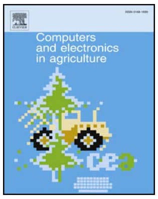
Computers and Electronics in Agriculture 143 (2017) 262–272

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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



The agreement between two next-generation laser methane detectors and respiration chamber facilities in recording methane concentrations in the spent air produced by dairy cows

Diana Sorg[a,*], Sarah Mühlbach[a], Frank Rosner[a], Björn Kuhla[b], Michael Derno[b], Susanne Meese[c], Angela Schwarm[c], Michael Kreuzer[c], Hermann Swalve[a]

[a] Martin Luther University Halle-Wittenberg, Institute of Agricultural and Nutritional Sciences, Theodor-Lieser-Str. 11, 06120 Halle, Germany
[b] Leibniz Institute for Farm Animal Biology (FBN), Institute of Nutritional Physiology 'Oskar Kellner', Wilhelm-Stahl-Allee 2, 18196 Dummerstorf, Germany
[c] ETH Zurich, Institute of Agricultural Sciences, Universitaetstrasse 2, 8092 Zurich, Switzerland

ARTICLE INFO

Keywords:
Laser methane detector
Respiration chamber
Methane
Dairy cow
OptiKuh research project

ABSTRACT

In this study, the handheld laser methane detector (LMD) was discussed as a tool for estimating the methane emissions of individual dairy cows by measuring the profiles of the exhaled air. Data obtained with the most recent generation of the device were compared with those of indirect open-circuit respiration chambers, which are commonly used to quantify methane emissions from ruminants. Data from two LaserMethane Mini-Green LMD units (Tokyo Gas Engineering Solutions) exhibited high agreement with those from four respiration chambers, two at the AgroVet-Strickhof, Eschikon, Lindau (Switzerland) and two at the Leibniz Institute for Farm Animal Biology (FBN) Dummerstorf (Germany). The results were determined using Pearson and concordance correlations and the Bland–Altman method. An inverse regression analysis was used to predict the amount of methane in the chambers from the LMD data. The two LMD units also agreed well with each other in the same respiration chamber and under farm conditions. Both the LMDs and chambers were suitable for detecting differences in mean methane concentrations in the spent air produced by dairy cows during different cow activities in the chamber ($p < 0.05$). Therefore, the most recent LMD model can reliably quantify the dynamics of methane concentrations in the air produced by dairy cows, although the devices were originally designed to detect gas leaks with high methane concentrations in industrial applications. Further studies are needed to investigate the utility of the current LMD technology in measuring the methane profiles directly at the animal's nostrils to quantify methane emissions from dairy cows and other ruminants.

1. Introduction

The quantification of methane emissions from ruminants has become an increasingly important goal. It is relevant for understanding fundamental processes of the rumen metabolism and microbial methanogenesis. For many applied research questions, there is also a need to accurately measure the methane produced by domestic animals. In animal nutrition, the aim of previous experiments has mainly been to test nutritional abatement strategies, thereby quantifying enteric methane emission individually and as precisely and accurately as possible. These experiments have mostly been realised using indirect open-circuit respiration chambers (calorimeters), which are regarded as the gold standard and extremely accurate (Hammond et al., 2016). However, chamber measurements can only be performed with a limited number of subjects per experiment and per treatment.

In recent years, animal scientists have increasingly focussed on traits related to feed efficiency and methane emission (Berry et al., 2012; Pinares-Patiño et al., 2013; Wall et al., 2010). However, for genetic statistical analyses and effective breeding schemes, it is necessary to include many phenotyped animals. For this purpose, rapid and labour-extensive methods of measuring methane are currently being analysed in terms of their precision and accuracy. One of these techniques is the non-invasive 'sniffer' breath sampling method (Difford et al., 2016). Another on-farm recording method is the hand-held laser

---

Abbreviations: LMD, laser methane detector; Lmm-g, LaserMethane Mini-Green; *r*, Pearson correlation; CCC, concordance correlation coefficient; SD, standard deviation; var, variance

[*] Corresponding author.

E-mail addresses: diana.sorg@landw.uni-halle.de (D. Sorg), sarah.muehlbach@landw.uni-halle.de (S. Mühlbach), frank.rosner@landw.uni-halle.de (F. Rosner), b.kuhla@fbn-dummerstorf.de (B. Kuhla), derno@fbn-dummerstorf.de (M. Derno), susanne.meese@usys.ethz.ch (S. Meese), angela.schwarm@usys.ethz.ch (A. Schwarm), michael.kreuzer@inw.agrl.ethz.ch (M. Kreuzer), hermann.swalve@landw.uni-halle.de (H. Swalve).

https://doi.org/10.1016/j.compag.2017.10.024
Received 11 July 2017; Received in revised form 28 September 2017; Accepted 25 October 2017
0168-1699/

methane detector (LMD; Tokyo Gas Engineering Solutions, Tokyo, Japan); this was designed to detect methane leaks from a safe distance in industrial settings, such as pipelines, petrochemical plants, landfill sites and mines, but in recent years, it has been used for the measurement of methane concentrations in the expiratory air of ruminants (Chagunda et al., 2009; Chagunda et al., 2013; Ricci et al., 2014). Chagunda et al. (2013) and Ricci et al. (2014) reported positive, but rather weak relationships between methane concentrations obtained in respiration chambers and those measured at the animals' nostrils using the LMD. In these studies, methane was measured with the LMD while the animals were in the chamber ($r = 0.47$ in cattle and $r = 0.18$ in sheep; Chagunda et al., 2013) or a barn ($r = 0.12$ in ewes; Ricci et al., 2014).

There has been continuous development in LMD technology. One model of the LMD was available from 2004 to 2010, before the current generation. This model has already shown a good agreement with the gas analyser of one indirect open-circuit respiration chamber when measuring the methane concentration in the ambient air of the chamber (one LMD, $r = 0.8$; Chagunda et al., 2009). Although the principle of using tunable diode laser absorption spectroscopy was not changed in the newest model, the LMD is now considerably smaller and lighter (70 × 179 × 42 mm, 0.6 kg) than the preceding one (112 × 250 × 248 mm, 1.35 kg), and it has an extended operation time (6 vs. 3 h). The range of operating temperatures has also been extended, such that measurements can now be performed at temperatures below 0°C. A change in the size and shape of the components probably contributed to the smaller and lighter appearance of the newer model; it may be that this structural change has led to a change in the accuracy or precision of the instrument. For this reason, two LMD devices of the newest generation were tested in the present study. In our research, Chagunda and Yan (2011) LMD–chamber comparison was broadened in the following ways: (1) extending the experimentation from one respiration chamber to four chambers with two different layouts, (2) using two LMD units instead of one and (3) testing the recovery of variations in methane concentrations caused by different cow activities. With this extension, we sought to assess whether there was variation in the agreement between different sets of the chamber and LMD, which was not analysed in Chagunda and Yan (2011) study. In addition, to our knowledge, there has been no comparison between two LMD units, although a high agreement is necessary to establish the device's reliability and the comparability of the data across studies conducted with different units. The cows' activity pattern was used as a known source of variation in methane as an additional tool to compare the LMD gas sensors' accuracy and flexibility of registering rapid changes in methane concentration compared to those of the respiration chambers.

2. Material and methods

2.1. The laser methane detector

The type of LMD used was the LaserMethane Mini-Green (Lmm-g; Tokyo Gas Engineering Solutions, Tokyo, Japan), and two units were employed. The principle of the measuring technology was described previously by Chagunda et al. (2009, 2013). Briefly, the device uses tunable diode laser absorption spectroscopy. The wavelength of the indium-gallium-arsenide laser (1 653 nm) is specific for a strong absorption band of methane. The reflected laser beam is detected by the device, and its signal is processed and converted to the cumulative methane concentration along the laser path in parts per million × metre (ppm × m). By dividing this value by the length of the path in m, the average concentration in ppm can be calculated. The LMD operates in a temperature range of −17 to 50°C and relative humidity range of 30–90%. The accuracy of pointing the device at a methane source is facilitated by a second, visible green helium-neon pointing laser (532 nm) next to the invisible measuring laser. In contrast to the previous models, the Lmm-g is connected to a smartphone or tablet running the GasViewer app (Tokyo Gas Engineering Solutions) via a Bluetooth connection for exporting and storing the data.

2.2. Respiration chambers

The open-circuit indirect calorimetry respiration chambers of two institutes were used for comparison with the LMD units in the present study. The working principle of respiration chambers was described by Johnson and Johnson (1995) and Hammond et al. (2016). Briefly, an artificially ventilated gas-tight chamber with a known flux of ambient air is used to house an animal for several days. By measuring the concentrations of methane, CO_2 and O_2 in the in- and outflowing air, the total volume of the animal's production or consumption of these gases can be calculated. We used two respiration chambers at each of two sites, namely AgroVet-Strickhof in Eschikon, Lindau, Switzerland (Site A; Chambers 1 and 2), as described by Buehler and Wanner (2014), and the Leibniz Institute for Farm Animal Biology (FBN) in Dummerstorf, Germany (Site B; Chambers 3 and 4), as described by Derno et al. (2009). The respiration chambers at both locations had infrared absorption–based analysers for methane (Site A: GA-4, Promethion Metabolic Screening System by Sable Systems Europe, Berlin, Germany; Site B: UNOR 610, Maihak AG, Hamburg, Germany).

2.3. Experimental setup in the respiration chambers

In each respiration chamber, one Holstein cow was kept for 2 consecutive days during an ongoing experiment that was independent from this study. The three cows in Chambers 1, 2 and 3 were lactating and milked during the experiment, while the cow in Chamber 4 was not lactating. These experiments were carried out in compliance with the veterinary office of the Swiss Canton of Zurich and the EU Directive 2010/63/EU for animal experiments; the veterinary office of the Swiss Canton of Zurich also approved this study (licence number 06/2014).

During the experiment at Site A, the LMD units were placed together in Chambers 1 and 2 for 1 day each. With this setup, the two LMD units' agreement with each other and the methane concentration of the air as recorded by the chamber's gas analyser was tested. The LMD units were positioned approximately 1.5 m above the floor and 0.8 m below the ceiling next to the cow and alongside each other, with a distance of 0.1 m between the two pointing lasers to avoid interference (Fig. 1a).

The LMD units were pointed diagonally toward the ceiling to prevent the cow from crossing the laser path. The laser was reflected from the ceiling in the centre of the radially mounted PVC pipes, where gas samples for the analysis were taken using the respiration equipment. With this design, the comparability of the air samples analysed by the LMDs and the chamber sensors was ensured. The chamber's gas analyser measured the methane concentration in the outflowing air once per s, and the software stored one average value per min. The LMD units recorded the methane concentration in the air near the outlet pipes twice per s. Two smartphones connected via Bluetooth were placed outside of the chamber; they were attached to an external electricity supply to ensure continuous operation (Fig. 2).

The batteries of the LMD were replaced every 4–5 h, and the measurement was interrupted for a few min each time. The chambers were also accessed at other times during the day via an airlock for animal care (feeding and milking), and they were opened for cleaning. In Chamber 1, the measurement lasted from 8 am to 6 pm; in Chamber 2, it took place from 9 am to 6 pm. In parallel to the methane measurement, the activity of the cow (standing idle, lying idle, standing while ruminating, lying while ruminating, eating, drinking, sleeping or moving around) was visually observed on a screen connected to a surveillance camera inside the chamber. Each min, the predominant activity was recorded and stored in a data file. Lying while ruminating was later combined with standing while ruminating as total rumination time, since the cows rarely ruminated when lying in the present experiment.