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Measuring methane emissions from two dairy farms: Seasonal and manure-management effects

A.C. VanderZaag[a,*], T.K. Flesch[b], R.L. Desjardins[a], H. Baldé[a], T. Wright[c]

[a] Agriculture and Agri-Food Canada, Science and Technology Branch, 960 Carling Avenue, Ottawa, ON, Canada K1A 0C6
[b] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB, Canada T6G 2H4
[c] Ontario Ministry of Agriculture and Food, Guelph, ON, Canada N1G 2W1

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ABSTRACT

There is a need to improve the understanding of methane (CH_4) emissions on multiple spatial and temporal scales, and on a sector basis. Livestock are significant contributors to the CH_4 budget, with emissions coming from enteric fermentation by ruminants and management of liquid manure. Inventory estimates for methane emissions are based on methodology that needs to be verified with actual on-farm measurements. Responding to these needs, the objectives of this study were to apply the backward Lagrangian Stochastic (bLS) technique on small dairy farms (50-100 lactating cows) and to examine its suitability to determine CH_4 emissions from whole farms and partition emissions from cattle and manure. Measurement campaigns were selected to characterize the emission response to farm management activities and seasonal changes. At both farms the whole-farm emission rate was measured when the liquid manure storages were either full or emptied. Emissions from manure were substantial, and in the fall when the manure storage was full, 60% of the whole farm emissions came from the manure storage. Substantial seasonal differences in whole-farm emissions were observed, with fall season emissions being ~40% higher than in the spring due to much higher manure emissions in the fall (673 g lactating-cow^{-1} d^{-1}) than the spring (249 g lactating-cow^{-1} d^{-1}). Peak emissions from stored manure were 47 kg CH_4 h^{-1}, (730 g lactating-cow^{-1} h^{-1}) during agitation. The enteric emission rate from the animals (after subtracting estimated barn floor emissions) showed clear diurnal variation and on a daily basis was similar for both seasons, ranging between 270 and 380 g lactating cow^{-1} d^{-1}. Implied Y_m values were lower than the IPCC default value. Methane emissions from manure exhibited pronounced temporal variation on multiple time-frames and as a result, more research is needed to fully describe annual CH_4 emissions from liquid manure management.

1. Introduction

Methane (CH_4) is an important greenhouse gas with a global warming potential 25 times greater than CO_2 (IPCC AR4, Forster et al., 2007), and a short atmospheric lifetime which means reductions in CH_4 emissions yield climatic benefits quickly (Dlugokencky et al., 2011). Although global methane emissions are thought to be well constrained between 500 and 600 Tg CH_4 yr^{-1}, there is a need to improve the understanding of emissions on national, regional, and sector levels (Dlugokencky et al., 2011). A recent comprehensive analysis of anthropogenic methane emissions in the United States using inverse modeling, showed that emission inventories (USEPA and EDGAR) underestimated CH_4 emissions on a national-scale by factors of more than 1.5 (Miller et al., 2013), owing to larger than expected emissions from the fossil fuel and livestock sectors. The study concluded that CH_4 emissions from livestock throughout the country are approximately double the amount estimated in the inventory.

The main sources of CH_4 in the livestock sector are enteric fermentation by ruminants and manure management from all livestock, especially when managed as liquid manure. In Canada's greenhouse gas inventory, CH_4 contributes 43% of all agricultural greenhouse gas emissions (Environment Canada, 2010). A recent uncertainty analysis of the Canadian livestock emission model used in the National Inventory (based on IPCC Tier 2) identified high uncertainty for methane emissions from enteric fermentation (38%) and especially manure-management (73%) (Karimi-Zindashty et al., 2012).

* Corresponding author. Tel.: +1 6137591254.
E-mail addresses: andy.vanderzaag@agr.gc.ca (A.C. VanderZaag), tflesch@ualberta.ca (T.K. Flesch), ray.desjardins@agr.gc.ca (R.L. Desjardins), hambaliou.balde@agr.gc.ca (H. Baldé), tom.wright@ontario.ca (T. Wright).

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Emission measurements are therefore needed for model verification, and to reconcile bottom-up and top-down emission estimates. These measurements should ideally be conducted at the farm scale in order to capture the reality of a farm as an integrated, multi-component emission source; and duplicated in different regions to understand the effect of climate and regional management on emissions. Measurements at multiple scales are also useful, and the work described in this paper is part of a larger study combining farm-scale and regional-scale measurements with aircraft. Aircraft-based measurements have the advantage of producing data on a large spatial scale, but the number of flights is limited due to cost. This is a crucial concern as CH_4 emissions from liquid manure can vary substantially over time due to changing storage volumes, and episodes of ebullition and agitation (e.g., Rodhe et al., 2012; Wood et al., 2013). There can also be substantial diurnal variability in enteric emissions (e.g., Jungbluth et al., 2001).

A challenge for obtaining CH_4 emission measurements from dairy farms is that each farm contains multiple sources that should be partitioned (enteric emissions from cattle, and emissions from manure). In prior work, CH_4 measurements have focused on single parts of the farm, e.g., the barn and cattle (e.g., Kinsman et al., 1995; Ngwabie et al., 2009), grazing cattle (e.g., Ulyatt et al., 2002; Dini et al., 2012), or the manure storage (Kaharabata et al., 1998; Amon et al., 2006; Sneath et al., 2006). In some cases, both enteric and manure emissions have been estimated, e.g., using chambers for enteric emissions, and covered barrels for manure emissions (Aguerre et al., 2011a,b). Few studies, however, have measured CH_4 emissions from both cattle and manure management on the same farm. Leytem et al. (2011, 2013) used the backward Lagrangian stochastic technique (bLS) to measure CH_4 emissions at very large dairies in the United States (Idaho). These farms contained ∼10,000 milking cows and ∼2000 dry cows, covered ∼80 ha of land, had horizontal extent on the order of 1000 m, wastewater storage 10 ha in size, and had emission rates >1000 kg h^{-1} from the facility during some seasons. They partitioned the emissions between the animals and the liquid manure management system (wastewater ponds), observing that the wastewater pond was the dominant source of CH_4 emissions during most of the year (Leytem et al., 2011).

As in parts of Europe and the Northeastern United States, dairy farms in Canada are relatively small – most have less than 100 lactating cows (Sheppard et al., 2011) – and tend to be compact with barns and manure storages usually situated within ∼10 m. This presents a challenge for measuring CH_4 emissions because of the small concentration rise that must be measured (due to smaller emission rates and sensor positioning downwind of buildings), and a challenge to partition the sources because of close proximity of different source types. Several researchers have conceptually evaluated the potential to use bLS for measuring emissions from small dairy farms (Gao et al., 2009, 2010) or partitioned into manure and enteric sources (e.g., McGinn, 2013), and it has been used to measure emissions from whole dairy farms without measuring enteric and manure sources independently (McGinn and Beauchemin, 2012). Certainly the bLS technique has been used to measure CH_4 emissions from groups of grazing animals (Laubach and Kelliher, 2005; McGinn et al., 2009; Tomkins et al., 2011; Laubach et al., 2013); however, significant complexity is added when the animals are housed in buildings because of the altered turbulence regime. Therefore, when buildings are present, sensors must be positioned further downwind where turbulence is restored, but at the expense of a smaller concentration rise.

Therefore the objectives of this study were to apply the bLS technique on small dairy farms (50–100 lactating cows) and to examine its suitability to determine CH_4 emissions from whole farm and component emissions. Specifically, we examine whether emissions could be partitioned consistently by measuring the manure and barns separately (with suitable farm configuration), and by measuring before and after manure removal. Finally, to improve the understanding of CH_4 emission magnitude and temporal changes (which we hypothesized would be large) by observing diurnal, seasonal, and manure-management effects.

2. Materials and methods

2.1. Experimental sites and farm characteristics

The study was conducted on two typical dairy farms (noted A and B; Fig. 1) in Prescott–Russell County of Eastern Ontario—a highly productive dairy region. Each farm contained Holstein-Friesian lactating cows all replacement animals including dry cows, heifers and calves.

Herd structure changed slightly over time, but on average, Farm A had 63 lactating cows (average bodyweight 700 kg), 12 dry cows, 52 heifers, and 15 calves (0 bulls), for a total of 149 Animal Units (AU = 500 kg live weight). The lactating cows were fed a total mixed ration (TMR) twice daily totalling 21 kg of dry matter per day. On an as-fed basis, the typical ration contained 27% corn silage, 27% alfalfa haylage, 19% alfalfa bale-silage, 18% high moisture grain corn, 4% corn distillers, and 5% supplements (including canola, cotton seed meal, soy meal, and vitamins). Lactating cows were housed in a naturally-ventilated barn with sand bedding. Liquid manure and bedding was collected in alleys and scraped to a collection pit which was then pumped daily to an earthen manure storage. The manure storage was bottom-loaded and was <25% covered by a thin floating crust in the fall, and there was no crust in the spring. A second barn housed all other animals on straw bedding with daily solid manure removal taken off site in a manure spreader. Non-lactating cows received the same diet as lactating cows but half as much. This farm produced, on average, 30 kg of milk (3.9% fat, 3.4% protein, =32.8 kg Fat and Protein Corrected Milk; FAO, 2010) per lactating cow per day (based on measurements by the dairy herd management service), and milked twice daily, at approx. 11:00 and 19:00.

Farm B had, on average, 98 lactating cows (750 kg), 15 dry cows, 90 heifers, 18 calves, and 1 bull, for a total of 245 AU. Lactating cows were fed a TMR twice daily between 8:00 and 9:00 and between 17:00 and 18:00. The daily dry matter intake per cow was between 25 kg (spring) and 26 kg (fall). The TMR typically contained, as-fed, 40% corn silage, 36% haylage, 11% high moisture grain corn, 7% protein supplement, 2% hay, 2% roasted soybeans, and 1% feed additives. Lactating cows were kept on sand bedding in a large naturally ventilated building which was attached to a building containing the milking parlor, several cows, and a bull. Liquid manure was scraped to an under-barn pit that was transferred daily (typically 8:30 and 19:30) into one of two outdoor storages, either a concrete tank or earthen basin. The transferred manure was surface loaded and there was negligible surface crusting. Another barn housed heifers and dry cows on straw bedding producing semi-solid manure transferred with a positive-displacement pump to an earthen basin. The fourth small barn housed calves. Several other barns were on the property containing equipment, straw, hay, etc. In the fall this farm milked 98 cows three times per day at 6 am, 2 pm and 8 pm and milk production was, on average, 38 kg per lactating cow per day (based on milk shipments). In the spring the farm changed to milking twice per day at 6 am and 6 pm and milk production was 30 kg per cow per day. The number of lactating cows gradually increased in the spring to compensate for the reduced milking frequency. Milk fat and protein content were consistent between spring and fall, averaging 4.1% fat and 3.1% protein.

In addition to having similar management, several criteria were used to select the farms: (i) flat terrain, meeting the bLS