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Methane and nitrous oxide analyzer comparison and emissions from dairy freestall barns with manure flushing and scraping

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HIGHLIGHTS

- Gas analyzer type significantly affected greenhouse gas emission estimates.
- Average daily mean methane emissions were approximately 390 g cow^{-1} d^{-1}.
- Average daily mean nitrous oxide emissions were approximately 970 mg cow^{-1} d^{-1}.

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ABSTRACT

Continuous methane (CH_4) and nitrous oxide (N_2O) emission measurements were conducted at two crossflow-ventilated dairy freestall barns located in the state of Wisconsin, USA during a 19-month period from 2008 to 2010. The two cross-flow mechanically ventilated buildings (275 and 375 cow capacities) were evaluated in the National Air Emissions Monitoring Study. In September of 2008, the barns' manure collection systems were changed from flushing open gutter using manure basin effluent to a tractor scrape. A photoacoustic multi-gas analyzer (PAMGA) and a direct methane/non-methane hydrocarbon analyzer (GC-FID) provided side-by-side measurements of methane (CH_4) for 13 months. The PAMGA also measured nitrous oxide (N_2O), and a side-by-side comparison was performed with a gas-filter correlation analyzer (GFC) for six months. Barn ventilation rates were measured by recording run times of the 127-cm diameter exhaust fans. All 125 belt-driven exhaust fans were identical, and in situ airflow measurements using the Fan Assessment Numeration System (FANS) were conducted once at the beginning and twice during the test. Daily CH_4 and N_2O emission rates were calculated over approximately 19 and 6 month periods respectively, on per barn, head, animal unit, floor area space and barn capacity bases. The differences between the analyzers' concentration measurements were compared in conjunction with water vapor and other gases. The analyzer type had a significant impact on the average CH_4 emission rate ($p < 0.001$) and the average N_2O emission rate ($p < 0.05$). Based on the CH_4 measurements with the GC-FID, average daily mean CH_4 emissions were approximately 290 g AU^{-1} d^{-1} (390 g cow^{-1} d^{-1}) with very limited seasonal effects. Little variation was observed in CH_4 emission rates before and after the change in manure collection method, suggesting that most of the CH_4 emissions were enteric losses directly from the cows. The average daily mean N_2O emission rates based on the GFC were very low, with an approximate rate of only 690 mg AU^{-1} d^{-1} (970 mg cow^{-1} d^{-1}). The change in manure collection had no apparent effect on N_2O emission.

1. Introduction

Animal agriculture is a source of greenhouse gases (GHG), which are generated at animal production operations from enteric fermentation, confinement barns, manure storage and treatment systems, and manure applied to land for crop nutrients. Although an earlier United Nation's Food and Agriculture Organization (FAO) study (Steinfeld et al., 2006) estimated that the livestock sector

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produces 18% of the world's GHG emissions as measured in carbon dioxide (CO_2) equivalents, more recent estimates for the United States are only 3% of the total GHG emissions (Pitesky et al., 2009). The GHG emissions from animal agriculture can be divided into emissions of CO_2, methane (CH_4), and nitrous oxide (N_2O). The largest source of CO_2 emissions from animal buildings is respiration which is considered a net zero source since it is part of the continuous CO_2 cycling between plants and animals. Thus, CH_4 and N_2O are the primary GHGs of interest for animal buildings and it is well known that they are respectively 21 and 310 times more potent than CO_2 in their 100-year global warming potential (IPCC, 2007). For livestock housing, EPA (2009a) designated enteric fermentation and manure management as two key source categories for overall livestock-related GHG emissions, although recent rules have focused on manure management-related CH_4 and N_2O release only (EPA, 2009b).

Life cycle assessments suggest that the US dairy industry produces approximately 2% of the total US GHG emissions (Thoma et al., 2013). It is recognized, however, that feed, cattle and manure management, and climate influence emissions at the farm level (Pitesky et al., 2009; Li et al., 2012). Sedorovich et al. (2007) presented a review of GHG from dairy farms and reported average CH_4 and N_2O emissions of 54 kg AU^{-1} yr^{-1} (148 g AU^{-1} d^{-1}) and 0.3 kg AU^{-1} yr^{-1} (0.8 g AU^{-1} d^{-1}) from dairy housing facilities, respectively. In this review, four studies measured methane emissions that varied from 1 to 100 kg AU^{-1} yr^{-1} (2.7–270 g AU^{-1} d^{-1}) while three reported on N_2O emissions that ranged from 0 to 0.6 kg AU^{-1} yr^{-1} (0–1.6 g AU^{-1} d^{-1}). Within these studies, Amon et al. (2001) measured 194 g CH_4 AU^{-1} d^{-1} and 0.6 g N_2O AU^{-1} d^{-1} in a tie-stall dairy barn that included the cows and manure while Sneath et al. (1997) measured 320 g CH_4 AU^{-1} d^{-1} and 0.6 g N_2O AU^{-1} d^{-1} in a loose housing dairy facility. Another study in the review, Jungbluth et al. (2001), reported rates of 223 g CH_4 AU^{-1} d^{-1} and 1.6 g N_2O AU^{-1} d^{-1} from a dairy building with both lactating and dry cows.

The challenges with gas concentration monitoring in livestock and poultry housing include an often moist environment, many gases present, and concentrations that can change seasonally by a factor of 10. In the studies mentioned above, CH_4 concentrations were measured with Fourier transform infrared (FTIR) spectroscopy (Amon et al., 2001), photoacoustic infrared (PIR) spectroscopy (Jungbluth et al., 2001) or with gas chromatography (GC) (Sneath et al., 1997). Nitrous oxide concentrations were also measured with FTIR and PIR, although Jungbluth et al. (2001) switched from PIR spectroscopy to GC since N_2O concentrations were too low to detect differences between ambient and barn exhaust levels with the PIR unit.

The PIR method relies on measuring the absorption of infrared spectra characteristic to a specific gas. However, the spectra of several gases may overlap and result in measurement errors if the interference is not considered (Zhao et al., 2012). In a laboratory setting, Zhao et al. (2012) showed that the internal cross-compensation algorithm of a photoacoustic multi-gas analyzer (PAMGA) that uses PIR eliminated interferences between target gases, but was insufficient to eliminate interferences of non-target gases on target gases and had potential to cause secondary interferences. In the tests by Zhao et al. (2012), the interference of water vapor was negligible for N_2O, but CH_4 was not included in the PAMGA filter configuration for the water vapor test. In broiler and dairy housing settings, Hassouna et al. (2013) demonstrated an overestimation of nitrous oxide and an underestimation of CH_4 resulting from non-compensated interferences with a PAMGA.

Current and long-term quality-assured CH_4 and N_2O emission measurement data are needed to strengthen existing databases of GHG emissions from dairy systems. This study first describes an on-farm side-by-side comparison of CH_4 and N_2O analyzer types. Second, the study describes the CH_4 and N_2O emission measurements that add to the database of emission information for commercial Midwest US dairies.

2. Materials and methods

2.1. Farm characteristics

Two freestall dairy barns located on a farm in western Wisconsin were monitored for carbon dioxide (CO_2), ammonia (NH_3), hydrogen sulfide (H_2S), and particulate matter (PM) emissions as part of the National Air Emissions Monitoring Study (Heber et al., 2008) and CH_4 and N_2O emissions as a supplemental greenhouse gas monitoring effort. The barns were constructed in 1990 (barn 1) and 1994 (barn 2) at the northern edge of the farm (Fig. 1). Barn 1 was 93 m long × 28 m wide with 4-m high sidewalls at the center cross alley, and four rows of stalls. Barn 2, located 29 m north of barn 1, was 107 m long by 30 m wide with 4 m high sidewalls at the center cross alley, and five rows of stalls. The floor of each barn was sloped 1.5% to the center cross alley to accommodate manure flushing. The capacities of barns 1 and 2 were 275 and 375 Holstein cows, respectively. The inventory data from 13 September 2007 to 31 October 2008 was estimated from the weekly average inventories supplied by the producer. Total live mass was calculated based on an estimated average cow mass of 703 kg.

The freestall barns were connected by a covered breezeway equipped with manually adjusted rollup curtains along each side that were closed year around except for emergency ventilation in the case of power outages. The parlor was connected to the south side of barn 1. The milking center consisted of a holding area and a double-10 Boumatic herringbone parlor, with automatic computer identification of each cow, and automatic milk weight measurement. Cows were milked three times per day. Average milk production between October of 2008 and November of 2009 was 31 L cow^{-1} d^{-1} with a range of 27–34 L cow^{-1} d^{-1} (Cortus et al., 2010). A three-stage manure storage basin system and a forage storage area or bunker were located west and east of the freestall barns and milking center, respectively (Fig. 1). The feed bunker was nearly doubled in size in 2008 as shown by the dashed lines in Fig. 1.

Initially the stalls in barns 1 and 2 had sawdust-filled rubber mattresses, which were topped with wood shavings (beginning of study through mid-December of 2007, and after mid-May of 2008)

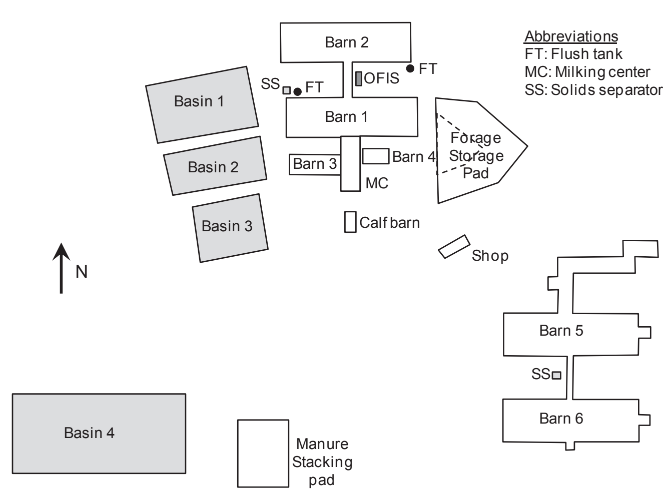

Fig. 1. Layout of dairy farm showing locations of monitored barns 1 and 2.