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A micrometeorological technique for detecting small differences in methane emissions from two groups of cattle

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HIGHLIGHTS

- A new micrometeorological approach for treatment-control comparisons was developed.
- With this approach we compared methane emissions from two groups of grazing cattle.
- A relative group difference in emissions of order 10% was detected ($P = 0.01$).
- This result was corroborated with a non-micrometeorological tracer-ratio technique.

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ABSTRACT

Potential approaches for reducing enteric methane (CH_4) emissions from cattle will require verification of their efficacy at the paddock scale. We designed a micrometeorological approach to compare emissions from two groups of grazing cattle. The approach consists of measuring line-averaged CH_4 mole fractions upwind and downwind of each group and using a backward-Lagrangian stochastic model to compute CH_4 emission rates from the observed mole fractions, in combination with turbulence statistics measured by a sonic anemometer. With careful screening for suitable wind conditions, a difference of 10% in group emission rates could be detected. This result was corroborated by simultaneous measurements of daily CH_4 emissions from each animal with the sulfur hexafluoride (SF_6) tracer-ratio technique.

1. Introduction

In countries with large numbers of ruminant livestock, methane (CH_4) emissions from these animals contribute significantly to the total greenhouse gas emissions of these countries. For example, in 2012 enteric CH_4 accounted for 31.5% of New Zealand's total greenhouse gas emissions (MfE, 2014). Micrometeorological techniques have contributed to determining emission rates of CH_4 from grazing animals (Judd et al., 1999; Laubach and Kelliher, 2004, 2005; McGinn et al., 2011), feedlots (Loh et al., 2008; Gao et al., 2011), manure heaps (Sommer et al., 2004), manure storage tanks (Park et al., 2010; VanderZaag et al., 2011), biodigesters (Flesch et al., 2011) and whole farms (Leytem et al., 2011; McGinn and Beauchemin, 2012) thereby providing valuable information upon which emission factors for national greenhouse gas inventories can be based. Merits and constraints of various micrometeorological techniques in this regard have been reviewed by Denmead (2008) and Harper et al. (2011).

It is less well established what role these techniques could potentially play in verifying the efficacy of mitigation approaches. Then, it is not the absolute emission rate that is of primary interest; rather, it is differences in emission rates as a consequence of different treatments, management practices, or selections of animals that would need to be accurately determined. This task is commonly undertaken by emissions measurements at the ‘animal scale’, in controlled conditions such as in calorimetric chambers (e.g. McGinn et al., 2004). Such experiments can be designed to

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directly compare specific treatments, and thus appear most suitable to identify promising mitigation approaches. However, once proof of concept for a mitigation treatment has been achieved, it must still be verified at the 'herd scale', or 'paddock scale', under representative farming conditions, that the expected emissions reduction is achieved there, too. This is particularly challenging with animals grazing outdoors, as is widespread year-round practice e.g. in New Zealand and Australia.

It was Pattey et al. (2006) who originally suggested that micrometeorological techniques could be designed for 'treatment versus control' experiments. McGinn et al. (2009) pioneered this idea, using the backward-Lagrangian stochastic (BLS) technique (Flesch et al., 1995) to detect a significant difference in CH_4 emission rates between two groups of 10 cattle each that were fed diets differing in grain and forage ingredients. An overall emissions difference was not stated by the authors, but the data shown suggest that it was of the order of 20–30%. In that experiment, the groups of cattle on different diets were each enclosed in a rectangular pen and the pen surrounded by a four-path laser system to measure CH_4 mole fractions. Each animal carried a Global Positioning System transmitter, so that the BLS flow model could be provided with accurate point-source locations in space and time. For the whole study period of 54 d, concurrent CH_4 emission measurements on each animal were made with the SF_6 tracer-ratio technique (Johnson et al., 1994), and used as a reference to assess the performance of the BLS technique. While this experiment provided a valuable proof of principle, it will only rarely be possible to devote such a large amount of effort and resources to a single treatment-control comparison.

Laubach et al. (2013) tried a different approach to test whether a number of different micrometeorological techniques were capable of detecting treatment effects. They measured CH_4 emissions from a group of cattle that were provided a forage diet at amounts increasing from one week to the next. The micrometeorological techniques successfully detected changes in weekly CH_4 emission rates of the order of 30%, in response to the feed intake changes. While, in targeted research trials with specific treatments, CH_4 emission reductions of that magnitude have sometimes been observed, practical application of such treatments may only become available with many more years of research (Eckard et al., 2010). For the foreseeable future, practical mitigation steps may come from small improvements of farm management practices, e.g. with respect to feed intake, and are likely to have relatively small effects. To demonstrate that a certain management practice makes a detectable difference in CH_4 emissions therefore poses a considerable measurement challenge.

Tackling this challenge, the present study was aimed at improving the approach of McGinn et al. (2009) and applying it to grazing animals. The BLS technique was employed to measure CH_4 emissions from two groups of cattle simultaneously, in a 'treatment versus control' set-up. The objective was to test whether a difference in mean group emissions of the order of 10% could be detected. The treatment to create a difference of this magnitude consisted in the spraying of oil onto the grass prior to grazing, since lipid additions to the diet are known to decrease the CH_4 emissions of ruminants (Grainger and Beauchemin, 2011).

One step to optimise the measurement technique was to use a single high-precision gas analyser to determine the emissions from both cattle groups, which removed the need for intercomparison of instruments. This idea was the same as in McMillan et al. (2014), who measured nitrous oxide emissions from a row of differently-fertilised paddocks, but the design details were different. Here, perforated pipes were used to provide line-integrated air samples to the CH_4 analyser. This was done because Laubach et al. (2013) found that approaches using line-averaged mole-fraction measurements performed better than approaches using point mole-fraction measurements, due to both a larger range of admissible wind directions and smaller run-to-run variations in obtained emission rates. They suggested as 'the ideal herd-scale technique one that combines the strengths of the accurate closed-path analyser with the strengths of a path-averaging approach'. The study reported here realised this idea. The intake pipes were symmetrically arranged upwind and downwind of the cattle groups, in order to obtain group emission rates as well as their difference. The combination of the BLS technique with perforated intake pipes was first employed by Loh et al. (2009). Their objective was to detect CO_2 and CH_4 escaping from underground storage. Using the same approach to detect emission differences between two differently-treated groups of animals is a novel application.

2. Materials and methods

2.1. Experimental design, animals, and treatments

The experiment was conducted at Aorangi Research Farm (40.336° S, 175.465° E), near Palmerston North, New Zealand, from 27 September to 14 October 2011. The site is ideally suited for micrometeorological techniques because the surrounding terrain is flat for several kilometres in all directions. Permanent fence lines on the farm are approximately aligned with the main compass directions. Temporary fences for this experiment were lined up parallel to the former, and references in the following to the compass directions are relative to the 'farm-North' defined by the main fences.

Two groups of 30 cattle each were selected, with equal mean liveweight. The cattle were one-year-old Hereford × Friesian steers. In a flat uniform paddock dominated by ryegrass (*Lolium perenne*), 32 rectangular strips were fenced, each 40 m by 25 m in size (Fig. 1). Paired strips were allocated to the two groups on a daily basis, such that one group was always 65 m north of the other. First, for 6 days (Period 1) no treatment was applied, to test whether the emissions from the two groups were indistinguishable. For the following 10 days (Period 2), the grazing strip for the N group (treatment group) was sprayed with canola oil at a rate of 120 L ha^{-1}. This was expected to cause a reduction in CH_4 emissions compared with the S group, which did not receive any oil (control group). Grass height at the start of the experiment was 0.25 (±0.05) cm, growing to 0.45 (±0.05) cm at the end, providing biomass well in excess of dietary requirements.

For three days in Period 1 and four days in Period 2, individual CH_4 emissions over 24 h from all steers were measured with the SF_6 tracer-ratio technique (Johnson et al., 1994). This served as a reference method to independently check on a daily basis whether there was a difference in group emissions. Group dry-matter intakes (DMI) were estimated from herbage mass measured daily with a plate meter, before and after grazing. Individuals' DMI were estimated in Period 2, based on faecal outputs and *in vitro* feed digestibility. Faecal output was estimated using titanium dioxide (TiO_2) as external faecal marker (Pinares-Patiño et al., 2008). The cattle were rounded up and moved away into crushes in order to administer the faecal marker and change the collection gear for the SF_6 tracer-ratio technique. These tasks were usually performed between 0800 and 1100 h.

2.2. Measurements of CH_4 mole fractions and meteorological variables

Mole fractions of CH_4 in air were measured as line averages, along four lines. These were placed parallel to the W and E fences of the two rectangles that were grazed simultaneously (Fig. 1). Each