Atmospheric Environment 83 (2014) 245–253

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Characterizing CH_4 and N_2O emissions from an intensive dairy operation in summer and fall in China

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HIGHLIGHTS

- Methane and N_2O rates for milking cows and heifers in China's intensive dairy lots were provided.
- Intensive dairy production in China had lower methane conversion factor.
- Intensive dairy production in China had lower methane emission intensity.
- Methane emission intensity of intensive dairy operations in China is close to developed countries.

ARTICLE INFO

Article history:
Received 14 July 2013
Received in revised form
30 October 2013
Accepted 1 November 2013

Keywords:
Milking cow
Heifer
Methane
Nitrous oxide
Emission intensity

ABSTRACT

Evaluation of the global warming potential of the dairy industry both in China and globally necessitates reliable characterization of CH_4 and N_2O emissions. However, CH_4 and N_2O emissions from dairy operations differ with feeds, herd structures and manure management practices, and the lack of N_2O and CH_4 emission measurements for China, especially for intensive dairy operations, causes substantial uncertainty in accounting for GHGs from dairy operation both in China and globally. In this study, CH_4 and N_2O emissions during summer to fall period from an intensive feedlot in China were characterized to fill the data gap. The diurnal CH_4 emission patterns for milking cows and heifers were driven by the feeding activities and the diurnal N_2O patterns by the diurnal changes in temperature. The CH_4 emission rates of 397 g $head^{-1}$ d^{-1} (23.63 L CH_4 kg^{-1} milk) (in summer) and 279 g $head^{-1}$ d^{-1} (in fall) for milking cows and heifers accounted for 5.17% and 7.68% of their daily gross energy intakes, whereas the N_2O emission rates of 36.7 g $head^{-1}$ d^{-1} (0.85 L N_2O kg^{-1} milk) for milking cows and 24.2 g $head^{-1}$ d^{-1} for heifers accounted for 4.25% and 6.86% of the daily feed N intake. The CH_4 conversion factor and CH_4 emission intensity in the measurement season for intensive dairy operations in China are lower than those for collective operations in China, and the CH_4 emission intensity is similar to those in developed countries.

1. Introduction

Chinese dairy industry is considered an important contributor to the global greenhouse gas budget, but the present estimates of N_2O and CH_4 emissions from the Chinese dairy industry are very uncertain (Zhou et al., 2007) because of the inherent uncertainties associated with emission rates (Crosson et al., 2011). Therefore, efforts to quantify the N_2O and CH_4 emissions from dairy operations with various feeds, herd compositions and manure management practices are highly needed.

Nitrous oxide is a major contributor to the GHGs budget of dairy farms (Schils et al., 2006). For instance, Chadwick et al. (1998) estimated an emission rate of 17.6 kg N_2O $animal^{-1}$ yr^{-1} for a dairy housing and manure management system, and N_2O emission rates for dairy open lots reached at 12.05 kg N_2O $animal^{-1}$ yr^{-1} (Leytem et al., 2010). Meanwhile, low or no N_2O from dairy operations was also found (Hamilton et al., 2010; Bjorneberg et al., 2009). Clearly, N_2O emissions from dairy operations vary greatly, and few studies of N_2O emissions from dairy production facilities have been completed in China. Therefore, quantifying N_2O emissions from dairy operations in China is necessary to accurately estimate the global warming potential (GWP) and the production efficiency of the dairy industry and identify mitigation practices (Luo et al., 2010).

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http://dx.doi.org/10.1016/j.atmosenv.2013.11.001

Methane emissions are also a major contributor to the GHG budget of dairy operations. Studies have demonstrated that milking cows and heifers generally have different CH_4 emission rates. For example, enteric CH_4 emissions for milking cows might range from 118 to 146 kg head^{-1} yr^{-1} (Grainger et al., 2007; Laubach and Kelliher, 2005), whereas the CH_4 emissions from heifers might vary from 32 to 83 kg head^{-1} yr^{-1} (Beauchemin and McGinn, 2006; DeRamus et al., 2003). In China, approximately 60% of the dairy population is milking cows, and the remainder is heifers. Previous studies in China only provided the overall emission rates of milking cows and heifers (Gao et al., 2011a,b) because they were managed in the same feedlots. The great difference in CH_4 emissions between milking cows and heifers indicated the importance of estimating the individual emission rates for these animals. In addition, these CH_4 emission rates were for dairy operations with an average milk production of approximately 5 t (approximately the average level in China). But improving the feed quality may both enhance milk production and decrease CH_4 emission intensities (Boadi et al., 2004; Lovett et al., 2005). Therefore, validation of this relationship between milk production and CH_4 emissions from high milk production operations is required.

Overall, mitigation practices should always be evaluated in a whole farm system context and account for the total greenhouse gas emissions including CH_4, N_2O and CO_2. For example, Jarvis et al. (1996) found that changing the N management practices reduced N_2O release by 70%, whereas the effects on CH_4 emissions were relatively small. Therefore, decreasing N losses per unit of animal production and achieving a tighter N cycle are potential strategies to improve efficiency and reduce GHG emissions (Luo et al., 2010).

In previous studies, open-path lasers have been widely used to quantify gas emissions from animal production facilities (Gao et al., 2011a,b; Bjorneberg et al., 2009; Laubach and Kelliher, 2005). However, sampling tubing with a certain number of inlets can also be used to obtain line-average concentrations (Denmead et al., 1998; Harper et al., 1999; McGinn et al., 2006). Therefore, in this study, this sampling system was adapted to work with an automatic control unit to collect air samples in an intensive dairy operation (7–8 t milk cow^{-1} yr^{-1}) along a time series in 30-min intervals. The measured CH_4 and N_2O concentrations were used in an inverse-dispersion model to quantify the CH_4 and N_2O emissions from a dairy feedlot in northern China.

The objective of this study was to (1) estimate the emission rates of CH_4 and N_2O for milking cows and heifers based on the diurnal pattern of CH_4 and N_2O emissions, (2) estimate their emission intensities based on their milk production, and (3) estimate the conversion factors (i.e., the losses of feed input) of CH_4 and N_2O for intensive dairy operations.

2. Materials and methods

2.1. Description of the experimental site

In this study, the CH_4 and N_2O emissions of an intensive dairy operation[1] with a mean milk production of ∼8 t cow^{-1} yr^{-1} (approximately 140 km south to Beijing) were quantified in 2012. There were no significant CH_4 and N_2O emission sources such as animal operations existed around the experimental farm. The full capacity was approximately 900 dairy cows. However, during the measurement period, the number of cattle was approximately 700 Holstein dairy cattle including milking cows (408 on average), dry cows (27 on average) and heifers (265 on average) (calves excluded).

Within this dairy farm, the milking cows and heifers were separately managed in different feedlots (Fig. 1). There were 4 open lots holding approximately 408 dairy cows, and the stocking density was approximately 40.64 m^2 cow^{-1}. Meanwhile, the heifers and dry cows were held in the other 4 open lots, with a stocking density of 40.16 m^2 head^{-1}. Approximately 30 calves were held in an open lot south of the farm. The milking hall and dairy hospital were both located east of the farm. In addition, the floor of the animal feedlots was earthen, and the manure in the feedlots was removed periodically from 1 to 4 weeks. The manure collected from the dairy pens was sold to local farmers. The field campaigns to measure CH_4 and N_2O emissions were performed in the milking cow pens and the heifer pens, and the emissions from the dairy hospital and milking hall were excluded due to their minor contributions to the total emissions.

During the measurement period, milking cows and heifers were fed three times a day, at 6:30 am, 13:30 pm and 20:30 pm, and were milked three times a day, at 6:30 am, 13:30 pm and 20:00 pm, with an average fat and protein corrected milk (FPCM) production of 23 kg cow^{-1} d^{-1}. A total mixed ration (TMR) primarily including corn silage, guinea grass, alfalfa, wheat bran, soybean meal, cottonseed, sunflower seed, sesame meal, sugar beet pulp and corn was used to feed the dairy cows and heifers, and the compositions of the feeds are shown in Table 1. The gross energies (GE) for the dairy cows and heifers provided by the TMR were 397 MJ head^{-1} d^{-1} and 183 MJ head^{-1} d^{-1}, respectively.

2.2. Gas sampling and measurement

In this study, air samples over dairy feedlots were taken with an automatic sampling system. This system consisted of sampling tubing (ST), a mixing chamber (MC), a center control unit (CCU), solenoid valves (SV) and sample bags (SB). When this system was running, in principle, the air over the feedlots was pumped through 9 inlets, evenly spaced along the ST, and then was fully mixed in the MC (Fig. 2). Under the control of the CCU, the mixed air was pumped into different aluminum sampling bags for 30 min.

The path length of the sampling tubing was 80 m, and the concentration of the mixed air represented the line-average concentration along this path. The flow rates of the 9 inlets along the polyethylene sampling tubing (6-mm i.d.) were adjusted to approximately 3 L min^{-1} using flow-hold valves. In total, the average flow rate of the sampling tubing was approximately 30 L.

A mixing chamber of approximately 2 L was employed in this system to reduce the uncertainty of this sampling system and to provide representative air samples. On top of the mixing chamber, there was one inlet connected to the sampling tubing and were two outlets: one connected to the solenoid valves for sample collection and the other outlet open for waste gas release. The flow rate of 30 L min^{-1} was equivalent to approximately 15 volumes of the mixing chamber each minute; thus, the residual air from the previous collecting period had a very minor impact on the following one. The flow rate from the mixing chamber to the sampling bag through polyethylene tubing (inner diameter 3 mm) was approximately 60 mL min^{-1}. With this configuration, approximately 0.2% of the air pumped over the feedlots was for the concentration measurements. In addition, twenty-four 30-min sampling periods (i.e. the first 30 min in each hour) evenly distributed throughout the day were programmed into the CCU to capture the diurnal variations in the CH_4 and N_2O emission rates. The obtained 24 air samples were transported to the laboratory and analyzed using a gas chromatograph (GC, Agilent 6280, USA) within 48 h. The

[1] Intensive dairy operation defined in the Yearbook of China Dairy Industry (2008) are those characterized with a herd of over 100 heads, milk production over 6.6 t head^{-1} yr^{-1} (milk fat and protein contents were over 3.62% and 2.94%) and the use of TMR technology. The selected dairy operation met these standards.