and methane measured in a dairy cattle building with a liquid manure system

Month	N_2O		NH_3		CH_4		n
	Mean	SD	Mean	SD	Mean	SD	
December 2006	0.34	0.02	6.26	1.49	72	23	1379
January 2007	0.35	0.03	6.26	1.58	75	34	2273
February 2007	0.34	0.02	6.74	2.0	70	29	3051
March 2007	0.29	0.04	7.12	2.15	64	29	3404
May: Cows inside (5 pm–9 am)	0.33	0.04	4.06	1.12	35	13	444
May: Cows outside (11 am–3 pm)	0.39	0.03	3.22	0.89	4	3	105
SD: Standard deviation; n: Number of samples							

An average ventilation rate of 64000 $m^3\ h^{-1}$ with a variation of 26000 $m^3\ h^{-1}$ through out the entire sampling period was measured. Due to large fluctuations in the ventilation rate, emission rates were calculated using daily ventilation rate values. Figure 1 shows periodic daily variation in the emission rates of methane and ammonia, with high values attained when the concentrations in the building were high during manure removal, feed/cleaning and milking.

Methane emission rate during the entire period was 8.9–12.5 g $CH_4\ h^{-1}$ per 500 kg live weight (Table 2). This translates to a value of 78–110 kg $CH_4\ yr^{-1}$ per 500 kg live weight from this building and covers a reported emission factor of 109 kg CH_4 $head^{-1}\ yr^{-1}$ for dairy cows in Western Europe from enteric fermentation (IPCC, 2006). A lower emission of 8.9 g $CH_4\ h^{-1}$ per 500 kg live weight was measured in May during the night periods when the cows were in the building. Emissions of 11.1 g $CH_4\ h^{-1}$ per 500 kg live weight have been measured in Germany (Snell et al., 2003).

In cold weather conditions from December to March, the emission rate of ammonia was 0.97–1.10 g $NH_3\ h^{-1}$ per 500 kg live weight. This was within the limit measured in four other northern European countries with a range of 0.84–1.77 g $NH_3\ h^{-1}$ per 500 kg live weight

(Koerkamp et al., 1998). An emission rate value of 1.68 g NH_3 h^{-1} per 500 kg live weight has also been reported in Germany (Snell et al., 2003). In May, a lower emission of 0.88 g NH_3 h^{-1} per 500 kg live weight was measured due to the limited time the cows spend in the building.

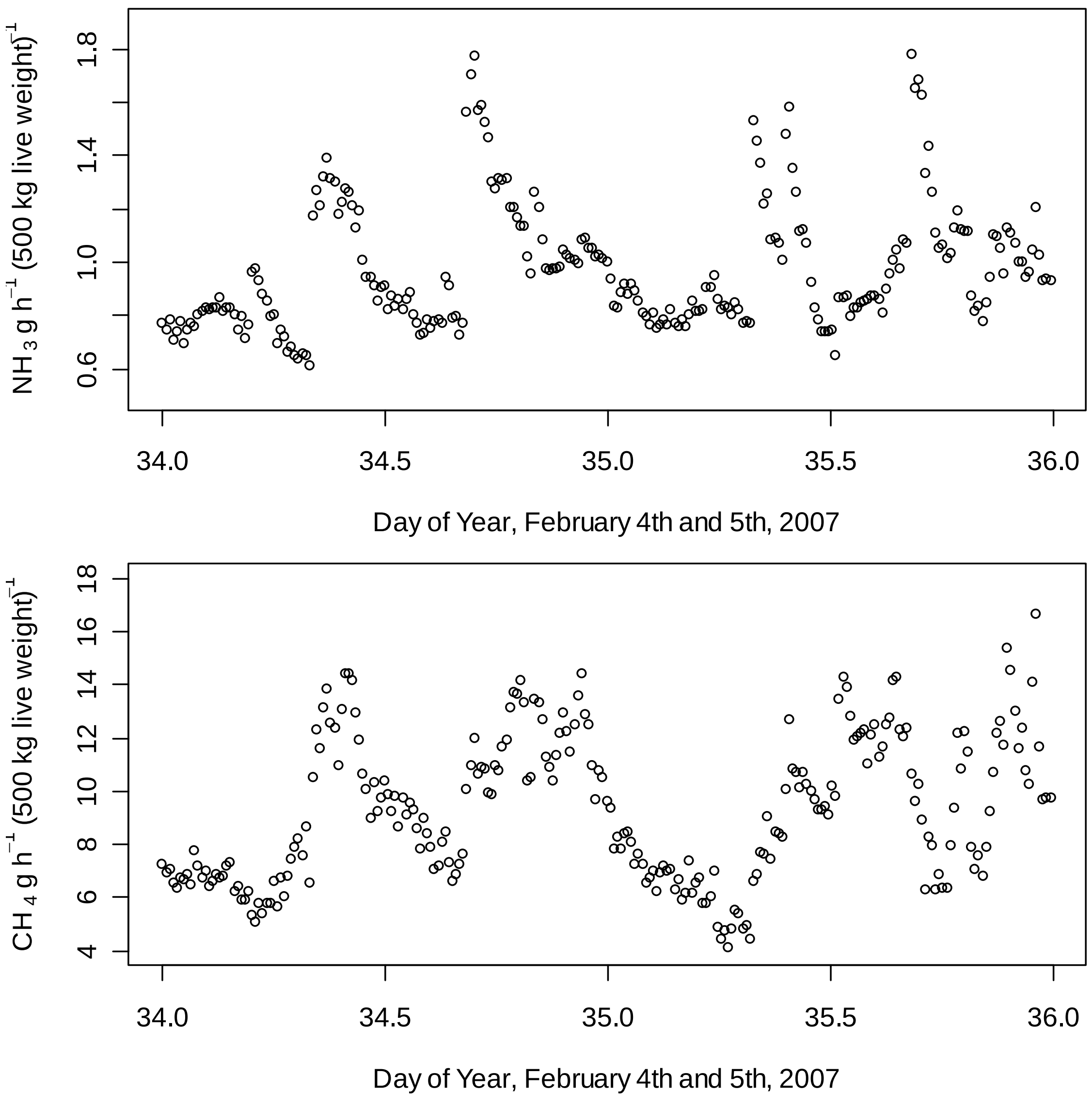

Figure 1. Daily variation in the emission rates of ammonia and methane.

Table 2: Emission factors from dairy cow measurements with slatted floor, g h^{-1} per 500 kg live weight

Month	NH_3		CH_4	
	Mean	SD	Mean	SD
December 2006	0.97	0.2	11.6	3
January 2007	0.99	0.3	12.5	6
February 2007	1.01	0.3	11.2	4
March 2007	1.10	0.3	10.9	5
May 2007 (5 pm–9 am)	0.88	0.3	8.90	3

Conclusions

The concentrations of ammonia and methane dropped significantly in May when the cows were indoors for part of the day only, compared to the winter period when they were indoors for the entire day. Less manure in the building and a lower animal activity during this period were reasons for the drop in gas concentrations. Nitrous oxide concentration in the building was independent of whether the cows were indoors or outside.

An average ventilation rate of 63400 $m^3 h^{-1}$ over a variation of 26000 $m^3 h^{-1}$ was measured using the carbon dioxide mass balance method in the dairy cattle building.

Emission rate values from December to March ranged from 10.9–12.5 g CH_4 h^{-1} per 500 kg live weight and 0.97–1.10 g NH_3 h^{-1} per 500 kg live weight. Lower emissions of 8.9 g CH_4 h^{-1} per 500 kg live weight and 0.88 g NH_3 h^{-1} per 500 kg live weight, measured in May was due to the absence of the cows in the building during the days as they were out grazing.

References

Chiba L I, E. R. Pro, Jr., A. J. Lewis (1987). Use of dietary fat to reduce dust, aerial ammonia and bacterial colony forming particle concentrations in swine confinement buildings. TRANSACTIONS of the ASAE 30(2), 464-468.

CIGR. Climatization of Animal Houses. Forth report of working group. Danish Institute of Agricultural Sciences, Research Centre Bygholm, 2002.

Hayes E T; Leek A B G; Curran T P; Dodd V A; Carton O T; Beattie V E and O'Doherty J V (2004). The influence of diet crude protein level on odour and ammonia emissions from finishing pig houses. Bioresource Technology, 91(3), 309-315.

Hill D T and Barth C L (1976). Removal of Gaseous Ammonia and Methylamine Using Ozone. Trans. ASAE, 19(935:944).

INNOVA (2003). Application Software Type 7300 for control of Gas Monitoring Systems. INNOVA AirTech Instruments A/S. Denmark.

INNOVA (2005). Technical Documentation of the 1412 Photoacoustic Field Gas-Monitor. INNOVA AirTech Instruments A/S. Denmark.

IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Emissions from Livestock and Manure Management.

Koerkamp P W G G; Metz J H M; Uenk G H; Phillips V R; Holden M R; Sneath R W; Short J L; White R P; Hartung J; Seedorf J; Schroder M; Linkert K H; Pedersen S; Takai H; Johnsen J O and Wathes C M. Concentrations and Emissions of Ammonia in Livestock Buildings in Northern Europe. J. agric Engng Res., 1998, 70(1), 79-95.

Luo J; Kulasegarampillai M; Bolan N and Donnison A (2004). Control of gaseous emissions of ammonia and hydrogen sulphide from cow manure by use of natural materials. New Zealand Journal of Agricultural Research, 47(4), 545-556.

Nimmermark S and Gustafsson G (2005). Influence of temperature, humidity and ventilation rate on the release of odour and ammonia in a floor housing system for laying hens. Agricultural Engineering International: the CIGR Ejournal, Vol. VII, Manuscript BC 04 008.

Snell H G J; Seipelt F and Van den Weghe H F A. Ventilation rates and gaseous emissions from naturally ventilated dairy houses. Biosystems Engineering, 2003, 86(1), 67-73.

Starmans D A J and Hoek K W V d (2007). Ammonia, the case of The Netherlands. Wageningen Academic Publishers.

Varel V H; Wells J E and Miller D N (2007). Combination of a urease inhibitor and a plant essential oil to control coliform bacteria, odour production and ammonia loss from cattle waste. Journal of Applied Microbiology, 102(2), 472-477.

Zhang G; Strom J S; Li B; Rom H B; Morsing S; Dahl P and Wang C (2005). Emission of Ammonia and Other Contaminant Gases from Naturally Ventilated Dairy Cattle Buildings. Biosystems Engineering, 92(3), 355-364.

Zhang Y; Tanaka A; Dosman J A; Senthilselvan A; Barber E M; Kirychuk S P; Holfeld L E and Hurst T S. Acute Respiratory Responses of Human Subjects to Air Quality in a Swine Building. J. agric Engng Res., 1998, 70(4), 367-373.