Quantification of Methane Emissions from Indoor-Fed Fogera Dairy Cows Using Laser Methane Detector

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Abstract

Portable laser methane detectors (LMDs) may be an economical means of estimating CH_4 emissions from ruminants. Here, we validated an LMD-based approach and then used that approach to evaluate CH_4 emissions from indigenous dairy cows in a dryland area of Ethiopia. First, we validated our LMD-based approach in Simmental crossbred beef cattle (n = 2) housed in respiration chambers and fed either a high- or low-concentrate diet. We found that the exhaled air CH_4 concentrations measured by LMD were linearly correlated with the CH_4 emissions determined by infrared-absorption-based gas analyzer ($r^2 = 0.55$). On the basis of these findings, we constructed an estimation equation to determine CH_4 emissions (y, mg min^{-1}) from LMD CH_4 concentrations (x, ppm m) as $y = 0.4259x + 38.61$. Next, we used our validated LMD approach to examine CH_4 emissions in Fogera dairy cows grazed for 8 h d^{-1} (GG, $n = 4$), fed indoors on natural-grassland hay (CG1, $n = 4$), or fed indoors on Napier-grass (*Pennisetum purpureum*) hay (CG2, $n = 4$). All the cows were supplemented with concentrate feed. Daily CH_4 emissions did not differ among the three groups; however, a numerically greater milk yield was obtained from the CG2 cows than from the GG cows, suggesting that Napier-grass hay might be better than natural-grassland hay for indoor feeding. The CG1 cows had higher CH_4 emissions per feed intake than the other groups, without significant increases in milk yield and body-weight gain, suggesting that natural-grassland hay cannot be recommended for indoor-fed cows. These findings demonstrate the potential of using LMDs to rapidly and economically evaluate feeding regimens for dairy cows in areas under financial constraint, while taking CH_4 emissions into consideration.

Introduction

There are about 1.5 billion cattle worldwide, which are a major source of greenhouse gas emissions. 18% of greenhouse gas emissions due to anthropogenic activities are attributable to livestock farming. More than 70% of the gastrointestinal CH_4 emissions in 2018 are attributed to cattle (FAO 2020). To reduce the greenhouse gas emissions associated with livestock farming, it will be important to develop methods of controlling the CH_4 produced by fermentation processes in the gastrointestinal tracts of ruminants.

An estimated 73% of pasture and rangeland in the world's drylands has been degraded, mostly as a result of overgrazing (O'Mara 2011). Ethiopia is one such country being impacted by serious soil erosion. To mitigate the soil erosion, grazing is restricted and indoor-fed animal production is encouraged in the country; to promote indoor feeding as an alternative to conventional grazing, accurate estimates of CH_4 production from ruminants are necessary. However, various methods developed for measuring enteric CH_4 production by ruminants (*i.e.*, respiration chambers for open- or closed-circuit calorimetry, SF_6 tracer gas technique, etc.) have the merits and demerits for their use. Cheaper and simpler methods of measuring CH_4 with acceptable efficiency and precision are needed.

LMDs have been proposed as a potential economical means of estimating CH_4 emissions without disturbing the normal activities of cattle (Chagunda *et al.* 2009). The CH_4 concentrations in the exhaled air of cattle, as measured by LMD, were correlated with those measured by using respiration chambers (Ricci *et al.* 2014). However, in such previous studies, the LMD values were obtained after first measuring the CH_4 emissions in respiration chambers using the same animals. Further validation of the LMD approach by using values recorded simultaneously by means of an already validated method (*e.g.*, respiration chambers) is needed before LMDs are applied in feeding trials examining CH_4 emissions.

We examined the use of an LMD-based approach to estimate CH_4 emissions through two in-*vivo* experiments for cattle. First, we validated our LMD-based approach against a respiration chamber-based approach in Simmental crossbred beef cattle (experiment 1 [exp 1]). Then, we performed a feeding trial to examine the effects of indoor feeding on the CH_4 emissions and lactation performance of Fogera dairy cows (experiment 2 [exp 2]).

Methods and Study Site

Validation of CH4 emissions estimated by LMD against those measured by infrared-absorption-based gas analyzer in an indirect open-circuit respiration calorimeter chamber (exp 1)

The CH_4 emissions of two Simmental crossbred male beef cattle (body weight [BW], 224 and 260 kg) were estimated by both respiration chamber and LMD at Linze Research Station, Lanzhou University, China. Each animal was provided one of two diets throughout the 12-d experimental period: high- and low- concentrate diet (HC and LC), both of which comprised alfalfa hay, wheat straw, and commercial concentrate feed.

Each animal was transferred after 5-d cubicle accommodation to an indirect open-circuit respiration calorimeter chamber. The CH_4 concentration in the exhaust air from each chamber was measured by using the gas analyzer every 15 min for two 12-h periods (18:00−06:00). For the same periods, the CH_4 concentration (LMD-CH_4) was measured with an LMD once an hour; the LMD-CH_4 measurement was at 0.5-s intervals by using the LMD held at a distance of 0.6−1.2 m from the animal's nostrils.

Assuming a double normal distribution (Figure 1), each of the LMD-CH_4 datasets was split into two sub-datasets for eructation and for respiration, and five statistical parameters were calculated for each dataset: the means and SDs for LMD-CH_4 values within each of the two sub-datasets, and the ratio distribution for the two sub-datasets that achieved the highest likelihood. 34 LMD-CH_4 datasets were separated into two normal distributions. Each of the 34 datasets contained three mean values: ones for the two sub-datasets (for respiration and eructation) and the other for the combined sub-datasets (before their separation into respiration and eructation). Each of the three mean-value groups was then regressed by using the least-squares method against the dataset obtained with the gas analyzer at 0, 30, 60, and 75 min after the LMD-CH_4 measurement. By using the pair of datasets with the highest correlation coefficient, an equation to estimate daily CH_4 emissions using the LMD values was formulated.

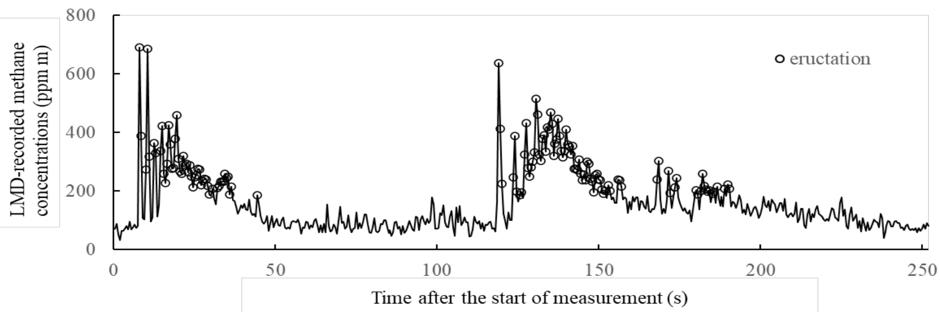

Figure 1. Representative CH_4 concentrations of Simmental crossbred beef cattle in respiration chambers, as determined by LMD (exp 1). Values with ○ were statistically separated from the values without ○, and were considered to represent CH_4 emissions by eructation.

Comparison of CH₄ emissions from grazing versus indoor-fed dairy cows (exp 2)

A feeding trial for indigenous cows (Fogera breed) was performed for 24 d (21 Aug.−13 Sept. 2019) at Andassa Livestock Research Center, Ethiopia (annual rainfall, 1434 mm; average daily temperature, 8.8−29.5 °C). Twelve multiparous dairy cows (BW, 227.4 ± 23.1 kg) in mid-lactation (107 ± 27 d in milk) were allocated into three feeding groups: a grazing group (GG, *n* = 4; control) and two indoor-feeding groups fed with natural-grassland hay (CG1, *n* = 4) or with Napier-grass (*Pennisetum purpureum*) hay (CG2, *n* = 4). Species used for the natural-grassland hay in CG1 was similar the ones in pasturelands used for GG. Napier grass was examined because it was a major forage in the drylands of Ethiopia, owing to its high dry-matter (DM) yield (ILRI 2018) and high crude-protein (CP) content (Rambau *et al.* 2016). All three diets were designed to provide sufficient net energy and CP for a 3-kg daily milk yield. The GG cows grazed dairy for 8:00−16:00 were expected to ingest similar amounts of natural-grassland hay as the CG1 cows; no roughage was provided for the GG cows when they were accommodated indoors. All the cows were supplemented with concentrate feed.

As in exp 1, LMD-CH_4 values were recorded for each cow each hour for two periods of 18:00−06:00. 263 LMD-CH_4 datasets were separated into two normal distributions for respiration and eructation. By using the regression equation obtained in exp 1, the mean value of each of the three mean-value groups—for eructation, respiration, or both—was converted into a daily CH_4 emission for each cow. DM digestibility was calculated by using the acid detergent lignin concentrations in the feed and fecal samples as internal markers. For GG cows, ground Cr_2O_3 was mixed with the concentrate feed, and the Cr_2O_3 concentrations in the feed and fecal samples were used as external markers to calculate their DM intake.

Results

Experiment 1

Gas analysis revealed that CH_4 emissions increased immediately after feeding. The CH_4 emissions of the cattle fed HC were higher than those of the cattle fed LC (1.9 vs. 1.5 g $kg^{-0.75}$ BW d^{-1}). The mean-value group comprising the respiration sub-datasets (x) was most significantly correlated with the gas analyzer dataset up to 60 min after the LMD-CH_4 measurement (y, Table 1).

Table 1. Correlation coefficients between the gas analyzer and LMD datasets (exp 1)

	Respiration	Eructation	Overall
Period after the LMD measurement, min			
0	0.20^{**}	0.12	0.12^{*}
0−30	0.34^{***}	0.12^{*}	0.17^{*}
0−60	0.55^{***}	0.22^{**}	0.30^{**}
0−75	0.45^{***}	0.17^{*}	0.22^{**}

*, $0.01 \le p < 0.05$; **, $0.001 \le p < 0.01$; ***, $p < 0.001$.

Experiment 2

The gross-energy intake (GEI) calculated by using a reported equation (NARO 2010) was 88, 77, and 92 MJ d^{-1} for GG, CG1, and CG2. CH_4 emissions per milk yield did not differ among the groups. However, the CH_4 emission per DM intake was significantly higher in CG1 than in the other groups.

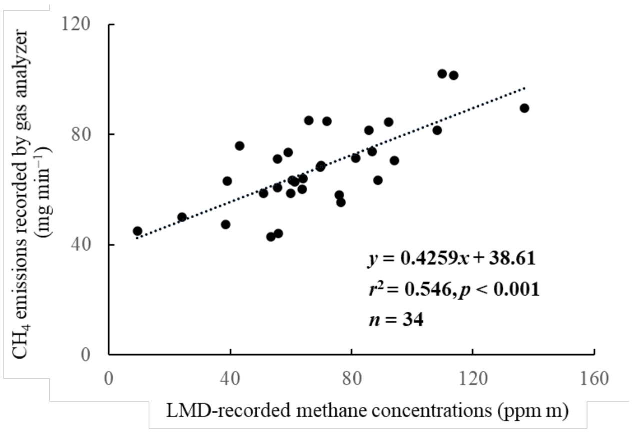

Figure 2. Linear regression of CH_4 concentrations recorded by LMD (x) versus average CH_4 emissions recorded by gas analyzer for 60 min after LMD measurement (y) in exp 1.

Discussion

Correlation of CH_4 emissions estimated by LMD with those measured by gas analyzer in a respiration chamber

More than 80% of the hourly measurement datasets could be used to produce the two normal distributions. The percentage of LMD-CH_4 values categorized into eructation in each of the LMD-CH_4 datasets ranged from 11.7% to 48.3% (exp 1), which was consistent with the previous report (Ricci *et al.* 2014). Each LMD-CH_4 value in the LMD-CH_4 dataset was properly categorized into one of the two sub-datasets.

Higher correlation coefficients obtained by using the respiration sub-datasets than the eructation sub-datasets (Table 1) indicated that respiration was more useful than eructation for quantifying the CH_4 emissions of individual cattle. The respiration sub-datasets were well correlated with the gas-analyzer dataset for 0−60 min after LMD-CH_4 measurement ($r^2 = 0.55$; Table 1, Figure 2). Based on this dataset, we constructed an equation to estimate the CH_4 emissions in exp 2 as $y = 0.4259x + 38.61$ (y, CH_4 concentration, mg min^{-1}; x, mean of respiration sub-datasets recorded by LMD, ppm m).

Effects of grazing versus indoor feeding on productivity and CH_4 emissions of dairy cows

The higher Napier grass CP concentration (Table 2) than the reported minimum CP concentration (8%) when forage is provided as a sole diet to ruminants (Minson 1980), indicated that this grass could be used as a basal diet for Fogera dairy cows. By contrast, the CP concentration in natural-grassland hay lower than in the Napier grass suggested that natural-grassland hay could not be used as a basal diet.

Table 2. Chemical compositions of the feed ingredients used in exp 2

Feed	Chemical composition, % DM	
	CP	NDF
Natural-grassland hay	4.5	72.1
Napier grass	8.2	68.3
Grazed grass	2.5	77.8

The similarity in the CH_4 emissions per metabolic body size and in the ratios of CH_4 energy to GEI between GG and CG2, and the numerically higher milk yield and BW gain in CG2 than in GG (Table 3) suggested that Napier grass was a suitable forage for indoor feeding. Less fibrous diets with low neutral-detergent-fiber (NDF) concentrations promote dietary passage through the rumen and decrease digestibility (Ichinohe *et al.* 1994). This may explain the decreases in DM digestive coefficients in CG1 and CG2 compared with in GG.

Daily BW gain was insignificant in CG1 but positive in the other groups. Using the data obtained from the tri-axis accelerators attached to GG cows in our other study, we estimated metabolizable energy (ME) required for grazing at 7 MJ d^{-1} and for maintenance at 30 MJ d^{-1} (unpublished): ME requirement for the indoor-fed cow was 19% less than the GG cow. In the current study, the lower DM intake in CG1 than in GG resulted in 12% GEI decrease in CG1 compared with GG; this GEI difference was further calculated as 21% lower ME intake in CG1 than in GG (44 MJ d^{-1} vs. 56 MJ d^{-1}) by using the energy metabolizability estimated in the other study. The decrease in ME intake for CG1 compared with GG—which was more than the decrease acceptable for BW gain—and the comparable milk yield between CG1 and GG might have led to the lack of BW gain in CG1. Together with the lower DM digestibility in CG1 than in GG, these findings suggest that natural-grassland hay is not a suitable feed for indoor feeding.

Table 3. Values for milk-production performance and CH_4 emissions in Fogera dairy cows (exp 2)

Item	GG	CG1	CG2
Feed and nutrient intake			
DM, kg d^{-1}	4.59^{ab}	4.20^{b}	4.93^{a}
NDF concentration, %	65.5^{a}	60.4^{b}	59.3^{c}
Digestibility			
DM, %	58.6^{a}	46.4^{b}	50.8^{ab}
Milk yield, L d^{-1}	1.33	1.56	1.64
CH_4 emissions			
g d^{-1}	65.9	69.5	66.1
g kg-$BW^{-0.75}$ d^{-1}	1.12	1.20	1.12
CH_4-energy GEI^{-1}, %	4.14^{b}	5.00^{a}	3.99^{b}
BW gain, kg d^{-1}	0.25^{ab}	-0.07^{b}	0.55^{a}

$p \leq 0.05$

Assessment of the equation obtained by using CH_4 concentrations recorded by LMD to estimate CH_4 emissions

The CH_4 emissions per metabolic body size estimated in exp 1 and exp 2 were lower than those calculated by using the reported equations (Niu *et al.* 2018, Hristov *et al.* 2013). Nevertheless, the ratios of CH_4 emissions to GEI in exp 2 (4.1%–5.0%) were consistent with the previously reported ratios (2%–15%, Flachowsky and Lebzien 2012). The NDF concentrations of the ingested diets in our experiments (48%–66%) were higher than those used by Niu *et al.* (35%) and Hristov *et al.* (34%) for constructing their equations. In contrast, DM intake in our experiments (3.7–5.6 kg d^{-1}) was lower than those used by Niu *et al.* (18.5 kg d^{-1}) and Hristov *et al.* (16.5 kg d^{-1}). The lower CH_4 emissions that we obtained might have been due to the inappropriate extrapolation of values by the reported equations, which were constructed by using datasets of cattle breeds different from those used here (Holstein, Ayrshire, Jersey, Brown Swiss, Angus, Hereford).

Conclusions/Implications

We obtained an equation to estimate CH_4 emissions (y, mg min^{-1}) from LMD CH_4 concentrations (x, ppm m) as $y = 0.4259x + 38.61$ ($r^2 = 0.55$). It was suggested that Napier grass is a suitable feed for indoor feeding. We demonstrated that LMDs can be used to test feeding regimens with consideration to the CH_4 emissions of dairy cows. Using LMDs will make feeding trials cheaper and simpler than with other currently available methods for determining CH_4 emissions, and will be useful for studies conducted in countries under financial constraints.

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