Computers and Electronics in Agriculture 150 (2018) 110–117

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

Using a portable laser methane detector in goats to assess diurnal, diet- and position-dependent variations in enteric methane emissions

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ARTICLE INFO

Keywords:
Laser Methane Detector (LMD)
Enteric methane
Goat

ABSTRACT

The Laser Methane Detector (LMD) technique has proven to be reliable for estimating enteric methane (CH_4) output in ruminants. The number of peer-reviewed publications related to LMD measurements in ruminants is still small. Studies are largely limited to measurements of animals in controlled research environment and respiration chambers, while measurements on animals outside respiration chambers are rare. Most studies focused on cattle or sheep, but the LMD has not yet been applied to goats. Finally, no systematic measurement protocol is available for different livestock species. Thus, the experimental setup of studies varies considerably, making a comparison of results difficult, although previous papers have provided guidance. In the present study, the LMD technique was applied in two experiments with goats to evaluate the effect of; the position of goats, the time after feeding, CH_4 peaks and troughs, the recording interval and the proportion of concentrate feed and hay in the diet on enteric CH_4 emission. Measurements were taken on four (Experiment 1) and 12 (Experiment 2) 1-year old female Boer goats. The position affected the mean enteric CH_4 emission, with higher values for lying than for standing goats. However, results across goats differ. In contrast, a day effect was observed that was consistent across positions and goats, with highest CH_4 emissions obtained for day 3 (Experiment 1). As could be expected, the time after feeding strongly influenced the CH_4 concentrations that were highest directly after morning feeding. CH_4 concentrations gradually decreased with increasing time after feeding and were lowest early in the morning. No diet effect (quality and quantity) was observed (Experiment 2). This indicates a high individual variation of enteric CH_4 emissions that could be exploited to select and breed animals with lower CH_4 output. For subsequent experiments utilizing the LMD technique, it is recommended to use a 0.1-s interval for recording point measurements of CH_4 concentrations, and for analysis to consider peaks only. A reduction of the recording interval to 1 s and 4 s only using CH_4 peaks led to high deviances from the reference (0.1-s records, CH_4 peaks and troughs), whereas the 0.1-s recording interval cleaned from CH_4 troughs and using only CH_4 peaks showed good accordance with the reference. Ongoing studies will verify the present results in view of developing a standardized protocol for measuring CH_4 output in the major ruminant livestock species.

1. Introduction

Methane (CH_4) as a potent greenhouse gas traps 25 times as much heat as carbon dioxide. It is estimated that 50–65% of the total CH_4 emissions are related to human activities, including ruminant livestock production (IPCC, 2013). Enteric CH_4 is a natural by-product of the fermentation processes in the rumen of ruminant livestock species and is expelled through the breath. It currently comprises 17% of the global anthropogenic CH_4 emissions (Knapp et al., 2014) and is expected to further increase, particularly in developing countries (Tubiello et al., 2013). In addition, enteric CH_4 emissions lower livestock productivity and economic efficiency of ruminant livestock production because up to 12% of the gross energy intake is lost (Gerber et al., 2013). Several techniques have been developed to evaluate strategies to reduce enteric CH_4 emissions (Patra, 2016). The respiration chamber technique is considered as the gold standard method to quantify the enteric CH_4 output of ruminant animals. However, estimates obtained from chamber measurements are not transferable to grazing ruminants because they are obtained in an artificial environment (Storm et al., 2012). The portable laser methane detector (LMD) technique may offer a reasonable alternative because it allows the quantification of CH_4 from animals in their natural environment (Ricci et al., 2014) without interfering with the animal's behavior (Chagunda et al., 2009). Studies comparing the correlation of CH_4 values of cattle and sheep obtained in respiration chambers and by the LMD technique generally confirmed a high agreement between the two methods (Chagunda and Yan, 2011;

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https://doi.org/10.1016/j.compag.2018.04.010
Received 14 December 2016; Received in revised form 9 April 2018; Accepted 13 April 2018

Ricci et al., 2014). Thus, the LMD technique is increasingly used to estimate CH_4 outputs of ruminants, but studies were mostly performed with cattle (Chagunda et al., 2009, 2013; Grobler et al., 2014), while measurements on small ruminants are so far limited to sheep (Chagunda et al., 2013; Ricci et al., 2014). In addition, the lack of a reproducible measurement protocol makes it difficult to compare results obtained from different studies. Evaluating the limited number of studies (3) that applied the LMD technique to ruminants outside respiration chambers, experiment durations of 1–10 days and measurement distances of 1 and 3 m between the LMD device and the animal are found. Measurements were taken in the morning, between midday and evening milking, late in the afternoon, or in several observation periods per animal (at 2, 3, 5, 6 and 7 h after feeding). They were repeated within days or over several weeks, and lasted from 1 to 4 min each. Finally, the recording interval of the LMD device was set at 0.5, 1 or 4 s (Chagunda et al., 2009; Grobler et al., 2014; Ricci et al., 2014).

To complement and broaden the scope of the above-mentioned studies, this research uses for the first time the LMD technique for CH_4 measurements in goats. It addresses open questions to advance the development of a systematic measurement protocol in order to assess enteric CH_4 output in ruminants under natural grazing and outdoor conditions as well as for broad scale on-farm monitoring. The first experiment (Experiment 1) aimed at evaluating the effects of the position of goats, namely standing or lying, on enteric CH_4 output. Feed quality and feed intake were of subordinate relevance in this experiment. The second experiment (Experiment 2) addressed the following research questions: (1) Is the LMD technique able to accurately detect variations in the CH_4 output based on different hay:concentrate feed ratios, assuming that a higher concentrate feed intake would lead to lower enteric methane output? (2) Does the LMD technique identify the diurnal variation in the CH_4 output of goats, assuming higher CH_4 concentrations directly after feeding, and decreasing CH_4 concentrations with increasing time after feeding? (3) What is the optimum interval to record CH_4 values? Recommendations are derived to handle diurnal and animal-specific variability of ruminal CH_4 output.

2. Materials and methods

All procedures used to test animals complied with current animal welfare requirements.

2.1. Measuring device

The portable laser methane detector “Laser Methane mini-Green” (LMm-G) has the potential to detect CH_4 from a distance of up to 100 m (Crowcon Detection Instruments Ltd). The green light color of the helium–neon laser beam is more visible than the red light color laser beam of the “Laser Methane mini” (LMm) especially under strong sunlight. The LMm-G has a high selectivity for CH_4 and CH_4 containing gases. It is based on infrared absorption spectroscopy and measures the integrated CH_4 concentration between the detector and the target (in the present case the goats’ nostril) which equals the fraction of the backscattered laser beam reflected from the target (Iseki, 2004). The LMm-G can detect CH_4 concentrations between 1 and 50,000 ppm m with a detection accuracy of ± 10%. It operates in a temperature range between −17 °C and +50 °C and a humidity range of 30–90%. With a detection speed of 0.1 s, it can also work through glass. The device has been originally developed for industrial and commercial property surveys, gas power plants, landfill monitoring, natural gas transmission and distribution pipeline surveys (Crowcon Detection Instruments Ltd, 2016). The use of the LMD technique in livestock was first introduced by Chagunda et al. (2009).

In the present experiments, the duration of each measurement was 2 min. These individual 2-min measurements are further referred to as *individual measurements*. The LMm-G recorded the CH_4 concentration every 0.1 s, which resulted in approximately 1200 data points for each individual measurement (*profile*). Individual measurements were repeated three times with 2-min breaks in-between measurements (further referred to as *repeated measurements*). The measurement data were stored on an Android device that was connected via Bluetooth to the LMm-G, and data sets were copied to a PC at the end of each measurement day. A fixed distance of 1 m between the nostril of the goat and the LMm-G was used. Thus, no correction of the assessed CH_4 values for the distance between animal and methane detector was needed. The offset value of the LMm-G was set to zero and no correction for background CH_4 concentration was done because these values proved to be highly variable without any correlation to the day, the time of day or the moment of the assessment of the background CH_4 concentration (before and after each measurement period), so that no correction algorithm could be developed.

2.2. Study location

The experiments were conducted at the experimental facilities of the Department of Animal Sciences, Georg-August-Universität Göttingen (GAUG), Germany. The experimental goats were housed in pens of $1.8 \times 2\,m^2$ in a separate area of the closed livestock building. Pens had concrete floors with wood shavings for bedding (2–3 cm height). Every morning, dry wood shavings were added, and every third day the wood shavings were completely removed. The indoor temperature was kept constant at 18 °C. The lights in the building were switched off at 18:00 h and switched on at 6:00 h. Light regime and room temperature were the same in both experiments. Ventilation was stopped during the measurement periods.

2.3. Experimental setup, animals and diets

2.3.1. Experiment 1 (position of goats)

Four female 11-months old Boer goats with an average body weight of 33.4 ± 4.52 kg were selected from the experimental flock of the Department of Animal Sciences of GAUG. Goats were penned individually and fed a daily standard diet composed (on dry matter (DM) basis) of 2.6 kg hay and 0.4 kg concentrate feed. The concentrate feed consisted of pellets, whole oat grains and molassed sugar beet pulp in equal parts. The pellets contained 16.0% crude protein (CP), 11.5% crude fiber (CF), 2.8% crude fat, 9.5% crude ash, 1.6% calcium, 0.5% phosphorus (P) and 0.5% sodium (all on DM basis), and an estimated 10.2 MJ of metabolizable energy per kg DM. The pellets were composed of molassed sugar beet pulp, wheat bran, wheat gluten feed, barley, alfalfa meal, extracted rape seed, extracted soybean meal and oat bran. The molassed sugar beet pulp contained (on DM basis) 13.1% CF, 13.9% total sugars, 0.7% calcium. The hay contained 93.3% organic matter, 66.7% neutral detergent fiber, 37.0% acid detergent fiber, 8.0% CP and 0.02% P, on DM basis. The concentrate feed was offered in one meal at 8:00 h in the morning, and the hay in three equal parts at 8:00 h, 13:00 h and 18:00 h. While the concentrate feed was completely consumed, hay refusals averaged approximately 1/3 of the daily offer. Water and mineral blocks were offered *ad libitum*.

LMD measurements were taken on four days (17, 18, 21 and 22 December 2015). First, goats were measured while lying in their pen (15:00–16:00 h). This was the position that all but one goat voluntarily expressed during the period of time in question. Hence for one goat, no single measurements for lying were obtained. For another goat the measurements for lying were missing for one day. After completing the measurements for lying, all goats were measured while standing in their pen (16:00–17:00 h). Goats were prompted to stand up in the case they were still lying. The order of measuring goats was changed every day, but kept constant within days. During standing measurements, the head of the goat was held by one person with the help of a head collar to ensure that the laser beam targeted the nostril. The LMm-G operator held the device in his hands for both positions (lying, standing), standing frontally to the goats. In total, 81 individual measurements