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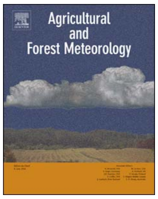

Methane emissions from cattle grazing under diverse conditions: An examination of field configurations appropriate for line-averaging sensors

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ABSTRACT

Micrometeorological techniques offer the possibility of a non-interfering measurement of enteric emissions from cattle in their natural environment, where animals do not need to be encumbered or handled. However, the grazing environment is a difficult application for these techniques. This study reports on an experimental design using an inverse dispersion method (IDM) to measure enteric methane (CH_4) emissions, and its application to 15 rather distinct cattle trials in three types of feeding situations: summer grazing, winter swath grazing, and winter feeding. The IDM design was based on long and narrow animal paddocks with line-averaging sensors measuring CH_4 concentration alongside the long axes of the paddock. Emissions were calculated based on the difference in concentration between the two measurement paths. The narrow paddock has many advantages for an IDM calculation: it avoids the need to monitor animal positions; it helps ensure measurable downwind concentration; and it increases the range of useable wind directions. Four different sensor configurations were used in the trials, differing in the number of concentration sensors (one or two) and sensor paths (two or four). Some configurations used sensor aiming motors to give multiple measurement paths and others used mirrors to create segmented paths (i.e., to go around a paddock corner). Cattle emissions measured with the IDM design showed good agreement across the 15 trials, consistent with high forage diets. When expressed in terms of CH_4 yield (g/kg dry matter intake), the three feeding situations averaged 21.3 (summer grazing), 23.4 (winter grazing), and 23.9 (winter feeding). Based on the trial-to-trial consistency of the results, the similarity with other literature studies, and the success of a previous tracer-release study, we conclude that the narrow paddock IDM design provides a flexible and accurate method for calculating CH_4 emissions from grazing cattle.

1. Introduction

Methane (CH_4) emitted from ruminant livestock (enteric emissions) is the largest global contributor to greenhouse gas (GHG) emissions from agriculture (Francesco et al., 2013), providing strong motivation for the accurate measurement of these emissions. In the Canadian context, beef production is the main source of enteric emissions, with cow-calf operations being responsible for the majority of these emissions (Beauchemin et al., 2010; Basarab et al., 2012). However, these operations are characterized by animals grazing on pasture, a difficult setting from which to measure emissions.

Open-circuit respiration chambers (chambers) and the sulphur hexafluoride (SF_6) tracer technique are commonly used to measure enteric emissions. Chambers can precisely measure gas emissions, but the controlled chamber environment is far different from the grazing environment, which adds uncertainty to the extrapolation to pasture scales. The SF_6 technique (Johnson et al., 1994) can be used in grazing environments. The technique relies upon ruminally released SF_6 as a gas tracer. A device worn on the animal collects a breath sample and the ratio of CH_4/SF_6 in the sample is used to calculate the CH_4 emission rate. The labour requirements for daily sampler changes, halter maintenance, and analysis typically limit the number of animals that can be monitored. The technique is easier to use with dairy animals that are accustomed to daily handling; use with beef cattle requires extensive animal training (DeRamus et al., 2003).

Micrometeorological methods (McGinn, 2013) offer the possibility of a non-interfering measurement of emissions, as animals can be examined in a natural environment without being encumbered or

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handled. Among the suite of micrometeorological techniques, the combination of long line-averaging concentration sensors (e.g., open-path lasers) and inverse-dispersion methods (IDM) has proven useful in animal studies, particularly for intensive agricultural operations like feedlots (Flesch et al., 2007) or livestock barns (VanderZaag et al., 2014). In a typical application, open-path sensors are positioned upwind and downwind of the animals and the downwind increase in concentration, upon interpretation using an atmospheric transport model, determines emissions. A typical grazing environment presents a more challenging application for IDM. The low intensity of emissions from dispersed animals requires sensors with the sensitivity to detect small increases in CH_4. And in principle, IDM calculations require knowledge of the location of the emission source(s), which may be unknown for grazing animals.

Laubach and Kelliher (2005) and Laubach et al. (2008) used IDM and open-path lasers to calculate emissions from grazing dairy and beef herds. Their success was likely helped by high stocking densities and a relatively even distribution of animals across confined paddocks. McGinn et al. (2011) used IDM to measure enteric emissions in a lower stocking density setting (18 animals in a 1 ha paddock). To increase the probability of detecting a concentration rise, McGinn et al. used multiple laser paths running across the paddock, so that at least one laser path was likely to be near the animals. And because animals do not spread evenly when the stocking density is low, McGinn et al. used GPS collars to record animal positions and treated the animals as moving point sources in the IDM analysis. The need for positional information added significantly to logistical requirements.

Hu et al. (2016) tested an IDM design for measuring emissions from grazing animals. The goal of the design was to be able to measure emissions accurately without knowing the animal positions. The design was based on a long and narrow paddock, with open-path sensors measuring concentration alongside the long axes of the paddock. In a tracer-release study that mimicked a cattle herd, the emission rates were measured to within 4% of the actual release rate (on average). Our study reports on the application of the Hu et al. design to measure enteric emissions in 15 cattle trials in Alberta, Canada. We describe how the design was modified for a variety of sensor configurations, and we highlight the key measurement principles. The CH_4 measurements from trials are then evaluated and compared to literature results to help assess the usefulness of the methodology.

2. IDM design

The IDM design described by Hu et al. (2016) was adapted and used in 15 different cattle trials. The common design feature was the use of long and narrow paddock strips, with open-path sensors measuring the line-average CH_4 concentration (C_L) along both sides of the long axes of the paddock. When the wind direction establishes a clear upwind and downwind side of the paddock, the increase in the downwind C_L above the upwind value determines emissions. Any CH_4 source in the paddock will be measured (exhaled or rectal emissions, manure emissions). Because manure emissions from pastures are small compared to enteric emissions (Beauchemin et al., 2010), particularly in the few days after deposition, we assume manure emissions are insignificant.

The narrowness of the paddock is a strategy to avoid the need to monitor animal positions. An animal moving along the length of the paddock does not alter its distance to the downwind sensor path (the "fetch"), so the downwind C_L is insensitive to the along-paddock position of the animal, which is therefore irrelevant in the IDM calculations. Across-paddock movement does change the fetch, but the narrowness of the paddock both restricts this range of movement and forces a relatively uniform widthwise distribution of a herd in the paddock. The overall result is a situation where IDM calculations are rather insensitive to animal locations. There are other benefits to a long and narrow paddock. With C_L paths running close to the paddock edge the animals are always relatively close to the sensor paths, which helps ensure measureable downwind C_L increases, and results in increased measurement precision. A narrow paddock also maximizes the range of wind directions that provide unambiguous separation of "upwind" and "downwind" sides. Hu et al. (2016) found it necessary to reject only the intervals for which wind direction was aligned within +/–10 ° of the long axis of the plot.

The exact configuration of the measurement layout varied from trial-to-trial as the number and type of concentration sensors changed, the terrain of the pasture changed, the animal numbers changed, etc. Fig. 1 shows the four basic configurations used, which are described below.

2.1. Two sensors – two paths

The 2sensor-2path configuration was the simplest design (Fig. 1a). Two fixed path sensors (lasers) measured C_L alongside the paddock. The advantage of this design is simplicity, e.g., compared with the other designs there was no need for sensor aiming devices. A disadvantage was the need to cross-calibrate two concentration sensors. The configuration was problematic for trials needing longer paddocks, e.g., to handle more animals. For the longest of our paddocks the needed pathlengths (~ 300 m) were beyond the range of our particular sensor-reflector combination (laser and retroreflector with a polycarbonate lens). And on rolling terrain long paths can have large variability in the path height above ground, which adds to IDM uncertainty. The 2sensor-4path configuration described below addresses some of these concerns.

2.2. Two sensors – four paths

The 2sensor-4path configuration places two sensors at a mid-paddock position, with automated sensor path-switching and re-aiming systems. The needed full paddock length C_L is created by combining the measurements from opposing paths (Fig. 1b). Sensor path lengths need only be half that of the above 2sensor-2path configuration, which lessens the two concerns noted for long measurement paths. The use of sensor aiming systems does add complexity. It also means that C_L is not continuously measured: the sampling duration of each path is less than half the measurement interval. We assume that the sequencing frequency for the paths, with dwell times from 45 to 150 s, suffices to accurately estimate the average C_L during an interval (15 or 30 min). Because the design uses two sensors, cross-calibration is still required.

2.3. One sensor – two paths

The complication of using two open-path sensors provided incentive for a single sensor configuration. For a single sensor to measure C_L on opposite sides of a paddock, on paths parallel to the paddock axes, requires an aiming system and a segmented measurement path (Fig. 1c). Based on the experience of Flesch et al. (2016) and discussions with the laser manufacturer (Boreal Laser Inc., Edmonton, AB), we employed a flat mirror to direct a sensor beam around the paddock to give the 1sensor-2path configuration (Fig. 1c). Field testing of the mirrored path was successful but there are minor complications in using the mirror. Aiming a segmented path is more time consuming than for a direct path, and segmented paths required more frequent re-aiming (the automated aiming system for the Boreal Laser was helpful here). Mirror vibration in high winds can result in unusable low-signal levels. Segmented paths also require a more complicated IDM analysis (see discussion below).

2.4. One sensor – four paths

The 1sensor-4path design uses a single sensor and two flat mirrors to achieve a four path configuration: two paths on one side of the paddock and two on the other (Fig. 1d). Compared to the 1sensor-2path design, this variation has the advantages of shorter path lengths (benefits discussed earlier). But perhaps the most important advantage of the design is the capability to measure emissions concurrently from two paddocks (e.g., treatment and control, Fig. 1d) using only a single