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Research Paper

Measurements of emission factors from a naturally ventilated commercial barn for dairy cows in a cold climate

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Emission rates of CH_4, N_2O and NH_3 were measured in a commercial free-stall barn that housed 141 lactating dairy cows, and 75 dry cows and replacement heifers. Animal activity, measured using the ALPRO™ dairy herd management system was used together with the CO_2 balance method to calculate the ventilation rate. Methane emission was also modelled using the IPCC Tier 2 method. Animal activity variations similar to reported patterns indicated that the activity monitoring system provided high resolution measurements since all cows were considered. Diurnal variations were observed in the emissions with mean values of 12.2–13.9 g CH_4 LU^{-1} h^{-1}, 0.43–0.64 g NH_3 LU^{-1} h^{-1} and 29.4–41.3 mg N_2O LU^{-1} h^{-1}. Modelled enteric CH_4 emission was 312 g CH_4 $head^{-1}$ d^{-1} (10.58 g CH_4 LU^{-1} h^{-1}). It was estimated that indoor manure emitted 73 g CH_4 $head^{-1}$ d^{-1} (2.5 g CH_4 LU^{-1} h^{-1}), with enteric fermentation representing 81% of the total barn CH_4 emission. Lactating cows emitted about 363 g CH_4 $head^{-1}$ d^{-1} (11.42 g CH_4 LU^{-1} h^{-1}) while non-lactating cows emitted 241 g CH_4 $head^{-1}$ d^{-1} (9.67 g CH_4 LU^{-1} h^{-1}).

1. Introduction

The agricultural sector is a significant contributor to greenhouse gas (GHG) emissions, accounting for 8% of the total 2010 GHG emissions in Canada, indicating a 19% increase from the 1990 level (Environment-Canada, 2012). In particular, agriculture accounts for 24% and 72% of the Canadian CH_4 and N_2O emissions, respectively, with the main sources coming from cattle and pig raising as well as the use of synthetic nitrogen fertilisers. In total, Canadian livestock contribute about 60% of the total agricultural GHG emissions.

Increasing trends in estimated national emission factors have been observed in some livestock categories, e.g. CH_4 emission from enteric fermentation in dairy cows increased

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Nomenclature

ADF	acid detergent fibre
AU	animal unit (500 kg animal mass)
CF	correction factor for the heat produced at any temperature T_i (°C)
$CO_{2indoors}$	CO_2 indoor concentration (ppmv)
$CO_{2outdoors}$	CO_2 outdoor concentration (ppmv)
CP	crude protein
DMI	dry matter intake (kg head^{-1} d^{-1})
E	average metabolisable feed energy content (MJ kg^{-1} dry matter)
EE	ether extract
G	daily gain in weight of a heifer (kg d^{-1})
GEI	gross energy intake (MJ^{-1} head^{-1} d^{-1})
GHG	greenhouse gas
HPU	heat produced unit
IPCC	Intergovernmental Panel on Climate Change
LU	livestock unit (500 kg animal mass)
M	average animal mass (kg)
NDF	neutral detergent fibre
NE	no emissions assumed
NFC	non-fibre carbohydrate (g kg^{-1})
PTFE	polytetrafluoroethylene
RA	relative animal activity measured
T_i	temperature (°C)
TDN	total digestible nutrients (%)
VR_{HPU}	ventilation rate per heat producing unit (m^3 h^{-1} HPU^{-1})
Y	average daily milk production (kg d^{-1})
Y_m	methane conversion factor
Φ_{tot}	total heat produced by dairy cows and heifers (W)
$\Phi_{dairy\ cows}$	heat produced by dairy cows (W)
$\Phi_{heifers}$	heat produced by heifers (W)

from 109.4 kg head^{-1} yr^{-1} in 1990 to 127.1 kg head^{-1} yr^{-1} in 2010, with an associated increase in milk production (Environment-Canada, 2012). However, significant differences still exist between emission factors at the barn, provincial and national levels due to the simplified approach needed for national scale inventories and the diversified nature of dairy management and climatic conditions (Environment-Canada, 2012; IPCC, 2006). Canadian dairy cows are mostly kept indoors in naturally ventilated barns but in some cases they are sent outdoor for a few hours during the day in warm weather (Sheppard, Bittman, Swift, Beaulieu, & Sheppard, 2011). On average, Canadian dairy cattle manure storage is evenly distributed among solid and liquid forms (~40% each), with ~20% being deposited on pastures; however in certain provinces, the proportion of dairy manure handled as liquid can be as high as 89% or as low as 20% (Environment-Canada, 2012; Statistics-Canada, 2003). Although several measurements have been conducted to quantify and study the variation patterns of NH_3 and GHG emissions from dairy cow barns in the cold regions of North America and Europe (Harper et al., 2009; Ngwabie, Jeppsson, Gustafsson, & Nimmermark, 2011; Zhu, Dong, & Zhou, 2012), only a few measurements have been conducted in Canada (Bluteau, Masse, & Leduc, 2009; McGinn & Beauchemin, 2012; McGinn, Flesch, Harper, & Beauchemin, 2006). More measurements are therefore needed to fully understand and quantify emissions from commercial dairy cow barns in Canada. However, direct measurements can be expensive and the application of models (IPCC, 2006; Li et al., 2012) to estimate emission factors may provide a more reliable and cheaper alternative especially when input data from specific barns is used. Estimates from such models for Canadian dairy cows at the provincial level have carried out (Jayasundara & Wagner-Riddle, 2014) and they need to be validated with direct measurements.

The determination of emission factors from livestock buildings requires measurements of gas concentrations and ventilation rates. While several techniques and instruments to measure gas concentrations in livestock buildings have been used and extensively reviewed (Ni & Heber, 2008; Ni et al., 2009; Ogink, Mosquera, Calvet, & Zhang, 2013; Wheeler, Weiss, & Weidenboerner, 2000), measurements of ventilation rates, especially in naturally ventilated buildings (popular in the dairy industry) remains highly difficult. The CO_2 balance method is recommended for ventilation rate determination in naturally ventilated buildings but it has a temporal resolution of 24 h, which can be improved if the animal activity is known (CIGR, 2002). Several methods have been applied to obtain values for the animal activity: modelling (CIGR, 2002; Cornou & Lundbye-Christensen, 2012), infrared detectors (Pedersen & Pedersen, 1995) and cameras (Costa, Borgonovo, Leroy, Berckmans, & Guarino, 2009). There is a need for easily used methods that can also improve the spatial resolution of the measured activity since most detectors and sensors have a limited field of view. A system that is increasingly used in highly automated barns is the ALPRO™ herd management system which is incorporated into the DeLaval system (Tumba, Sweden). Amongst its features is an activity monitoring system that is used to determine when animals are in oestrus so as to identify optimal insemination times and for monitoring animal health deviations. It is a promising tool for emission research which may provide high spatial resolution data for animal activity to be used in ventilation rate determination by the CO_2 balance method. This is because it measures the activity of each animal that is fitted with a collar.

Given the considerations mentioned above, measurements were conducted in a naturally ventilated barn for dairy cows during the spring and the fall transitional seasons with the aim of (a) studying diurnal variations (variations within a day) in the emissions the CH_4, N_2O and NH_3; (b) determining the emission factors of these gases through direct measurements; and (c) comparing CH_4 emission factors obtained through direct measurements and through modelling using the IPCC (2006) Tier 2 method with local barn data.

2. Materials and methods

2.1. *Dairy cow barn*

Measurements were carried out during the transitional seasons in the spring (February–April) and in the fall (September and October) of 2012 in a dairy cow barn located