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Diurnal and seasonal variations of greenhouse gas emissions from a naturally ventilated dairy barn in a cold region

Dandan Huang, Huiqing Guo*

Biological Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, SK, S7N 5A9, Canada

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ABSTRACT

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions were quantified for a naturally ventilated free-stall dairy barn in the Canadian Prairies climate through continuous measurements for a year from February 2015 to January 2016, with ventilation rate estimated by a CO_2 mass balance method. The results were categorized into seasonal emission profiles with monthly data measured on a typical day, and diurnal profiles in cold (January), warm (July), and mild seasons (October) of all three gases. Seasonal CO_2, CH_4, and N_2O concentrations greatly fluctuated within ranges of 593–2433 ppm, 15–152 ppm, and 0.32–0.40 ppm, respectively, with obviously higher concentrations in the cold season. Emission factors of the three gases were summarized: seasonal N_2O emission varied between 0.5 and 10 μg s^{-1} AU^{-1} with lower emission in the cold season, while seasonal CO_2 and CH_4 emissions were within narrow ranges of 112–119 mg s^{-1} AU^{-1} and 2.5–3.5 mg s^{-1} AU^{-1}. The result suggested a lower enteric CH_4 emission for dairy cows than that estimated by Environment Canada (2014). Significant diurnal effects ($P < 0.05$) were observed for CH_4 emissions in all seasons with higher emissions in the afternoons and evenings. The total greenhouse gas (GHG) emission, which was calculated by summing the three GHG in CO_2 equivalent, was mainly contributed by CO_2 and CH_4 emissions and showed no significant seasonal variations ($P > 0.05$), but obvious diurnal variations in all seasons. In comparison with previous studies, it was found that the dairy barn in a cold region climate with smaller vent openings had relatively higher indoor CO_2 and CH_4 concentrations, but comparable CO_2 and CH_4 emissions to most previous studies. Besides, ventilation rate, temperature, and relative humidity all significantly affected the three gas concentrations with the outdoor temperature being the most relevant factor ($P < 0.01$); however, they showed less or no statistical relations to emissions.

1. Introduction

Agriculture production is a large source of N_2O and CH_4 emissions (Aneja et al., 2009); and livestock production is a major contributor to greenhouse gas (GHG) emissions in agriculture. According to Steinfeld et al. (2006), about 18% of global GHG emissions were caused by livestock production in some way. In Europe, it was indicated that dairy accounted for the largest livestock-related GHG emissions followed by beef, and together the two sectors emitted more than 70% of GHG emissions from livestock production (Lesschen et al., 2011). In the United States, it was reported that dairy cattle and all livestock contributed 0.55% and 2.75% of total anthropogenic GHG emissions, respectively (US EPA, 2012). In Canada, agriculture accounted for 27% and 70% of the national CH_4 emission and N_2O emission, with a contribution of 62% of total agricultural emissions from livestock emissions, and the largest contributor to GHG emissions in livestock section is beef followed by dairy cattle (Environment Canada, 2014).

Canada has committed to reducing its total GHG emissions to 17% below the 2005 level by 2020 (Environment Canada, 2014). Though the emission factor has been estimated in the inventory based on 2006 IPCC guideline for different sources, doubt to the accuracy of the estimated data has been raised by researchers (VanderZaag et al., 2014). The inventory itself has reported an uncertainty of up to 21% for enteric CH_4 emission (Environment Canada, 2014). Thus, the inventory results need to be evaluated. Besides, large variations existed in GHG emissions among different countries, which were partially due to differences in animal production systems, feed types, and nutrient use efficiencies by animals (Lesschen et al., 2011), as well as climate differences. Therefore, there is a need to collect data of GHG emissions at both national and regional levels.

Limited measurements have been carried out to quantify CH_4 and N_2O emissions from dairy facilities. Joo et al. (2015) measured CO_2, CH_4, and N_2O from two naturally ventilated free-stall dairy barns in the USA and investigated the impact of the three related parameters:

* Corresponding author. Mechanical Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, SK, S7N 5A9, Canada.
E-mail address: huiqing.guo@usask.ca (H. Guo).

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temperature (T), relative humidity (RH), and ventilation rate (VR). Saha et al. (2014) revealed the seasonal and diurnal variations of CH_4 emissions from a naturally ventilated dairy building in German. Ngwabie et al. (2014) measured CO_2, CH_4, and N_2O emissions with animal activity and air temperature from February to May for a naturally ventilated dairy building in Sweden. Zhu et al. (2014) estimated CH_4 and N_2O emissions based on their diurnal patterns from a dairy barn in China. In Canada, Ngwabie et al. (2014) measured CH_4, N_2O, and NH_3 emissions from a commercial free-stall dairy barn in Southern Ontario; however, they only considered spring and autumn time. Two other dairy farms in Eastern Ontario were studied by VanderZaag et al. (2014) in autumn and spring, where the whole farm CH_4 emission was quantified, and enteric CH_4 emission and the contribution of manure removal in affecting CH_4 emission were estimated. So far, there is still a lack of sufficient data on CH_4 and N_2O emissions from dairy barns in different regions across Canada, and no GHG data is available for dairy barns in the Canadian Prairies, which is a cold region in Western Canada. For naturally ventilated dairy buildings specifically, which are significantly affected by local climate, acquiring complete profiles of diurnal and seasonal variations in GHG emissions is essential to improve the emission database and modify the estimated results in inventory, to compare the results from different regions, and to further develop proper policy and mitigation strategies.

Hence, this study was conducted at a naturally ventilated free-stall dairy barn in the Canadian Prairies climate aiming to 1) reveal the diurnal variations in cold, warm, and mild seasons and seasonal variations throughout a year for the concentrations and emissions of CO_2, CH_4, and N_2O, and total GHG emissions; 2) compare with the enteric CH_4 emission factor estimated in the inventory (Environment Canada, 2014); 3) compare with the dairy barns from different regions or countries; and 4) examine the influence of parameters (T, RH, and VR) on the three GHG concentrations and emissions.

2. Material and methods

2.1. Description of the dairy barn

The dairy barn was located in Saskatoon, Saskatchewan (106.62° W and 52.13° N), with northeast-southwest orientation. The floor was solid and the area was 3, 230 m^2 with around 112 cows housed, within the normal range of 68–178 cows of dairy farms across Canada (Government of Canada, 2016). The display of the inside is given in Fig. 1. In the free-stall area, 4 pens of 12 cows each were housed on the south side of the barn and were milked in parlour, while 52 stalls were on the north side where cows were milked in the robotic milker or optionally in the parlour. The milk production was averaged at 38 L cow^{-1} day^{-1}. Cows were fed twice daily; one was around 9:30 a.m. and another around 3:00 p.m. The automatic gutter scraper was programmed to clean the alley ways 4 times daily. Manure and all wash water were pumped to a covered slurry tank outside every other day.

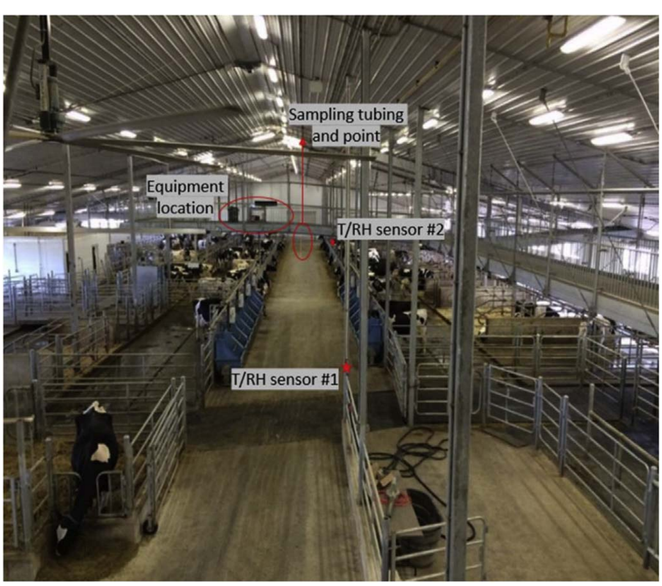

Fig. 1. Inside view of the dairy barn.

The barn was naturally ventilated by adjusting sliding window panels on the side walls in the mild and warm seasons. To increase ventilation, the end-wall door was open on warm days in summer. In the cold season, all the windows and doors were closed and 6 small ceiling exhaust fans were running for ventilation. Besides, there were 3 large-volume recirculation fans installed in the milking parlour area for mixing the room air. Radiant natural gas heaters were used to keep the temperature above freezing in the cold season when necessary.

2.2. Sampling and measurement

There were two types of sampling work performed on the overhead walk-way inside the barn. The sampling point was fixed by Teflon® tubing at a height of 1.8 m above the center area of the floor, as labeled in Fig. 1. The first one was monthly sampling under typical weather condition of Saskatoon for giving the gas emission profiles throughout the year, which was carried out for one selected day (when the weather was typical) in each of the 12 months from February 2015 to January 2016. Due to that cow activity (eating, walking, excretion, milking, etc.) was observed to be low in the early morning, but relatively higher in the late afternoon and early evening, we did sampling in both the early morning and early evening periods considering the impact of cow activity on the generation of GHG. Thus, on those sampling days, CO_2 concentration was measured continuously on site for two hours from 6:00 to 8:00 a.m. and for another two hours from 6:00 to 8:00 p.m. by an CO_2 sensor (K30 CO_2 sensor, CO_2 Meter, USA), with the range of 0–10000 ppm and accuracy of ± 30 ppm ± 3% of measured value. Every 5 min one measured value was recorded by a data logger (CR10X, Campbell Scientific Corporation, Canada). Two replicate air samples during the same morning period and another two during the same evening period were collected using Tedlar® air bags around 7:00 a.m. and 7:00 p.m. for a duration of 30 min, and were transported to the Soil Laboratory at University of Saskatchewan for measurements of CH_4 and N_2O concentrations by Gas Chromatograph (GC). The average of the morning and afternoon results were used to represent the daily mean.

The second one was diurnal sampling for selected two days in the months of February 2015, July 2015, and October 2015, which represented the cold, warm, and mild seasons in Saskatoon. On these sampling days, five diurnal periods were categorized for CH_4 and N_2O measurements, including 6:00 a.m. to 9:00 a.m., 9:00 a.m. to 12:00 p.m., 12:00 p.m. to 3:00 p.m., 3:00 p.m. to 6:00 p.m., and 6:00 p.m. to 9:00 p.m. The concentration of CO_2 was continuously monitored from 6:00 a.m. to 9:00 p.m., while for each of the five diurnal periods, two replicate air samples were collected for a duration of two and a half hours (half an hour for washing bags) and analyzed for CH_4 and N_2O concentrations. The CO_2 sensor was maintained regularly and was calibrated every three months. The GC was calibrated before each measurement. The indoor T (T_{in}) and RH (RH_{in}) were also monitored continuously by two wireless T/RH data loggers (OM-EL-USB-2, Omega, Canada) with −35 °C to 80 °C and 0–100% RH measurement ranges, and ± 0.5 °C and ± 3.5% RH accuracies. The two sensors were installed at the same height of 1.8 m above the floor as the gas sampling point, with one at one-third length of the feed alley (center zone of the barn) and the other at two-thirds (as shown in Fig. 1). The data of outdoor T (T_{out}) and RH (RH_{out}) were downloaded from the website of Environment Canada.