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# Comparison of a laser methane detector with the GreenFeed and two breath analysers for on-farm measurements of methane emissions from dairy cows

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ABSTRACT

To measure methane ($CH_4$) emissions from cattle on-farm, a number of methods have been developed. Combining measurements made with different methods in one data set could lead to an increased power of further analyses. Before combining the measurements, their agreement must be evaluated. We analysed data obtained with a handheld laser methane detector (LMD) and the GreenFeed system (GF), as well as data obtained with LMD and Fourier Transformed Infrared (FTIR) and Non-dispersive Infrared (NDIR) breath analysers (sniffers) installed in the feed bin of automatic milking systems. These devices record short-term breath $CH_4$ concentrations from cows and make it possible to estimate daily $CH_4$ production in g/d which is used for national $CH_4$ emission inventories and genetic studies. The $CH_4$ is released by cows during eructation and breathing events, resulting in peaks of $CH_4$ concentrations during a measurement which represent the respiratory cycle. For LMD, the average $CH_4$ concentration of all peaks during the measurement (P_MEAN in ppm × meter) was compared with the average daily $CH_4$ production (g/d) measured by GF on 11 cows. The comparison showed a low concordance correlation coefficient (CCC; 0.02) and coefficient of individual agreement (CIA; 0.06) between the methods. The repeated measures correlation ($r_p$) of LMD and GF, which can be seen as a proxy for the genetic correlation, was, however, relatively strong (0.66). Next, based on GF, a prediction equation for estimating $CH_4$ in g/d (LMD_cal) using LMD measurements was developed. LMD_cal showed an improved agreement with GF (CCC = 0.22, CIA = 0.99, $r_p$ = 0.74). This prediction equation was used to compare repeated LMD measurements (LMD_val in g/d) with $CH_4$ (g/d) measured with FTIR (n = 34 cows; Data Set A) or NDIR (n = 39 cows; Data Set B) sniffer. A low CCC (A: 0.28; B: 0.17), high CIA (A: 0.91; B: 0.87) and strong $r_p$ (A: 0.57; B: 0.60) indicated that there was some agreement and a minimal re-ranking of the cows between sniffer and LMD. Possible sources of disagreement were cow activity (LMD: standing idle; sniffer: eating and being milked) and the larger influence of wind speed on LMD measurement. The LMD measurement was less repeatable (0.14–0.27) than the other techniques studied (0.47–0.77). Nevertheless, GF, LMD and the sniffers ranked the cows similarly. The LMD, due to its portability and flexibility, could be used to study $CH_4$ emissions on herd or group level, as a validation tool, or to strengthen estimates of genetic relationships between small-scale research populations.

*Abbreviations:* LMD, laser methane detector; T, threshold; Q1, first quartile; Q3, third quartile; FTIR, Fourier transformed infrared; NDIR, non-dispersive infrared; RR, respiratory rate; CCC, concordance correlation coefficient; LME, linear mixed effect model; CIA, coefficient of individual agreement; REP, repeatability; RMSE, root mean square error; CCRC, closed circuit climate respiration chambers; DMI, dry matter intake; CH4, methane; CO2, carbon dioxide; GF, GreenFeed; AMS, automated milking systems; LMm-G ®, LaserMethane Mini-Green ®; IQR, interquartile range; TMR, total mixed ration

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## 1. Introduction

The production of enteric methane ($CH_4$) by dairy cattle and other ruminants poses a threat to our climate due to the high global warming potential of $CH_4$, ~28 times that of carbon dioxide ($CO_2$) (IPCC, 2014). Abatement strategies such as dietary formulations, anti-microbial vaccines and additives as well as genetic improvement through selection, have received considerable attention in recent years (Hill et al., 2016). The latter has the advantage of being cumulative and persistent but requires accurate, reliable and heritable individual measurements on a large number of animals made under the conditions in which the animals are expected to perform (Falconer and Mackay, 1996).

Numerous methods to record $CH_4$ emissions from individual animals have been developed, each with their own advantages, disadvantages and scope of application (Storm et al., 2012; Hill et al., 2016; Patra, 2016). The gold standard method against which other methods are benchmarked is the climate respiration chambers (CRC). However, CRC are costly to establish and run, as well as time consuming and labour intensive, proving prohibitive to obtaining measurements on large numbers of animals in the order $10^4$–$10^5$ required in genetic evaluations. Furthermore, individual confinement within the CRC imposes restrictions of the feeding and natural behaviour of individuals, which can result in reduced dry matter intake (DMI) and consequently $CH_4$ emission, leading many to question the extrapolation of results to commercial or grazing systems (Pinares-Patiño and Clark, 2008).

Not surprisingly, alternative methods with higher throughput and short measurement periods have been developed, for instance the patented GreenFeed (GF) system (C-Lock Inc., Rapid City, SD, USA; Zimmerman, 2011). The GF system is a short-term, mass flux measurement which can evaluate 15–25 animals per day depending on the unit type and housing conditions. Briefly, animals visit the unit multiple times a day for periods of 3–7 min during which they are supplemented with concentrate as bait. The active airflow, $CH_4$ concentration and animals proximity to the feed bin within the unit are continuously recorded and through an internal algorithm, the 24 h $CH_4$ production ($CH_4$ g/d) is approximated (Hammond et al., 2016; Hristov et al., 2016).

A second method to record $CH_4$ emissions involves different types of breath analysers (sniffers), where $CH_4$ and $CO_2$ sampling points are installed inside the feed bin of automated milking systems (AMS) (Lassen et al., 2012) or concentrate dispensers (Negussie et al., 2016). Approximately 40–80 animals are measured multiple times per day for a duration of 3–12 min per visit, using only one unit. The $CH_4$ production (L/d) is approximated using the recorded ratio of $CH_4/CO_2$ and the predicted $CO_2$ production (L/d) from production traits or metabolizable energy intake (Madsen et al., 2010; Pedersen et al., 2008). One of the disadvantages of these methods is that the cow eats during the recording and the influence of this activity on the estimation of $CH_4$ production is not known.

A further recording method is the laser methane detector (LMD), a hand held open path laser measuring device. Different models of this device are available and have been further developed over time. For studies on livestock, the LaserMethane® (Iseki, 2004) and its successor LaserMethaneMini® (both Tokyo Gas Engineering Solutions, Ltd., Tokyo, Japan) were used, which operate with the same technology, namely tunable diode laser absorption spectroscopy. They were originally developed for the detection of gas leaks, and therefore, discriminate between high $CH_4$ concentrations and the low background concentration in the atmosphere (Crowcon, 2017). However, the LMD was shown to reliably quantify the dynamics of $CH_4$ concentrations exhaled by dairy cows for the first time by Chagunda et al. (2009) and later verified in the CRC (Chagunda and Yan, 2011; Sorg et al., 2017a). When it is used to study the $CH_4$ emission of animals, an operator points the device at the snout of a cow at a fixed distance for a duration of several minutes, once or multiple times a day, and the cumulative $CH_4$ concentration along the laser path is quantified and recorded in real-time. The mean $CH_4$ concentration of a profile recorded with this protocol did not change when the length of the profile varied between 2 and 5 min (Sorg et al., 2017b). The LMD device is highly responsive with a measurement made once every 0.1–0.5 s allowing for the characterisation and separation of eructation and respiration peaks (Pickering et al., 2015; Ricci et al., 2014; Mühlbach et al., 2018; Roessler et al., 2018). Roessler et al (2018) showed that it is favourable to record at a high interval, i.e. 0.1 s as opposed to 1 or 4 s. The flexibility of the LMD permits measurements under different conditions and during different activities of the animals. It is possible to detect differences in $CH_4$ concentrations recorded with the LMD during drinking, feeding, ruminating, standing and lying in cows (Chagunda et al., 2009, 2013; Sorg et al., 2017a) and between lying and standing in goats (Roessler et al., 2018). The LMD can also record concentrations of $CH_4$ produced by animals on pasture (Grobler et al., 2014; Mapfumo et al., 2018). However, in outdoor experiments the environmental conditions (wind speed, humidity, air pressure) have a significant effect on recorded concentrations and should be considered when analysing the data (Chagunda et al., 2013; Mühlbach et al., 2018). It is also important to note the angle from which the LMD was pointed to the cow (side or front) and the person operating the LMD, as well as the specific device number when using two or more devices in parallel, since they may also have a significant effect on recorded $CH_4$ values (Mühlbach et al., 2018). Two LMDs of the same model and of similar manufacturing date did not differ in recorded $CH_4$ values when they were statically set up in parallel to pass through the same portion of air in a CRC or in a barn (Sorg et al., 2017a). In a large data set of $CH_4$ profiles, however, recorded directly at the snout of cows, one of three LMDs differed from the others (independently from operator) in mean recorded $CH_4$ concentrations (Sorg et al., 2017b). The differing LMD was of the same model as the others, but from a later manufacturing date.

From a genetic evaluation perspective, a new method that is cheaper or faster is considered equivalent to a gold standard method when the genetic correlations between the two methods exceeds 0.80 (Robertson, 1959). However, the required number of related animals measured by both methods to accurately estimate genetic correlations with meaningful standard errors, is very high ($10^3$–$10^4$ animals) (Visscher, 1998). The number required is even greater if measurements are made on different animals or animals at different points in time (Bijma and Bastiaansen, 2014). Within a European context, many of the methods currently under research for genetic evaluations are limited to one or two countries and often to single research herds with different breeds, further hindering evaluation of methods through genetic correlations (Lassen et al., 2014).

It is of value to researchers to determine the equivalence or the degree to which two methods differ, prior to the considerable investment of recording tens of thousands of animals. One approach utilised in biomedical and psychological studies is to record simultaneous repeated records on multiple subjects using either two or more methods (Barnhart et al., 2007a). This allows for the comparison and quantification of different sources of (dis)agreement such as accuracy and precision, as well as the calculation of agreement indices such as concordance correlation coefficient (CCC; Lin, 1989) and coefficient of individual agreement (CIA; Barnhart et al., 2007b). Of added value to genetic evaluations is the calculation of within-method repeatability and between-method repeated measures correlations which serve as theoretical upper thresholds for heritability and genetic correlations, respectively (Falconer and Mackay, 1996; Wolak et al., 2012). To our knowledge, there have been no studies about the agreement of LMD and other on-farm methods so far. Therefore, the aim of the present study was to analyse the agreement of three on-farm measuring methods for $CH_4$ concentration, by comparing the LMD with the GF, and the LMD with sniffers (main study). A further goal of the first comparison in the main study (LMD-GF) was to enhance the comparability between LMD (which records concentration) and the sniffers (which allow for an